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## CARNET OAV Architecture Analysis – Update

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### Abstract

This document is an update of a previous published analysis of the mapping of the CARNET architecture to the TM Forum's Open Digital Architecture aiming to provide a standardised view of the components and implementations of orchestration, automation and virtualisation within Research and Education organisations connected to the NRENs.



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## Executive Summary

Analysing National Research and Education Network (NREN) architectures from an orchestration, automation and virtualisation (OAV) point of view using a common reference architecture helps align efforts between the NRENs and find similarities in the way different functionalities and components are implemented, which in turn facilitates potential collaboration and future interoperability between organisations.

The TM Forum Open Digital Architecture (ODA) is being used as a reference model to map several architectures in the GÉANT project. Mapping the architectures to a single blueprint makes it easier to cross-compare them, and helps the organisations working on digital transformation. A reference architecture like ODA supports the transition from traditional work organisation based on manual work and procedures to a model where services/products are automatically provisioned and orchestrated.

This document presents an updated version of the mapping of the components implementing the Croatian Academic and Research NETwork's (CARNET) network observability and other main components into the ODA functional blocks. It highlights the evolution and updates made to these components over the past three years. Since the publication of the first version, several components have been enhanced and updated to align with needs, ensuring improved functionality and scalability.

# 1 Introduction

The purpose of this document is to update the previous analysis of the components of CARNET's network management system architecture, focusing on the orchestration, automation and virtualisation (OAV) aspects of its implementation. The NREN community can use this analysis to compare their own components and approaches with those of CARNET, and may find similarities which inspire them to work together on their journey towards OAV. This mapping is part of a set of mappings of different NREN management architectures against ODA, thus providing a common reference point and the means for a cross-NREN comparative analysis of components and approaches.

The Croatian Academic and Research NETwork – CARNET – is a public institution operating within the Ministry of Science and Education in the field of Information and Communication Technology and its application in education [\[CAN\]](#). The CARNET network is a private network connecting both the academic, scientific and research community of the Republic of Croatia, and the primary and secondary education system institutions. CARNET also connects government sites and almost all health institutions in Croatia – hospitals, health centres, Croatian health insurance fund, and others. The CARNET network covers more than 5,000 locations, enabling a highly distributed community, especially when considering that this includes over 718 islands on the Croatian coast. CARNET's mission is to provide reliable information flows for both the remote online education and the exchange of health-related data.

The main activities carried out by CARNET are focused on three key areas: internet service provisioning, information society development, and education for the new era [\[CNW\]](#).

CARNET was founded in 1991, and was the first internet service provider in Croatia. Services (products in TM Forum ODA) such as helpdesk, file storage and online education courses were provided from the very beginning. The CARNET Computer Emergency Response Team (CERT) was also established in the early years, transforming in 2007 into the Croatian National CERT.

The CARNET network has grown constantly over the years to keep pace with increasing user demands. Today, the CARNET IP/MPLS core has 4 regional PoPs, 23 county network PoPs and 2 data centre sites.

In order to support a high-quality education experience, CARNET not only helps education providers to broadcast courses and events online, but also instituted its own “train the trainers” (later “e-Mentors”) programme that is in charge of building a community of CARNET trainers. The e-learning focus started in 2004 when the CARNET education centre Edupoint decided to strategically move to online delivery. Online courses are offered via the established E-learning Academy.

Starting in 2005, schools were connected to the CARNET network, and hosting services were offered to both primary and secondary schools. The schools on the islands have been connected via the e- Islands project since 2007, with CARNET providing broadband internet and video conferencing systems. This is when the CARNET Portal for Schools for teachers, students, parents, and schools was first launched. Most of the schools today use Loomen, the CARNET content management system (CMS) based on Moodle [\[PSS\]](#). In addition, CARNET hosts a portal for the exchange of school textbooks, and has also been involved in the creation of the first Croatian online encyclopedia. Via the CERT, content filtering is also provided for more than 555,000 students in primary and secondary schools. CARNET is also responsible for the State Final Examination Portal, first established in 2008. Today, the Edu.hr portal provides a central access point to all CARNET education services [\[EDU\]](#). The latest addition to the educational services family managed by CARNET is the MOOC courses portal [\[MOOC\]](#).

In addition to e-Education services, CARNET also provides services for the Research and Education (R&E) community, such as the CARNET Cruncher service that provides its members remote access to supercomputing facilities.

In 2007 CARNET established an integrated help desk for all CARNET users by merging the Customer Support Helpdesk (previously managed by the University Computing Centre) and the Helpdesk for Customer Support for the primary/secondary education system.

CARNET is also in charge of all activities related to the Croatian top-level domain .hr, including the administration of free secondary and tertiary domains. Payable domains are registered using authorised registrars.

To help CARNET system engineers with their daily activities, CARNET provides a number of “sys” services [\[SYS\]](#). This includes services such as sys.backup (for secure remote data archiving), sys.monitor (for remote web monitoring using Icinga2) and sys.virtual (a virtual provider for small organisations, managed by CARNET).

The CARNET Trusted Certificate Service (TCS) is provided via a portal and is provided to all CARNET members [\[CERT\]](#).

The e-Schools program, one of the largest projects for the digitalisation of the primary and secondary education system, has been successfully completed [\[ICTS\]](#). This initiative involved designing school networks across over 2,400 locations, installing active network equipment, establishing functional wireless networks, delivering over 85,000 laptops for school staff, and facilitating the development of new e-services.

The current focus is now on planning and implementing the e-Universities project. This project will upgrade the existing network equipment in all universities in Croatia. The equipment will include next-generation firewalls, routers, switches, and wireless access points with a centralised cloud management platform.

There is also the continuous upgrade and maintaining of e-Schools project services and the Croatian Science and Education Cloud [\[ZOO\]](#) project services.

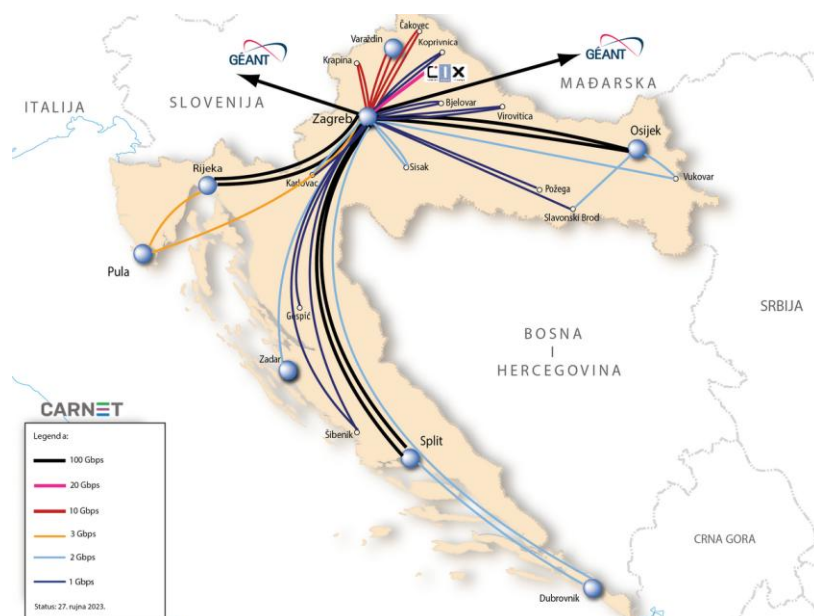


Figure 1.1: CARNET infrastructure

CARNET network has made connection to the global network through the pan-European research network GÉANT, at a current connection speed of 100 Gb/s. The link to other Internet service providers in Croatia is realised through the Internet exchange in Croatia, CIX.

Within Croatia, CARNET network connects larger and smaller Croatian cities at the mainland and a number of places on the islands. Major university centres (Dubrovnik, Osijek, Pula, Rijeka, Slavonski Brod, Split, Varaždin, Zadar, Zagreb) are connected with speed connections ranging from 2 Gb/s to 100 Gb/s, while smaller centers are secured at speeds of 1 Gb/s to 10 Gb/s. In Zagreb and Split, faculties and scientific institutions are connected through an infrastructure that supports speeds up to 10 Gb/s. CARNET network also connects institutions from the primary and secondary education system at access speeds of 4 Mb/s to 10 Gb/s.

In Rijeka, Zagreb, Split and Pula, CARNET connects the locations of the institutions to the CARNET network with its own built infrastructure.

CARNET’s OAV architecture analysis has been conducted using the TM Forum Open Digital Architecture (ODA) functional blocks as a reference point. The TM Forum ODA is promoted as a blueprint for new digital industry architectures and the rationale for its selection as a reference model by the Network eAcademy team of the Network Development work package (WP6) of the GN5-1 project is given in GN4-3 Deliverable D6.6 Transforming Services with Orchestration and Automation [D6.6]. The whole set of ODA documentation provides common terminology, a minimum set of core design principles, and groups of decoupled functionalities. Together they define the requirements for the implementation of an agile model-driven service management architecture that incorporates orchestration and automated operations, as well as virtualised or hybrid environments.

The main idea behind ODA is that of decoupling and integration of components which enables independent choice of solutions for each component, while at the same time maintaining a unified overall approach that supports the full end-to-end service lifecycle (including interoperability). The high-level ODA functional architecture maps the main components by their capabilities into the ODA function blocks (see [Figure 1.2](#)).

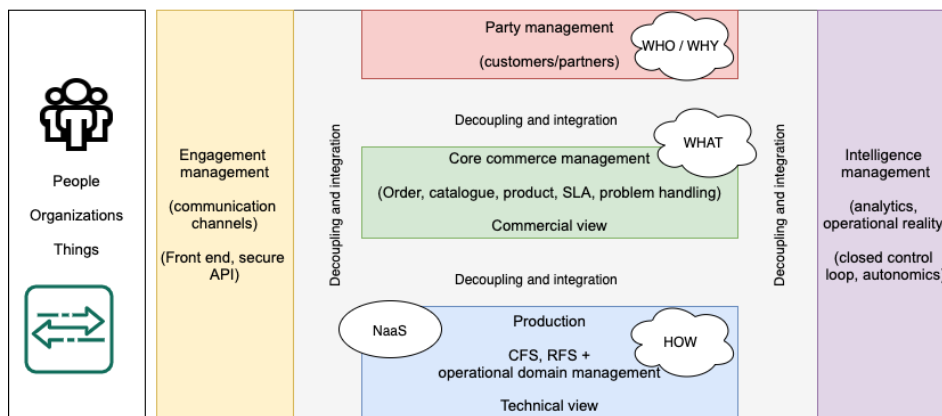


Figure 1.2: The TM Forum ODA functional architecture

In a nutshell:

- The **Engagement Management** functional block focuses on the engagement with the end-users (people and systems) that can interact via multiple channels.
- The **Party Management** functional block handles the processes that are related to all parties that interact with the organisation and defines their roles and relationships.
- The **Intelligence Management** functional block is in charge of the implementation of data analytics processes, and, based on the analysis, provides closed control loops for full automation wherever possible.
- The **Core Commerce Management** functional block focuses on the placement of products and services to the customers and manages the product lifecycle.
- The **Production** functional block manages the delivery and lifecycle of all customer-facing and resource-facing services that can be based on different technologies or might be a combination of multiple operational domains, including multi-domain services provided with the cooperation of other parties.

## 2 Architecture Analysis

### 2.1 High-Level OAV Approach

In recent years, CARNET has seen huge growth in the number of connected locations, to the point where its network now serves over 5,000 sites. This number includes many schools that need to be managed, with over 1,300 LANs, more than 8,000 LAN switches, and 35,000 Wi-Fi Access Points. However, the number of engineers available to work in this field is extremely small when considering the highly distributed scenario, and number of end-sites and devices. In addition, there is a plethora of educational services that need to be provided by CARNET on top of the network that are put into place [\[DMS\]](#). As a result, CARNET as an organisation is facing scalability challenges that can only be addressed by the implementation of OAV principles. The main principle that drives the evolution of service management in the NREN is the identification of repeatable tasks and their automation using scripting. This eliminates the need for all network engineers to acquire the expertise to handle each specific vendor equipment – which is of great interest to the NREN because its network is built using equipment sourced from multiple manufacturers.

To support this evolution, network engineers developed a Network Operations Centre (NOC) portal, which is continuously improved to keep up with the growth of the network and any changes that occur. This portal offers access to a wide array of tools, including internal resources and custom open-source solutions, facilitating the daily activities of network engineers.

Furthermore, CARNET has developed LAN Cloud Management [\[LANCLOUD\]](#), an in-house network management solution for school networks (which are predominantly wireless). Using this solution, the network provisioning and monitoring can be done remotely, via an API. This provides a vendor-agnostic perspective to school admins, and a remote global admin access to the CARNET Network Operations Centre (NOC) [\[ESC\]](#) [\[NMM\]](#). The admin tools in this case include topology visualisation, network behaviour analysis, security with unified threat management, mobile device management, etc. CARNET also developed a self-care portal for school admins. The portal enables efficient and proactive troubleshooting via passive and active monitoring. The main aim of the solution is to move all of the complexity into the private CARNET cloud that will provide security, centralised management, and granular visibility of each client, user, and application. The technical support for this solution is using a three-tier system. The first tier is the e-School technician, the second tier is the CARNET Helpdesk, and the third tier is the CARNET NOC. The e-services that are provided include AAI@EduHR, LMS, CMS, e-Class register, CARNET fi (simplified authentication), GDPR360 (for user master data management), Mobile Device Management MDM, and Enterprise Resource Planning.

### 2.2 Mapping to ODA Functional Architecture

When put into context of the TM Forum ODA functional representation, CARNET's Network Management System (NMS) architecture components can be represented as in Figure 2.1 below. The white boxes in the diagram represent CARNET's network management system architecture components, and their placement within the ODA functional blocks is defined based on their main functionalities [\[ODA\]](#). If the components provide complex multifaceted functionalities, they are broken down into sub-components which are placed in the respective functional block (e.g. membership database).



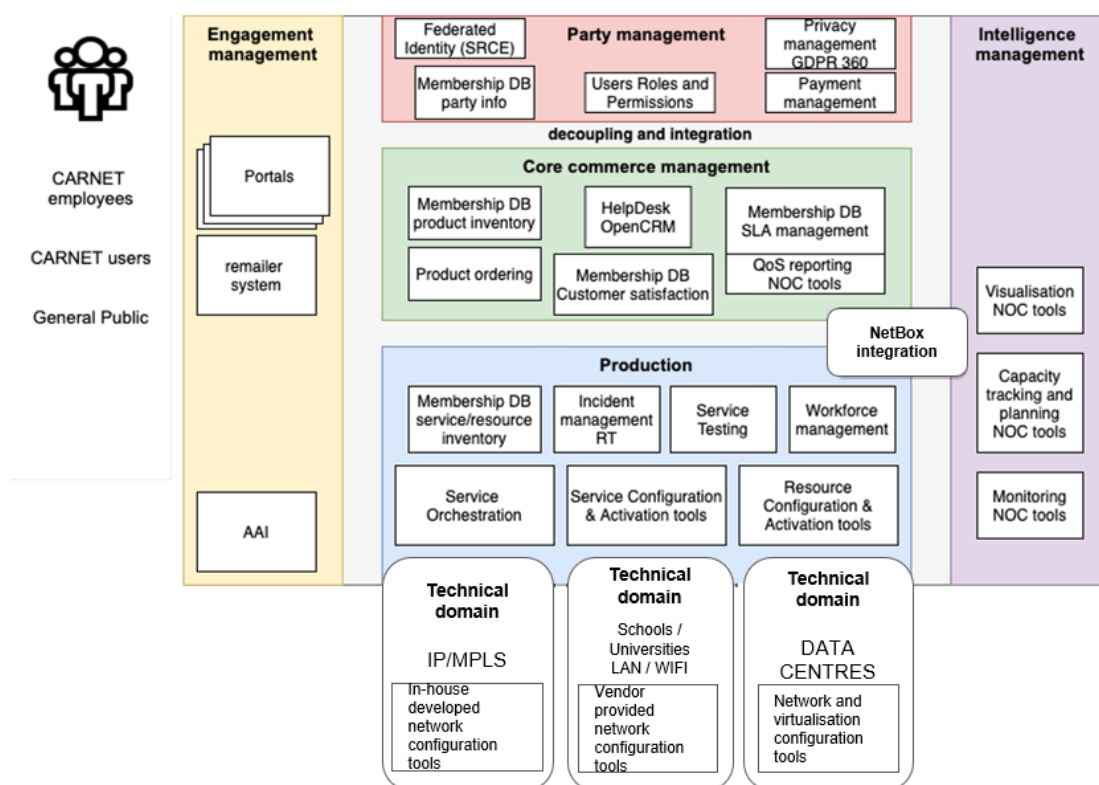


Figure 2.1: CARNET’s NMS components mapped to the TM Forum ODA

## 2.2.1 Engagement Management

A number of web portals offer access to the different services provided by CARNET. Information about most of the main services related to connectivity, internet service, training, collaboration, and security services is made available via the main CARNET web page. It then branches to different access portals depending on the service type, such as <https://domene.hr/>, <https://certifikati.carnet.hr/>, and <https://meduza.carnet.hr/>. In addition to the main website, there are a number of social media channels that are used by the NREN to highlight its activities and available services.

For CARNET member institutions that have already subscribed to the main connectivity services, the Membership portal provides all institution-specific information. Through the portal, institutions can view the status of their services, order additional services, access service monitoring tools, report and track problems (by creating a problem ticket), access all agreements and service-related documentation, and provide feedback.

The schools’ and school-related educational services are provided via a second set of portals including the government-supported e-Citizens system, on whose behalf CARNET manages the mToken application for generating one-time passwords. The educational portals that can be accessed by students, parents, teachers and schools include e-Dnevnik [\[DNE\]](#), Loomen [\[LOO\]](#), e-Lektire [\[ELE\]](#), Skole [\[SKOLE\]](#), e-Laboratorij [\[LAB\]](#), Nikola Tesla distance learning [\[TESLA\]](#), CMS, Sigma, Delta, and Edutorij.

System admins and technicians in institutions that collaborate with CARNET can also access the sys portal that provides them with training resources, tools and services used in their daily activities.

For CARNET employees, a special set of management portals has been developed.

The CARNET NOC portal is a central gateway to all network tools. It has features to streamline operations. Key functions include managing device configurations (descriptions, locations, and root cause analysis), updating documentation, and installing devices and services with minimal effort. Users can search for devices, sites, connections, and configuration parts in a short amount of time, as well as send notifications and report issues. The portal also provides continuous monitoring of performance and resource usage, along with traffic consumption monitoring.



Figure 2.2: CARNET NOC Portal

Also, the NOC portal includes links to various essential tools, such as:

- NetBox – The Premier Network Source of Truth
- CARNET “Turbo Krt tool” – In-house tool serving as a NOC dashboard
- Network Weather Map
- Active/passive monitoring tools
- Vendor integration tools (e.g., Cisco Prime, Meraki, Forti Manager)
- Reporting, anti-DDoS and visualisation tools
- Trouble ticketing system
- NOC rosters and current responsibilities (people management)
- Basic overviews of current events in the core network

This setup gives network engineers instant access to resources. It boosts overall efficiency.

As part of GÉANT GN5-1 WP6, CARNET is currently developing a new NOC dashboard within Grafana for traffic consumption monitoring and analysis. This dashboard will centralise required information about facilities and devices, enabling NOC team members to respond fast to network issues. This enhancement significantly boosts the efficiency and responsiveness of CARNET’s network management, strengthening overall operational effectiveness. The dashboard is still under development, so the NOC team is currently testing its functionalities.

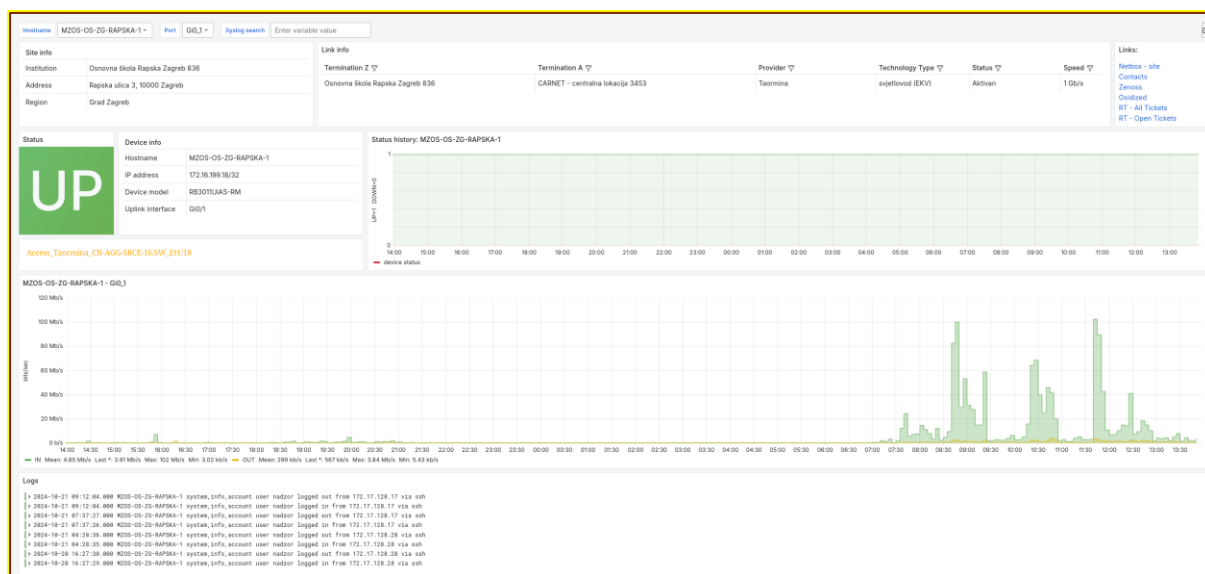


Figure 2.3: NOC dashboard with Grafana – visualisation overview

All portals are integrated with authentication and authorisation infrastructure (AAI), including role management to control access to services. The AAI interfaces are connected to the information about users, identities, roles and rights that is stored in the Party Management blocks. Based on this information, the portals provide a corresponding level of access to the underlying systems.

In addition to using the different available portals to order and manage active services, users can also send requests via email using the remailer system component. Each mail raises a ticket in the ticketing system that can be used to track the order through to fulfilment.

## 2.2.2 Party Management

The main information about CARNET customers is stored in the Membership database (DB). This is accessible to CARNET employees with different levels of access rights, and to the CARNET customers, i.e. the CARNET institution members who can view and manage only the information related to them or their institution.

From a TM Forum Party Management point of view, the Membership DB (see [Figure 2.4](#)) stores information such as:

- institution name and address
- type of affiliation to CARNET
- contact person in the institution (head of office, legal office contact, technical contact)
- participation in active CARNET projects

The Membership DB also tracks all active CARNET projects (such as e-Islands, e-Schools, e-Universities etc.) and their partners.

The level of access is managed through user roles and associated permissions. There are 14 different types of users defined, and the CARNET website provides information about the availability of each service to each type of user.

Federated identity in the Party management block refers to AAI@EduHR – the national federated identity provider (IdP) which is managed by the University Computing Centre, SRCE [AAI].

Početna
Ustanove
Adrese
Osobe
NOC
Izveštaji

Odjava

**[\*] Lidija Jakovčić**

**Ustanova:**

ID	Naziv	Adresa	Mjesto	Članstvo	IP range	hostname	RT
925	Osnovna škola "Kantrida" Rijeka	Izviđačka 9	51000 Rijeka	Punopravna članica		MZOS-OS-RI-KANTRIDA-1 Netbox	#690 <span style="float: right; border: 1px solid #ccc; padding: 2px 5px;">Host</span>

**Linkovi kojima je 'Osnovna škola "Kantrida" Rijeka' točka B** 
Prikazi neaktivne linkove
Popis ustanova
dodaj link

Naziv linka	Ustanova B	Ustanova A	Vlasnik veze	Ekli	Tip veze	Media converter	Brzina veze	Dat. spajanja	Dat.odspajanja
	Osnovna škola "Kantrida" Rijeka Izviđačka 9 / 51000 Rijeka	CARNET - Rijeka Ulica Radmile Matejčić 2 / 51000 Rijeka	CARNET	NE	svjetlovod (EKV)		1 Gb/s	21.12.2021	
ODF oznaka točke A/ poz. niti	ODF oznaka točke B/ poz. niti	ID veze	Problem prijavlje	QoS	Username/ prof./br. priključka	Tehnologija			
/	/		CARNET		//				

**Kontakt osobe:**

ID	Djelatnik	OIB	Titula	Funkcija	Telefon	e-mail	Napomena
6832				administrator resursa			
9640				e-Dnevnik administrator			
10709				stručnjak za tehničku podršku			

**SZK DOKUMENTI za ustanovu 'Osnovna škola "Kantrida" Rijeka'** (Arhiva) +

ID	Datum	Naziv	Vrsta	Ur. broj	Klasa	Dodao
18824	2024-09-06	Imenovanje administratora resursa	ulazni			
15940	2022-05-02	Zahtjev za izdavanje osobnih certifikata - PRODULJENJE	ulazni			
12455	2019-01-28	Imenovanje administratora imenika	ulazni			
10054	2017-06-29	Zahtjev za uključenje u e-Dnevnik sustav	ulazni			
8161	2015-10-16	Zahtjev za uključenje u e-Dnevnik sustav	ulazni			
7289	2014-12-24	Zahtjev za uključenje u e-Dnevnik sustav	ulazni			
5721	2013-02-06	Podaci za izradu tehničkog rješenja pokrivanja škole širokopoljnim signalom	ulazni			
3368	2011-03-04	Arhiva	ulazni			

Broj dokumenata: 8

**Projekti i usluge:**

ID	Naziv projekta	ID	Naziv usluge	ID	Ostalo
16	ProMikro	2	e-Dnevnik	18	Potpisan ugovor o članstvu
23	e-škole projekt (II. faza)				
24	e-škole CARNET sigma				
25	1.slot - e-škole: projektiranje				
38	1.slot - e-škole: pasiva				
53	e-škole Aktiva: FAZA 1				
56	2. slot - e-škole: aktiva				

Figure 2.4: Institution information and related links in the Membership DB

CARNET has also implemented the GDPR360 solution that manages the personal data of all users to ensure GDPR compliance. This solution enables the implementation of user-based privacy management for all services the user is subscribed to. Other GDPR considerations are related to the overarching organisation-level knowledge base that is built within Intelligence Management.

Membership DB also provides access to the yearly customer satisfaction questionnaires that need to be filled out by each institution. Using this system, the institutions can also report problems by creating a ticket that will automatically be sent out to the first-level support help desk, which uses OpenCRM to track tickets.

Considering that the business procedures and needs of Network department (NOC) were not fully met using Membership DB, the NOC started to adjust it and use NetBox as The Premier Network Source of Truth, more described in the next part of the document.

### 2.2.3 Core Commerce Management

The main products offered by CARNET include network connectivity, a number of top-level services (such as hosting, communication and collaboration, and computer security) and a wide variety of digital education services. These are offered to primary and secondary schools, universities, and the general public.

While the CARNET website acts as a product catalogue (listing all available services – products using TM Forum terminology – as discussed in [Section 2.2.1](#)) many of the services (especially the educational ones) have their own portals (for example <https://edutorij.carnet.hr/>).

For network connectivity services, the primary source of truth is NetBox. This tool serves as the central inventory and management platform, containing all essential data for network management, from lists of sites and locations to details about network devices, prefixes and link information. By utilising NetBox, teams can ensure accurate documentation and streamline processes related to network management, enhancing overall efficiency and reliability.

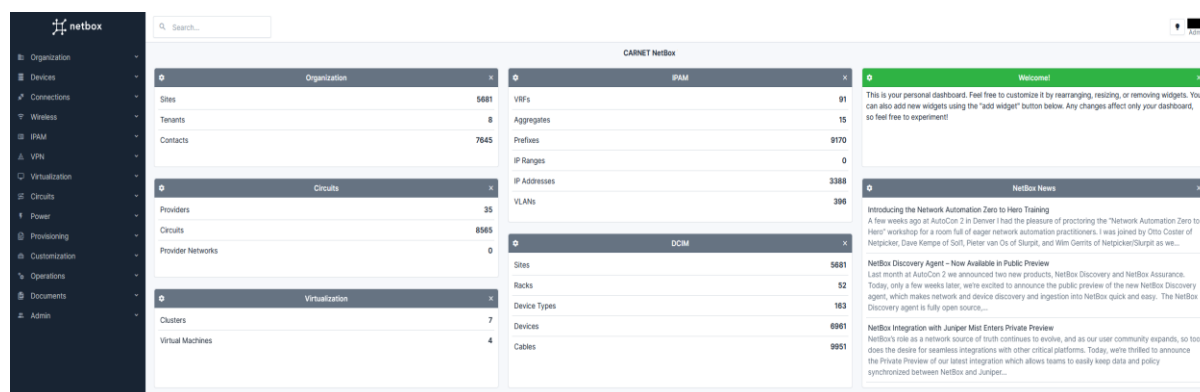


Figure 2.5: NetBox dashboard

HelpDesk is also one of the core services that provides basic technical support to users and information about CARNET and its current public activities and actions. HelpDesk is available by phone and email (integrated with openCRM).

## 2.2.4 Production

CARNET uses several components and tools to manage production services. Most of these are developed in-house, but CARNET also adapts open-source tool sets and tools provided by equipment vendors. As already mentioned in the previous chapter, NetBox is an open-source application designed for managing and documenting network infrastructure. NetBox can be integrated with various network automation tools and platforms, so it is used daily in CARNET.

One of the key advantages of NetBox is its API, which allows users to easily retrieve and manipulate data.

So, the NetBox contains data about:

- Sites – information regarding their location, membership type of the institution, size, participation in projects and associated contacts along with their roles.
- Network devices – details on all network devices within the CARNET network, including access devices at sites and core devices in data centres. This includes documentation, models, types, and essential configuration features.
- IPAM (IP Address Management) – data related to IPv4 and IPv6 prefixes, VRFs, and VLANs.
- Circuits (Network Links) – information about providers linked to each circuit, including unique circuit IDs, types, bandwidth (capacity) and terminations (endpoints).

All service-related incidents are tracked in the Request Tracker ticketing system [\[RTS\]](#) which manages escalations to second level of alarms that originate from the help desk, and all NOC-issued alarms. The monitoring information gathered via Zenoss is used to trigger open/close incident tickets.

CARNET's NOC engineers work is scheduled using a 24/7 roster. A minimum of five NOC engineers are on duty during work hours. Two main engineers support troubleshooting and configuration of CARNET CPE equipment during work hours 8.00 to 17.00 CEST. Two support the troubleshooting of the e-Schools project equipment, and act as support in service provider changes to uplink technologies, while one is assigned to field work. During non-working hours and weekends, there is always at least one NOC engineer on standby for the main network services/backbone. Incident alarms are sent as SMS notifications to the engineer on duty.

In addition to the NOC team, the Network Department also has:

- a team in charge of the network services and core equipment.
- a team in charge of monitoring tools development and maintenance.
- a team responsible for the procurement of access links to the CARNET networks via the telco providers.
- a specialised project team that is working on maintaining core network and the datacentre's, passive LAN, active LAN, and application monitoring of the e-Schools project, and currently planning the execution of the e-Universities project.

Excel sheets hosted in the cloud are used for roster management of all teams based on a two-month cycle.

Most of the automation and orchestration activities in CARNET are focused on the service and resource configuration, and activation procedures. These are implemented with the help of the NOC portal management tools. The NetBox tool plays the role of integration component, gathering and processing information from multiple components.

### 2.2.4.1 Service Orchestration

Within the CARNET NOC, special attention is given to the automation and orchestration [\[TNC\]](#) of several important actions including:

- Implementation of the antiDDoS service – the service blackholes’ destination addresses for a specified time span, based on a set of triggers such as NetFlow analysis results, link thresholds, predictive thresholds and triggers from antiDDoS boxes.
- VRF creation – auto-generation of configuration changes that can then be applied via MegaConf (another NOC tool) or manually.
- QoS management – auto-generation of configuration changes that can be applied via MegaConf or manually. The automated configuration of QoS is based on the time of the day (e.g. limiting system backup services during daytime).

Other examples of service orchestration implementation include the management of wireless and wired LANs in the schools using APIs.

### 2.2.4.2 Technical Domains

CARNET’s Production block can be divided into three broad technical domains that focus on different aspects of the NREN’s activities.

- IP/MPLS in the core network – This technical domain is the main focus of the CARNET NOC team, and, for the management of the specific activities for this domain, mostly in-house network configuration tools are used in combination with available open-source software tools. For the purposes of configuration creation and active configuration change, CARNET is using in-house developed tools (such as MegaConf, MegaTool, MultiTO) that utilise Netconf/SSH or API management:
  - MegaCONF – global configuration change for a large set of devices.
  - MegaTool – for execution of certain actions on groups of devices (such as getting NMAP information, grabbing telco provider IDs, checking IP interface status, etc).
  - MultiTO – “Multi ticket opener” – changes are tracked using the trouble ticketing system in CARNET, so this tool enables changes that affect many ticket instances at once. For example, the change of a last mile telco operator in a single area can affect 100 schools in that area. With this tool, 1 click equals 100 solved changes.
- Schools LAN and Wi-Fi for the e-Schools connectivity and services – For the purposes of management of the wired and wireless networks within the primary and secondary schools, a set of vendor-provided tools are used [\[ICT\]](#). These include Cisco (Meraki and Cisco Prime) and Fortinet devices (Fortimanager and FortiAnalyzer).
- e-Universities project for LAN and Wi-Fi connectivity and services is in procurement and preparation stage, and installation of network equipment is planned to be finished for all universities in Croatia by the end of 2025.
- Datacentres – The virtualisation layer in the CARNET data centres is implemented using OKD, which is a distribution of Kubernetes that is optimised for continuous application development and for multi-tenant deployments [\[OKD\]](#). OKD is actually an open-source version of RedHat’s OpenShift. This is a Platform-As-Service solution where Docker containers are orchestrated using Kubernetes. The communication between pods is done by establishing a pod network which is configured using OpenShift SDN. For automation purposes, Ansible playbooks are used to define the cloud-hosted infrastructure and to apply any post-provisioning configuration. Good automation and orchestration practices are of great importance for this technical domain due to the lack of resources and the continuously growing demand for services.

## 2.2.5 Intelligence Management

Within the Intelligence Management functional block there are a number of CARNET components that focus on gathering different types of information from multiple sources and visualising it using customised visualisation tools.

These tools include:

- Monitoring with Zenoss (SNMP, alarm trigger, performance, link/interface threshold)
- Monitoring with LibreNMS (still under development)
- NetFlow information (NFSEN)
- Network weather map
- Grafana with Influx DB integration for performance management

A number of different performance-reporting tools are used for capacity tracking and planning, where the focus is on identifying both under-utilisation and over-utilisation of links.

CARNET has developed a predictive, threshold-based system for link monitoring. If the institution or backbone link is utilising more bandwidth than a learned baseline, an alarm is shown in the NOC console.

In the e-Schools realm, the CARNET Delta service focuses on learning analytics and educational data mining [\[DELTA\]](#) [\[CDE\]](#). The goal of this service is to improve the decision-making and policy-making processes by supporting the CARNET NOC with relevant information, as well as improve overall learning outcomes. The learning analytics architecture is designed to store logs from all e-School-related services in an Oracle-based data lake (centralised repositories that store structured and unstructured data at any scale). The data lake is then accessed by an enterprise data warehouse system that performs business intelligence (DW/BI). The results from the analytics are presented through the service portal. In the future development of the e-Schools project, the service will be augmented with machine learning and related artificial intelligence algorithms for deep insight analytics and predictions.



### 3 Conclusions

CARNET provides a large number of services and manages related requirements from its vast community of users. Network users demand an efficient and effective approach to service management that can scale easily.

Having faced a rapid growth in locations and traffic, CARNET has leaned heavily on automation and orchestration opportunities to be able to produce solutions that are highly reliable and scalable in times of great demand. CARNET engineers have embraced the golden rule of automation – by focusing on automating repetitive daily tasks, engineers become more efficient, freeing them up to focus on more complex issues.

The analysis of the components used for service management in all ODA functional blocks show that, for most of the network and service management activities, CARNET has decided to either use a large set of tools developed in-house or customise existing open-source solutions. The main components that provide functionalities across several ODA functional domains are NetBox and the CARNET NOC portal.

The OKD solution for hosting services provides an agile platform for rapid application development, while the network devices' automated configuration scripts are accelerating the process of network management in the backbone and school LANs.

The e-Schools project and the ongoing e-Universities project are significantly contributing to the digital transformation of Croatia's research and education landscape into a fully digital platform. These initiatives lay the foundation for a technologically advanced platform that facilitates efficient knowledge exchange and enhances access to education.

The results of the previous architecture analysis [\[COAA\]](#) provided valuable insights into the existing framework, identified areas for improvement and optimisation shaping the development of these initiatives.

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## Glossary

<b>AAI</b>	Authentication and Authorisation Infrastructure
<b>API</b>	Application Programming Interface
<b>BI</b>	Business Intelligence
<b>CARNET</b>	The Croatian Academic and Research NETWORK
<b>CEST</b>	Central European Standard Time
<b>CERT</b>	Computer Emergency Response Team
<b>CLI</b>	Command Line Interface
<b>CMS</b>	Content Management System
<b>CPE</b>	Customer Premise Equipment
<b>DB</b>	Database
<b>DDoS</b>	Distributed Denial of Service
<b>DNS</b>	Domain Name System
<b>DW</b>	Data Warehouse
<b>GDPR</b>	General Data Protection Regulation
<b>IdP</b>	Identity Provider
<b>IP</b>	Internet Protocol
<b>IX</b>	Internet Exchange
<b>LAN</b>	Local Area Network
<b>LMS</b>	Learning Management System
<b>MDM</b>	Mobile Device Management
<b>ML</b>	Machine Learning
<b>MOOC</b>	Massive Open Online Courses
<b>MPLS</b>	Multiprotocol Label Switching
<b>NMS</b>	Network Management System
<b>NOC</b>	Network Operations Centre
<b>NREN</b>	National Research and Education Network
<b>OAV</b>	Orchestration, Automation and Virtualisation
<b>ODA</b>	Open Digital Architecture
<b>PoP</b>	Point of Presence
<b>OKD</b>	Origin Kubernetes Distribution
<b>QoS</b>	Quality of Service
<b>SDN</b>	Software Defined Network
<b>SIM</b>	Subscriber Identity Module
<b>SLA</b>	Service Level Agreement
<b>SMS</b>	Short Message Service
<b>SNMP</b>	Simple Network Management Protocol
<b>SSH</b>	Secure Shell
<b>R&amp;E</b>	Research and Education
<b>TCS</b>	Trusted Certificate Service
<b>URL</b>	Uniform Resource Locator
<b>VLAN</b>	Virtual LAN

<b>VLE</b>	Virtual Learning Environment
<b>VRF</b>	Virtual Routing and Forwarding
<b>VoIP</b>	Voice over IP
<b>WP</b>	Work Package