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ReMuNet

Pioneering resilient and adaptive multimodal transport networks

D5.2

Multimodal transport network for delivering auxiliary supplies to Ukraine

Hanken School of Economics

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Executive Summary

In recent years, the European Union's freight transport network has been affected by a series of systemic disruptions, including the COVID-19 pandemic, Brexit, and the ongoing Russia–Ukraine war. These events have demonstrated that transport resilience is not merely a matter of infrastructure redundancy, but of dynamic adaptation across modes, corridors, and actors. Within this context, the Resilient Multimodal Transport Networks (ReMuNet) project develops a digital platform designed to strengthen multimodal freight resilience through disruption-aware routing and synchromodal coordination.

This deliverable presents a social pilot use case focused on delivering humanitarian assistance to Ukraine under conditions of sustained armed conflict. The case was deliberately selected for its extreme operational environment, where infrastructure damage, fluctuating security conditions, border congestion, and modal shifts occur simultaneously. Rather than treating humanitarian logistics as a separate domain, the report positions it as a real-world stress test of multimodal transport systems. The analysis follows a structured progression. First, it examines how the evolving conflict environment reshaped transport networks, corridor accessibility, and infrastructure functionality. Second, it analyses how humanitarian actors adapted within this constrained environment, coordinating across multiple nodes and borders. Third, these observations are translated into use cases for the ReMuNet platform testing, focusing on disruption-aware routing and prioritisation logic. The humanitarian deliveries examined in this report rely on multimodal transport routes across several European countries, often involving consolidation points near the Ukrainian border and coordination among humanitarian actors to maintain alternative corridors under changing security conditions.

The study employs a mixed-methods approach that combines desk-based research, expert interviews, and partner data validation. Desk research involved mapping ports, airports, rail hubs, consolidation centres, and border crossings across Estonia, Latvia, Lithuania, Poland, and Ukraine. Quantitative data on freight capacity, routing, and transit times were complemented by qualitative insights gathered from semi-structured interviews with humanitarian logistics experts. Humanitarian partner data, including shipment volumes, warehouse locations, and transit patterns, supplemented the development of pilot scenarios.

The deliverable documents the operational preparation of the order dataset used to simulate the Finland-Ukraine and Germany-Ukraine corridors within the platform. The dataset is derived from empirical humanitarian shipment data and transformed into structured, time-sensitive freight orders. To reflect operational realities, shipments are categorised into urgency classes (urgent, standard, and flexible), each associated with differentiated pickup windows, planning horizons, and delivery constraints. Orders are staggered to generate overlapping time windows and competing service requirements. This structured temporal logic enables the platform to be tested against heterogeneous constraints, including feasibility filtering under tight deadlines, trade-offs between speed and cost across modes, prioritisation among concurrent shipments, and potential late-window rerouting behaviour.

The humanitarian pilot thus functions as an operational bridge between empirical observation and platform experimentation. By embedding real-world stress characteristics into a structured routing problem, the report demonstrates how lessons from conflict-induced disruption can inform broader resilience modelling. The insights generated extend beyond humanitarian logistics and contribute to strengthening the robustness of multimodal freight systems facing diverse forms of disruption across Europe.

1. Introduction

The European transport network has faced multiple systemic disruptions in recent years, from the COVID-19 pandemic and the economic effects of Brexit to the continuing Russia–Ukraine war. These crises have exposed the vulnerability of critical infrastructure and underscored the need for adaptable, multimodal logistics systems that can sustain essential flows during disruptions. Against this backdrop, the ReMuNet project aims to strengthen the resilience of European multimodal freight transport networks by developing a digital platform that dynamically identifies, evaluates, and orchestrates alternative routing options under disruptive conditions. Having established a typology of disruptive events and constructed a structured database of historical disruptions in earlier phases of the project, the current work package focuses on testing and validating the platform's logic through applied pilot scenarios.

Task 5.2 introduces a social use case: the delivery of humanitarian aid to Ukraine amid sustained armed conflict. This use case was deliberately selected not because it represents typical freight operations, but because it represents an extreme operational environment. Active conflict generates compound disruptions, including damaged infrastructure, fluctuating security conditions, border congestion, modal shifts, and coordination challenges across multiple actors. In such contexts, transport systems are forced to reveal their structural weaknesses and adaptive capacities. Humanitarian deliveries to Ukraine rely on a network of multimodal transport routes across several European countries, often involving consolidation points near the Ukrainian border. Routing decisions are shaped by a dynamic conflict environment, requiring humanitarian organisations to maintain alternative corridors and coordinate operations in order to sustain aid flows while avoiding duplication of effort.

This report aims to demonstrate how this specificity manifests in practice, providing the empirical context and operational data needed to support future testing of the ReMuNet platform. To do so, it examines the transport routes and logistics networks that enable aid delivery to Ukraine from northern Europe via the Baltic corridor. Unlike commercial freight, humanitarian logistics operates in the face of severe uncertainty, requiring flexibility, rapid coordination, and contingency planning across borders and transport modes. By focusing on multimodal corridors from the Baltic States and Poland into Ukraine, this report analyses how existing freight infrastructure can be leveraged to enhance humanitarian access and response capacity during conflict conditions. It builds upon existing academic literature, situating humanitarian mobility within existing European transport infrastructure. It also extends the analysis beyond infrastructure to include operational realities, such as gauge changes, customs delays, and the fluctuating capacity of intermodal terminals, that shape the movement of goods in practice.

This report, therefore, positions humanitarian logistics in Ukraine as a real-world stress test of multimodal resilience. By examining how freight flows reorganise under persistent disruption, the study extracts insights into corridor fragility, modal substitution patterns, terminal dependency, and cross-border bottlenecks. These observations are not treated as isolated humanitarian phenomena; rather, they are analysed as manifestations of broader transport system behaviour under stress. The central narrative of this report traces how disruption reshapes transport networks, how humanitarian logistics flows operate within these constraints, and how these observations can inform the development of ReMuNet's synchromodal routing logic.

To structure this analysis, the report follows a three-stage analytical progression.

First, it examines the stress environment created by the evolving conflict in Ukraine. This includes the geographical expansion of affected areas, infrastructure damage, fluctuating border conditions, and the resulting redistribution of freight flows across corridors. In this phase, disruption is treated as a structural force that reshapes network topology and exposes latent vulnerabilities within multimodal systems.

Second, the report examines humanitarian logistics operations within this disrupted environment. Drawing on empirical shipment data from humanitarian operations, combined with mapping of multimodal transport corridors and expert validation, the report reconstructs how aid flows can move through the disrupted transport network.

Third, these observations are translated into pilot scenarios and structured order datasets that can be used to test routing behaviour within the ReMuNet platform. The report prepares realistic experimental conditions that reflect the operational constraints observed in humanitarian logistics.

The sections that follow therefore move from analysing the disruption environment, to examining humanitarian logistics flows and the transport network that supports them, and finally to operationalising these insights through pilot scenarios and dataset preparation for future platform testing.

1.1 Structure of the report

This report is structured to reflect the analytical progression outlined in the Introduction, moving from contextual disruption analysis to operational adaptation and finally to platform-oriented implications.

Section 2 provides the background to the conflict in Ukraine, outlining its causes and how it has affected the country's transport network. Section 3 reviews relevant literature on conflict dynamics, supply chain adaptation, humanitarian logistics, and existing data platforms documenting access constraints and infrastructure disruptions. The purpose of this section is not solely to situate the study academically, but to identify recurring structural patterns such as modal shifts, border congestion, infrastructure fragility, and distributed coordination that inform the subsequent analysis. Section 4 outlines the methodological approach, including humanitarian data analysis, transport network mapping, and validation through expert interviews and partner consultation. This section explains how empirical shipment data and corridor analysis are translated into insights relevant for multimodal routing evaluation.

Section 5 presents findings from the humanitarian data and corridor assessment. It examines routing alternatives, infrastructure constraints, and network characteristics within and around Ukraine, highlighting the structural pressures acting on multimodal freight flows under conflict conditions. Section 6 develops the two pilot scenarios: Finland to Ukraine and Germany to Ukraine, translating the identified corridor dynamics into scenario narratives suitable for platform testing. The section also discusses resilience considerations and multimodal flexibility within active conflict settings. Section 7 documents the operationalisation of the pilot scenarios through the design of a structured order dataset. Derived from empirical humanitarian flows, the dataset embeds differentiated urgency classes, temporal constraints, and staggered order creation to simulate heterogeneous service requirements. This section establishes the experimental framework through which synchromodal routing logic can be evaluated.

The report concludes by synthesising insights from the humanitarian stress environment and translating them into implications for multimodal resilience modelling and platform development within the ReMuNet project.

2. Background to the conflict in Ukraine and its impact on transport infrastructure

In this section, an overview of the conflict is presented to outline the social use case for the ReMuNet platform. It includes a brief description of its origins and demonstrates how a shifting frontline leads to multiple changes in access across different parts of Ukrainian territory. Finally, it considers the extent of damage to the country's transport infrastructure, which affects the modes of transport available for delivering life-saving humanitarian aid.

2.1 The current conflict in Ukraine

In February 2014, the Revolution of Dignity, also known as the Maidan Revolution, led to the removal of President Viktor Yanukovych, marking a shift towards more pro-European Union policies in Ukraine. That ousting led to separatist, pro-Russian protests in the Crimea peninsula, which, with the support of Russian forces, voted on a contested referendum and declared its independence from Ukraine. The region was annexed by Russia in March 2014. (Platonova, 2021).

Separatist groups were also active in the Donbas area. Backed by Russia, the Donetsk People's Republic (DPR) and Luhansk People's Republic (LPR) declared independence in April and May of the same year, leading to active armed conflict involving Russian and Ukrainian forces (Platonova, 2021). As a result, Ukraine lost control of a portion of its eastern territory, critical infrastructure was destroyed, and over 2 million people became internally displaced in Ukraine by 2016 (United Nations High Commissioner for Refugees, 2017).

The conflict in eastern Ukraine continued until it was subsumed by the full-scale Russian invasion on 22 February 2022. In addition to Donbas, Kyiv, Kharkiv, and Mariupol were targeted in major early offenses. Ukrainian forces mobilised a strong resistance, and Russia was unable to take over Kyiv as initially planned, withdrawing troops from the Ukrainian capital (Al Jazeera, 2022). Heavy fighting continued throughout that year, especially in the east and south of Ukraine, leading to Luhansk, Donetsk, Kherson, and Zaporizhzhia regions being declared as annexed by Russia. From 2023 to the present time, the frontline has remained relatively static, although there have been changes in the territorial control of smaller areas adjacent to it (PBS NewsHour, 2025).

Between 2014 and 2025, the consequences of the conflict in Ukraine have been immense. Over 42,000 civilians have been injured or killed, and more than 6.9 million have become refugees (UNHCR, 2025). Currently, around 12.7 million people in Ukraine require humanitarian aid, including 2.8 million internally displaced individuals (Norwegian Refugee Council, 2025), making efficient supply chains for the delivery of assistance a priority for both the country and the international community.

2.2 Evolution of affected areas in Ukraine over time

Starting from Crimea, Luhansk, and Donetsk in 2014, the frontline has expanded to encompass a large portion of eastern and southern Ukraine by 2023. Although not to the same extent as in 2022, fighting for territorial control continues, resulting in a dynamic conflict environment. Active fighting in 2025 is taking place on multiple fronts, from the Donbas, Zaporizhzhia, and Kharkiv in the east to Sumy in the north-east of Ukraine, extending into the west of Russian territory in the Kursk region (International Crisis Group, n.d.). Figure 1 shows the changes in territorial control since 2014.

Nevertheless, there are cases of explosions and remote violence in the west and centre of Ukraine (BBC, 2025), and the significant number of internally displaced people in these areas leads to the continued need for distribution of humanitarian assistance throughout the country.

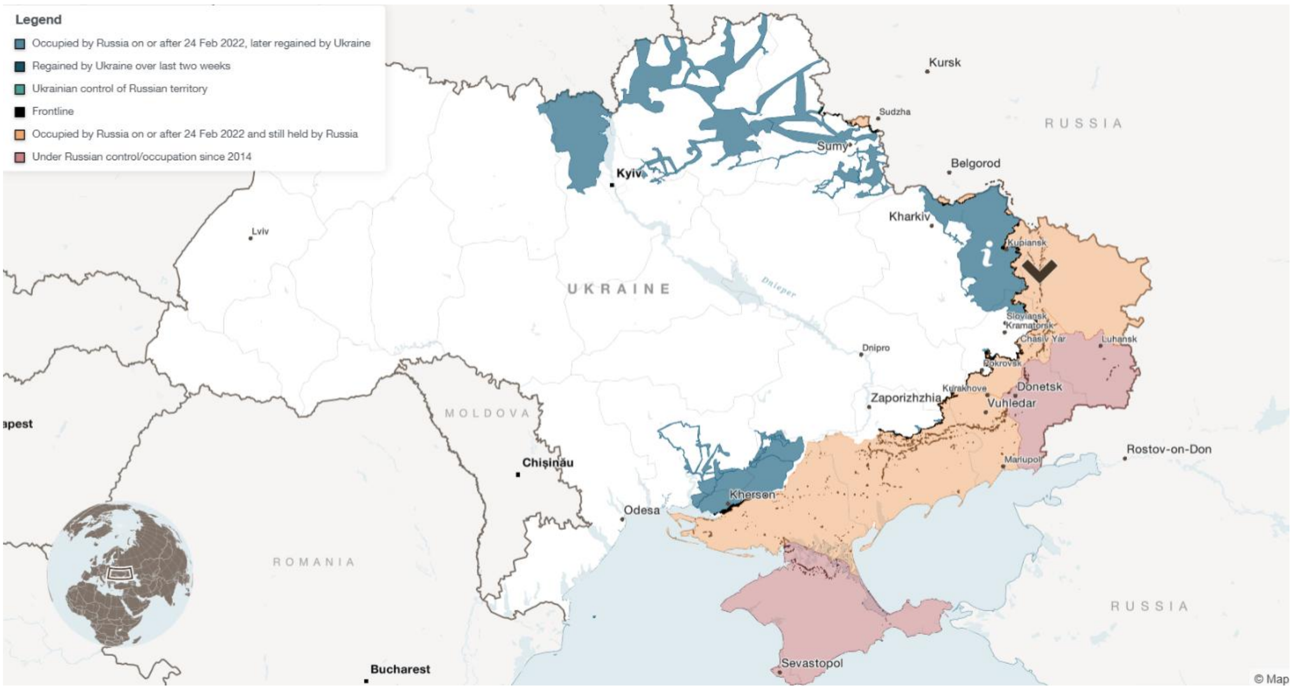

Figure 1: Changes in territorial control since 2014 (Map created by the authors via MapCreator)

Humanitarian organisations currently providing aid in Ukraine tend to have different starting locations for their operations based on whether they had established their presence in the country before February 2022. Those who had been present prior to the full-scale invasion had operations focused on the eastern region, as it was the area affected by conflict and in need of aid. In contrast, organisations that were not active in Ukraine before February 2022 initially set up their operations in the Western part of the country, closer to the borders, or in neighbouring countries such as Poland (Teles Hamideh & Schiffling, 2025).

For the organisations that had not been active before, security was a significant consideration when deciding where to establish their presence. Cities near the western borders, such as Lviv, were deemed safer than the capital Kyiv or those closer to the frontline. To safeguard staff, many decided to set up operations there, even if they were not where the need for humanitarian assistance was greatest. Over time, as it became clearer that most of the fighting would be concentrated in the eastern regions of Ukraine, offices and warehouses began to relocate towards the centre of the country. As an example, the changes in the World Food Programme's warehouse locations since 2014 are shown in Figure 2. The points marked in blue represent the locations chosen in early 2022; in red, those that closed later in the same year. Finally, the points in green were set up after 2023, showing how the network moves further east (Teles Hamideh & Schiffling, 2025).

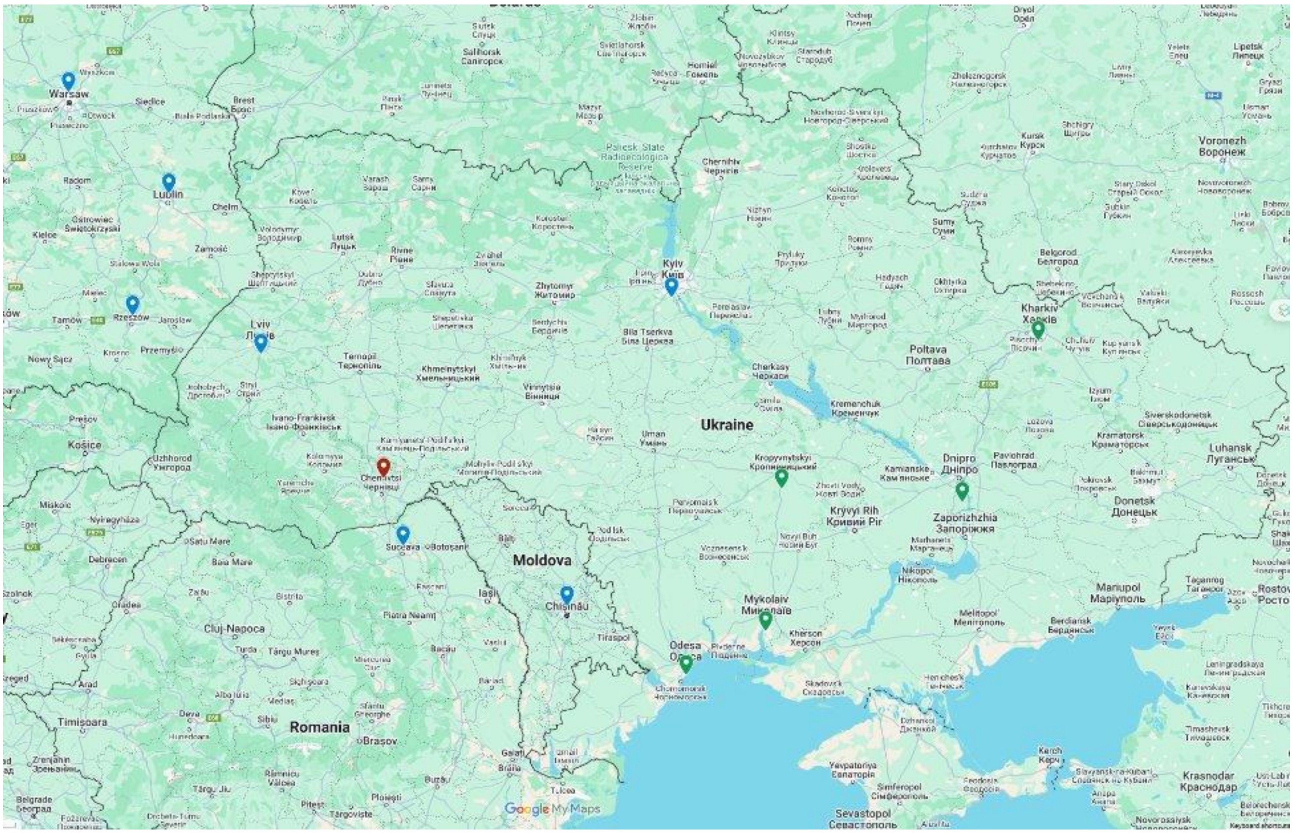

Figure 2: World Food Programme warehouses in Ukraine and neighbouring countries (Teles Hamideh & Schiffling, 2025)

That structure has also affected the type of aid distributed and where it was distributed. The comparison of the number of beneficiaries reached by location in 2022 and 2024 reveals that in the earlier years of the conflict, more aid was distributed in western regions, which were easier to access. After 2023, revised security assessments showing the relatively stable frontline allowed organisations to prioritise aid in areas where it was most needed (Teles Hamideh & Schiffling, 2025).

2.3 Transport network within Ukraine

Before the full-scale Russian invasion, air, sea, road, and rail were the main shipment options in Ukraine. After it began, several constraints emerged, restricting the modes available for delivering goods within the country. The airspace for civilian use is closed due to the war. At the beginning of the Russian attack in 2022, aviation infrastructure was targeted and, as of January 2024, 19 airports and civilian airfields had been damaged (KSE, 2024). The Russian blockade in the Black Sea restricts sea freight, and key ports located in Russian-occupied territory are not accessible. Out of the 18 ports, five have been occupied in the Russian annexation of Crimea in 2014, and 4 others after 2022. As of January 2024, the total damage to port infrastructure, including seaport infrastructure and inland waterway transport facilities, was estimated at $0.85 billion (KSE, 2024). Previously, the port structure was vital to the country's economy. In January 2022, 80% of Ukrainian exports, especially agricultural goods, were transported by sea; by April of the same year, the number was around 13% (Melnyk *et al*., 2024).

Table 1 shows the status of Ukrainian ports based on information from the LogCluster’s Port Assessment.

Table 1: Status of Ukrainian ports (compiled by the authors based on the LogCluster's Port Assessment)

Port	Status	Location
Chornomorsk	Damaged, partially operational	Black Sea
Odesa	Damaged, partially operational	Black Sea
Pivdennyi	Damaged, partially operational	Black Sea
Izmail	Damaged but operational	Danube River
Reni	Damaged but operational	Danube River
Ust-Dunaisk	Damaged, partially operational	Danube River
Bilhorod-Dnistrovsk	Blocked and damaged	Black Sea
Kherson	Blocked and damaged	Dnipro River
Mykolaiv	Blocked and damaged	Dnipro River
Kerch	Occupied since 2014	Crimea
Yalta	Occupied since 2014	Crimea
Sevastopol	Occupied since 2014	Crimea
Feodosia	Occupied since 2014	Crimea
Yevpatoria	Occupied since 2014	Crimea
Mariupol	Destroyed and occupied in 2022	Sea of Azov
Berdyansk	Occupied in 2022	Sea of Azov
Genichesk	Occupied in 2022	Sea of Azov
Skadovsk	Occupied in 2022	Black Sea

Roads are currently a viable option for delivering aid in Ukraine, although the territories occupied by Russia are virtually inaccessible. Damage to roads across the country is not evenly distributed; as shown in Figure 3 below, it is concentrated in the eastern and southern regions, where fighting has been most intense.

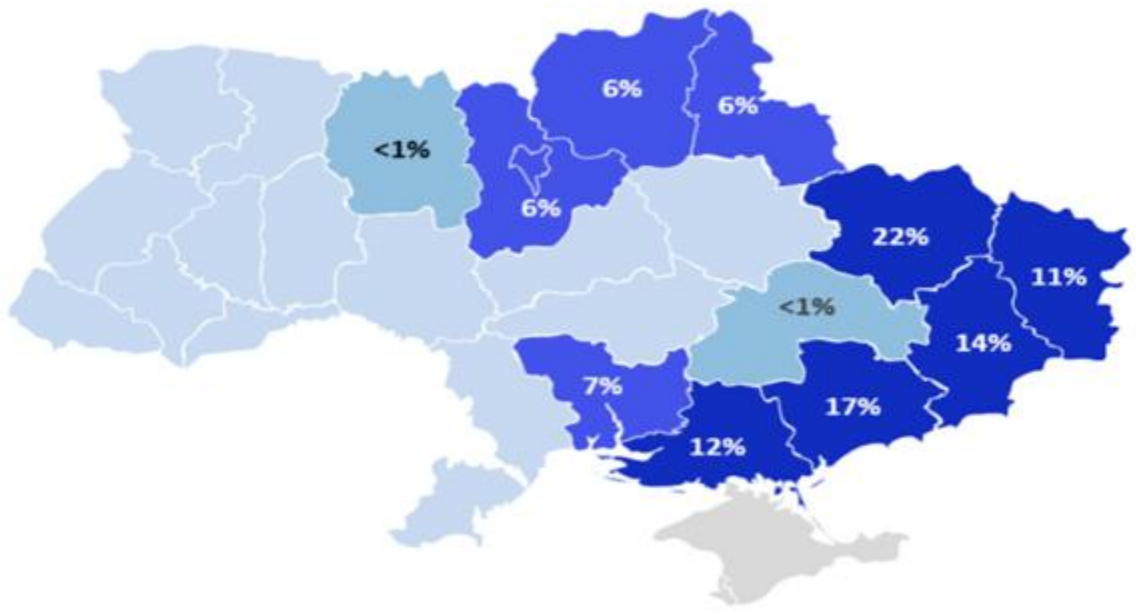

Figure 3: Distribution of damages to roads by regions (KSE, 2024)

Rail is also a viable transportation option. Even after the full-scale invasion by Russia, 82% of all ground freight in Ukraine is by rail. The national rail company remains operational, transporting cargo in most of the country. Damage to the rail network (Figure 4) has followed the same pattern of concentration in the eastern and southern regions, with at least 126 railway stations damaged or destroyed (KSE, 2024). Additionally, the stations in Russian-occupied territories have been disconnected from the main grid and are no longer used.

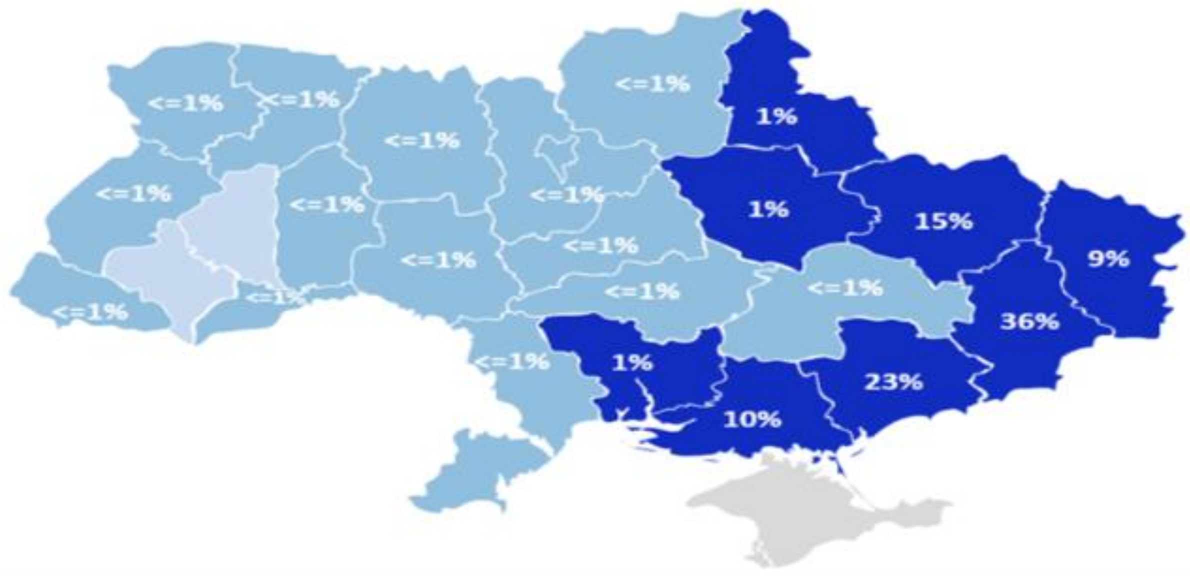

Figure 4: Distribution of damages to the railway infrastructure by regions (KSE, 2024)

Preliminary estimates place the total amount of damage to transport infrastructure in Ukraine at over $36 billion. Beyond the conflict, environmental challenges must be considered when transporting goods in Ukraine, including droughts, earthquakes, extreme temperatures, flooding, wildfires, and high winds. Some of these weather events are difficult to predict, while others are expected; for example, humanitarian organisations are aware of and prepare for the fact that road access is usually constrained during wintertime (November-February) due to freezing temperatures. (KSE, 2024)

The evolving geography of the conflict does not merely alter humanitarian need; it reconfigures the functional topology of the transport network. As territorial control shifts and infrastructure is damaged or secured, the accessibility of nodes and corridors changes accordingly. What appears geographically peripheral may become strategically central as alternative routes absorb displaced flows. This dynamic redistribution of transport pressure exposes latent chokepoints and highlights the importance of redundancy across modes. For ReMuNet, this underscores a critical principle: resilience cannot be assessed statically. It must be evaluated as a function of evolving spatial disruption patterns.

3. Literature review

In recent years, the EU transport network has rapidly evolved to respond to emergencies, transforming transport corridors into lifelines for aid, as witnessed during the COVID-19 pandemic. The Russia–Ukraine war has further exerted a multifaceted impact on this network, influencing border regulations, workforce availability, fuel pricing, and security considerations. Developing resilient transport systems amid an ongoing conflict requires an understanding of complex contextual and operational realities. This section presents a literature review conducted to guide the humanitarian aid pilots in the ReMuNet project. It draws together perspectives on the evolving dynamics of armed conflict, analyses of changes in supply chain configurations in Ukraine, and the actors involved in delivering aid in that country. These insights help frame the context in which the ReMuNet humanitarian aid pilot operates and highlight the knowledge gaps that the qualitative study aims to address.

3.1 The humanitarian response in Ukraine

The humanitarian response to the crisis resulting from the Russia-Ukraine war has seen impactful coordinated efforts across the EU from NGOs, governments, and private actors. As the conflict has evolved, so has the response. Grossi & Vakulenko (2022) have mapped out how these different actors, including the European Commission, the World Bank, the International Monetary Fund, NATO, the United Nations, and the Red Cross, have mobilised to provide aid, although they note that there was a tendency to prioritise short-term humanitarian and military aid over long-term reconstruction planning.

This diversity in the actors mobilised is a key characteristic of humanitarian supply chains, which may pose challenges for communication and coordination. Compared with the commercial sector, humanitarian supply chains face greater uncertainty, including demand, operational environment, available transport capacity, and possible delivery routes for aid (Kovacs & Spens, 2007; Day *et al.*, 2012; Van Wassenhove, 2006; Pettit & Beresford, 2009; Hilhorst, 2002). To manage these uncertain conditions and fulfil their goal of saving lives and alleviating human suffering (Tatham & Kovács, 2010), logistics planning and transport play a key role.

Humanitarian supply chain literature suggests and evaluates different logistics planning models, especially during disaster relief operations. To cite a few examples, Balcik & Beamon (2008) discuss how to determine the number and location of distribution centres, while Mete and Zabinsky (2010) propose an optimisation model for the location of critical medical supplies. Rawls and Turnquist (2010) also explore how to determine warehouse location for the pre-positioning of emergency supplies, and Rennemo *et al.* (2014) suggest a model for the distribution of relief items, including amounts of goods, vehicle routing and transport infrastructure uncertainty due to potential damage. There is a particular emphasis on the literature on vehicle routing, including work done by De la Torre *et al.* (2012), Tzeng *et al.* (2007), Campbell *et al.* (2008), Lin *et al.* (2011), and Yuan and Wang (2009). These works attempt to balance the diverse set of possible priorities when delivering humanitarian aid, such as minimizing total cost, minimizing total travel time, and increasing beneficiary satisfaction.

The use of digital tools is often recommended, especially when complex mathematical optimisation models are involved. Literature from the context of commercial supply chains shows how they can help with data collection, set up and optimise models, and dynamically update them as conditions change, as discussed in works such as Albrecht *et al.* (2024). In humanitarian supply chains, the discussion on the use of digital technologies in humanitarian supply highlights more general aspects, such as how they can help to improve communication, coordination, visibility and transparency (Dubey *et al.*, 2018), promote sustainability (Zarei *et al.*, 2019), manage risk and uncertainty (Dette, 2018), and improve resilience (Papadopoulos *et al.*, 2017).

Regarding the humanitarian response in Ukraine, a significant part of the existing literature focuses on the role of local actors. According to Cullen Dunn & Kaliszewska (2023), they were responsible for virtually all humanitarian aid inside the country in the weeks after the Russian invasion. As Stoddard *et al*. (2022) point out, the participation of local groups in the response developed organically, usually starting with volunteers organizing to gather resources and responding to requests for assistance in their respective geographical areas. The participation of international aid organizations was limited by a variety of factors, including the fact that most HOs operating in the country at the time were working on non-emergency programming, lacking the preparedness and resources to respond to a full-scale invasion.

Moallin *et al.* (2022) make a similar argument that the Ukraine crisis forces humanitarian actors to rethink traditional principles and power structures, as the locally led response often can be critical of international actors' hierarchical, donor-driven approaches. In the analysis of land convoys delivering medical supplies to Ukraine, Lansiaux *et al.* (2024) confirmed the importance of local participation, while also noting how the high intensity of the conflict puts pressure on the supply chain, especially when the frontline is shifting and there are security threats.

This shift toward more engagement by private actors and citizens can also be seen in the solidarity movements beyond Ukraine, in practices of "everyday humanitarianism". Citizens in Poland, for instance, expressed immediate support for Ukrainian refugees. They quickly mobilised to both receive them and send aid to people still in Ukraine, even if in a disorganised manner, as the actual needs of the recipients were not known. According to Pawlak (2022):

> *Personal networks were mobilized to provide the most urgent need: accommodation – Ukrainians coming to Poland were hosted in large numbers in private apartments. This was organized foremost through personal social networks as it requires trust on both sides – hosts and guests. Similarly, transportation from the border was organized through private resources – people used their private cars to transfer refugees. (...) Next to the mobilization of social networks, civic organizations with greater know-how (including some that previously aided refugees) got involved immediately. Enterprises and large for-profit corporations also rushed to provide aid – for example, mobile phone operators providing packages allowing new arrivals to call, send texts, and use free internet for 30 days; banks reduced their fees to zero for Ukrainians; insurance companies offered free policies for one month, etc. Local authorities stepped in to organize accommodation, collection points for donated items, and, crucially for migration of a large number of children, admissions to schools. School admissions were organized by local communities who took responsibility for the families of 'their new children' by donating basic goods, clothes, arranging accommodation, and covering costs of school meals and supplies.*

Podgórska *et al.* (2024) have analysed how effective two cities in Poland have been in hosting Ukrainian refugees, again noting the role of individuals and volunteer groups, while Ociepa-Kicińska & Gorzałczyńska-Koczkodaj (2022) showed how the legal system in the country eventually created rules to support the reception.

Although no academic papers specifically discuss how Finnish civil society groups have mobilised to provide aid to Ukraine, the phenomenon has been widely covered by local media. Two years after the scale-up of the conflict, Finnish non-profit organisations were reported to have donated over 75 million euros (Finland Abroad, 2024). In addition to financial assistance and basic goods, several rescue vehicles have been donated to Ukraine. According to Finland's government, 126 vehicles and 414 truckloads of other civilian material assistance had been sent by August 2025 (Finnish Government, 2025).

3.2 Supply chain management during conflict

Although the impact of the conflict on the configuration of supply chains in Ukraine has been explored in the literature, it has focused on commercial operations, not on the specifics of the delivery of humanitarian aid. Still, the adaptation of commercial transport infrastructure can provide critical insights into the evolution of the transport networks and related policies in response to the crisis and maintaining the flow of essential goods in the face of disruption and conflict. Melnyk *et al*. (2024) explain how the conflict has affected the logistics sector in Ukraine. Before 2022, transport and logistics services accounted for 42.7% of the country's service sector, being highly attractive for both national and foreign investors. With the war, major logistics routes, including a significant number of ports were blocked, and several roads, bridges, and railways were totally or partially destroyed, reducing the country's logistics capabilities. Nevertheless, the supply chain has adjusted to continue exporting goods such as cereals and metals, switching transport that was previously done by sea to rail. Dyczkowska *et al.* (2023) have detailed the different factors affecting logistics in the country, breaking them down into four main categories: people, legislation, security and infrastructure, and proposed potential solutions to mitigate them (Figure 5), including the integration into the EU TEN-T transport corridor.

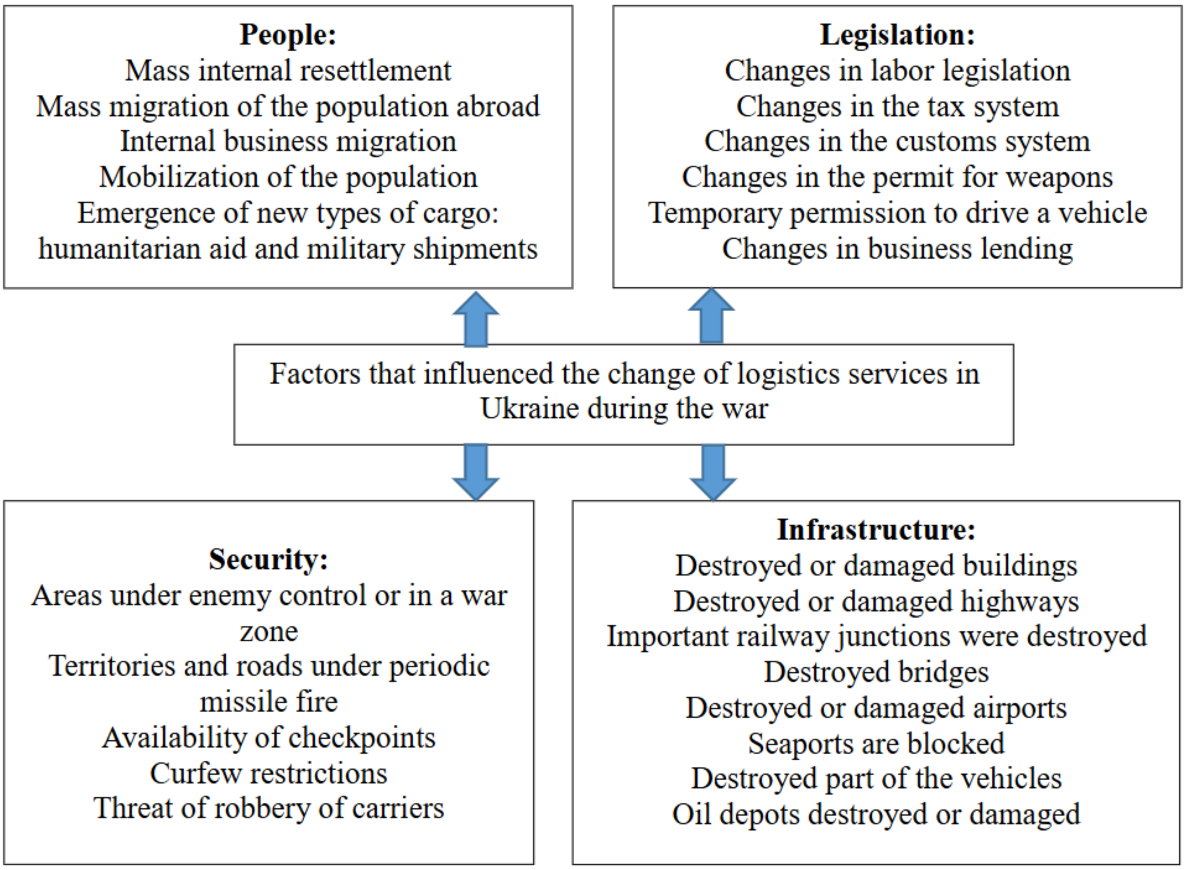

Figure 5: Factors that influenced the change of logistics services in Ukraine during the war (Dyczkowska *et al.*, 2023)

The strategies for addressing the situation have been analysed by Srai et al. (2023), ranging from short-term rerouting options to longer-term, more strategic interventions such as "friend-shoring". These are essential, as the conflict has persisted for many years and companies are seeking pathways to stabilisation and resilience. In Pavlenko et al. (2023), transport-specific strategies were tested, confirming that container rail-based supply chains offer the best balance of cost, reliability, and safety for Ukraine's grain exports during conflict, but added that river and other multimodal options should be considered. Rudyk *et al.* (2023) have a similar position, additionally arguing that digital tools, such as their proposed geographic information system (GIS)-based method can be used to monitor the situation, evaluating risks in real-time and identifying safe transport routes. These strategies are essential not only for Ukraine, as the risk of reduced grain exports was noted as a global food security concern (Jagtap *et al*, 2022; Ngoc *et al*., 2022), and El Baz *et* al. (2025) explored as how the scenario of instability and logistical disruption can increase the risk of illegal grain supply chains, with global consequences.

Furthermore, the armed conflict in Ukraine has evolved into a multidimensional contest that influences logistics networks across the Baltic-Poland-Ukraine axis. Beyond battlefield movements, the conflict has generated sustained increases in cross-border humanitarian and military traffic, disrupted supply chains, and ongoing political and economic measures (sanctions, rerouting of Russian trade) that reshape freight flows and port utilisation. These dynamics have already produced discernible volume shifts at Baltic ports (for example, Klaipėda recorded notable cargo growth in 2025) and increasing demand on northern European short-sea and feeder services used for diversion and surge movements.

Concurrently, the security environment in and around the Baltic Sea has become more contested. NATO and EU partners are actively reassessing critical transport infrastructure as part of military mobility and resilience planning; ports, coastal communications and subsea cables have been subject to increased protection measures and contingency planning because of hybrid-threat activity in the region. There have also been reported instances of dangerous maritime behaviour and interference with vessel tracking, illustrating a higher operational risk milieu for short-sea shipping and port approaches. These developments increase the operational and insurance costs of maritime diversion strategies and complicate surge routing plans.

At the same time, land corridors and border crossings into Poland are under pressure. Studies and operational reports show that transit capacity at border crossings and onward inland distribution points can be a limiting factor for Ukrainian exports and humanitarian flows; insufficient border capacity produces queues, extended dwell times and, ultimately, backlogs that ripple back to ports and staging areas.

While the literature reviewed provides extensive insight into conflict dynamics, supply chain adaptation, and the rise of distributed humanitarianism, its relevance to ReMuNet lies in the structural patterns it reveals. Across studies, recurring themes emerge modal shifts under constraint, border capacity as a systemic limiter, reliance on intermodal terminals for flow consolidation, and the increasing role of digital coordination mechanisms. These patterns collectively illustrate how transport ecosystems under pressure. The present study moves beyond descriptive analysis to operationalise these insights within the ReMuNet framework, examining how they can inform routing algorithms, disruption classification, and corridor-level resilience assessment.

4. Methodology

The methodological approach combines three complementary analytical components. First, humanitarian shipment data is analysed to understand the structure and evolution of aid flows into Ukraine. Second, transport infrastructure and multimodal corridors linking the Baltic region to Ukraine are mapped and validated through expert consultation. Third, these empirical observations are translated into structured pilot scenarios and operational order datasets designed to test synchromodal routing behaviour within the ReMuNet platform.

The methodological approach adopted in this study is designed not only to document humanitarian flows but to translate them into actionable system knowledge. By combining quantitative shipment data with qualitative field validation and corridor mapping, the research reveals how freight flows reorganise across the transport network under crisis conditions. The objective is to identify where disruptions concentrate, how rerouting occurs in practice, and which modal substitutions prove viable. This integrated approach enables the extraction of patterns that can be embedded into ReMuNet's disruption modelling and synchromodal routing logic.

The study employs a mixed-methods approach that combines desk-based research, expert interviews, and partner data validation to help assess the feasibility of routes and modes of transport to Ukraine in the humanitarian context. Qualitative insights from stakeholder interviews (conducted earlier in this project as well as additional interviews with humanitarian stakeholders) and secondary sources are integrated with quantitative inferences from the analysis of humanitarian aid delivery data from the Danish Red Cross (DRC). The DRC data is analysed to visualise the flows and patterns in the early stages of aid delivery, providing the basis for the creation of scenarios and testing of the ReMuNet platform. Table 2 shows the different data sources and approaches used in this study.

Table 2: Data sources and analytical approach used in this study

Data type	Source	Analytical approach	Role in study
Humanitarian aid data (products, volumes, countries of origin, transport time, destination)	DRC operational datasets	Quantitative analysis and data visualisations	Understanding the structure and evolution of humanitarian aid flows and identifying logistics patterns during the early stages of the conflict
Multimodal transport routes and infrastructure (ports, rail hubs, border crossings, corridors)	Desk-based research supported by expert interviews and partner validation	Qualitative transport network mapping and validation	Identifying the transport corridors and logistics nodes enabling humanitarian deliveries to Ukraine via the Baltic region and Poland

4.1 Humanitarian aid data collection and analysis

Founded in 1876, the DRC is a national society of the International Federation of Red Cross and Red Crescent Societies (IFRC) based in Denmark with a broad scope of humanitarian work both domestically and internationally. In Ukraine, they work in close cooperation with the Ukrainian Red Cross Society (URCS) to provide humanitarian assistance to those affected by the conflict. As a partner of the ReMuNet project, they have provided the following datasets (Table 3) documenting part of that work:

Table 3: Data provided to ReMuNet by the DRC

Document	Contents	Period
Mobilisation table DRC Ukraine Phase 1	Humanitarian aid mobilised for the initial response phase 1	March-October 2022
Mobilisation table DRC Ukraine Phase 2	Humanitarian aid mobilised for the initial response phase 2	November 2022-April 2023
Pipeline 13-04-2023	Registration of consignments of all goods received at the DRC logistic hub in Northern Romania from	March 2022-April 2023
Document sample 1	Goods received at DRC Hub in Romania	March 2022-April 2023
Document sample 2	Waybill out documents of incoming goods transported from the DRC Hub in Romania to the URCS Warehouse	March 2022-April 2023
Movement reporting to Tjernivtsi	“Second” Last Mile Delivery of goods received at Tjernivtsi Warehouse (various donors) and transloaded / transported by URCS to final destinations (Last Mile) for local distribution to Beneficiaries	June 2022

The data received from the DRC mainly consisted of Excel spreadsheets. They contained information such as goods procured and delivered to the Ukrainian Red Cross Society, the sources of these goods, intermediary warehouses where they were stored, and the corresponding dates. The data analysis was conducted in Microsoft Excel. Descriptive statistics, including totals, averages, and frequency counts, were computed using built-in functions. Pivot tables and charts were used to visualise data patterns and summarise the distribution of product categories. Selected information was then used to create visual representations, including Sankey flow diagrams, to illustrate the relationships and flows between categories. This data was used to understand which types of products were distributed, where they were sourced from, the average time to the destination, and how reception and distribution points were organised. This information was then used in the creation of the scenarios to be tested in the ReMuNet pilot, and data such as products and their respective weight were compiled as inputs for the platform.

Routing data collection, analysis and validation

The identification of transport nodes and modes within this study was based on a structured review of multiple reputable sources. Core references include official European Union documentation on the Trans-European Transport Network (TEN-T) and the Rail Baltica project, both of which outline the strategic multimodal infrastructure corridors spanning the Baltic region. Additional data was obtained from national transport authorities, port and airport operators, and logistics sector publications. The analysis was supported by open-source geospatial tools such as Google Maps and OpenRailwayMap to verify spatial accuracy, routing logic, and cross-border connectivity. Particular attention was given to the Via Baltica (E67) highway corridor, which forms the primary north–south freight artery linking Estonia, Latvia, Lithuania, and Poland, and which integrates with east–west rail and road corridors toward Ukraine. This combined methodology ensured a comprehensive mapping of intermodal transport routes across the Baltic States, eastern Poland, and into western and central Ukraine.

A series of targeted expert interviews were conducted to supplement the desk-based research and mapping of transport routes across the Baltic region and into Ukraine. The primary aim of these interviews was to validate operational realities, assess the functionality of identified nodes and corridors, and gather practitioner insights into the constraints affecting multimodal logistics under conflict conditions. Participants were selected based on their direct involvement in humanitarian operations, logistics coordination, and regional transport planning. The discussions provided a mix of strategic and field-level perspectives, offering both institutional and experiential validation of the identified routes, crossings, and modal interconnections.

Several interviews were conducted with senior humanitarian logistics and operations staff affiliated with the DRC. These interviews focused on practical mobility to and within Ukraine, aiming to understand which transport routes and modalities were functioning, where disruptions persisted, and how humanitarian agencies were adapting their delivery strategies. The discussions provided operational insights from individuals overseeing both emergency and long-term aid efforts, highlighting challenges such as customs delays, warehousing limitations, and the impact of air raid disruptions on scheduling and staff safety. The interviewees emphasised the need for bilateral coordination to expedite cross-border movements and the importance of maintaining adaptive logistical frameworks under rapidly changing conditions. These insights validated several of the key corridors and chokepoints identified in this study, reinforcing the significance of flexibility and contingency planning in sustaining humanitarian supply chains.

A series of expert interviews were conducted at two key stages of the research process. Initially, discussions were held to understand the operational realities and constraints affecting mobility to and within Ukraine, particularly under ongoing conflict conditions. These early interviews helped shape the analytical focus of the mapping exercise by identifying practical bottlenecks, viable corridors, and challenges faced by humanitarian logistics operators. Following the completion of the desk-based research, further interviews were undertaken to validate the identified routes, modes, and transport nodes, ensuring alignment between mapped infrastructure and field-level realities. The interviews provided both qualitative depth and real-world verification of the transport network linking the Baltic States, Poland, and Ukraine.

Following the initial identification and mapping of transport routes, modes, and nodes, the dataset was subject to a validation process to ensure operational accuracy and current relevance. The identified corridors, terminals, and crossings were cross-checked against information from industry experts and regional transport professionals with direct knowledge of infrastructure operations across Estonia, Latvia, Lithuania, Poland, and Ukraine. The findings were further shared with the project's 4PL logistics partner to confirm schedules, cargo-handling capacities, and mode interoperability. This collaborative validation confirmed that all listed ports, airports, rail hubs, and crossing points remain active and aligned with current freight flows and infrastructure capabilities. Where available, operational details such as road accessibility, rail gauge continuity, and intermodal connection times were verified to ensure the mapped network reflects real-world conditions as of 2025.

4.2 Pilot data construction

In addition to analysing humanitarian aid data and mapping the relevant transport routes, the study also involved the construction of structured pilot scenarios and a corresponding order dataset to enable experimentation within the ReMuNet platform. Based on insights derived from humanitarian logistics operations and the identified multimodal routes, hypothetical freight orders were generated to simulate realistic shipment conditions between selected origin and destination points. These orders incorporate differentiated urgency levels, temporal constraints, and staggered creation times to reflect the operational dynamics of humanitarian logistics. The resulting dataset forms the basis for testing synchromodal routing behaviour within the ReMuNet platform and is described in detail in Section 7.

5. Identifying routing alternatives

This section identifies potential routes for the delivery of aid to Ukraine via Poland and the Baltic countries. When interpreted alongside the shipment data, these corridors reveal the functional structure of the logistics network supporting humanitarian deliveries to Ukraine. This assessment covers key cargo nodes along the corridor through the Baltic states (Estonia, Latvia, Lithuania), transiting Poland and into Ukraine. Direct entry points for cargo are summarised in Table 4 below.

Table 4: Direct entry points for cargo in Estonia, Latvia, Lithuania, and Poland

Country	Location	Port	Airport
Estonia	Tallinn		✓
	Paldiski	✓	
	Muuga	✓	
Latvia	Riga	✓	✓
	Ventspils	✓	✓
	Liepaja	✓	
Lithuania	Siauliai		✓
	Vilnius		✓
	Kaunas	✓	✓
	Klaipeda	✓	
Poland	Warsaw		✓

	Rzeszow		✓
	Gdansk	✓	
	Gdynia	✓	

In Estonia, two key maritime nodes define the country’s cargo capacity under the state-owned organisation, ’Port of Tallinn’. Muuga port, just east of Tallinn, is the principal deep-water cargo hub, handling liquid bulk, containers, dry bulk, break bulk, and ro-ro traffic. It is equipped with crane lifting capacities ranging from 10 to 32 tonnes and is fully integrated with both rail and road networks. Muuga is connected directly to the Estonian mainline rail corridor and the E20 highway, and it hosts a Rail Baltica freight terminal, enhancing its multimodal capability.

Paldiski South Harbour, benefiting from free economic zone status, functions largely as a ro-ro, vehicle, and bulk terminal. It is linked by both rail and road to Tallinn and to southern transport corridors via Pärnu and the Ikla-Ainaži crossing into Latvia. Tallinn Airport serves as Estonia’s main air cargo gateway and maintains direct trucking links to both the Muuga Port and Tallinn Rail Hub. A new rail terminal, connecting the airport directly to the national network and Rail Baltica corridor, is under construction and expected to open in 2025.

In Latvia, Riga port stands out as a major multimodal logistics platform. Located within a free trade zone, it is directly integrated with the national rail and road networks, enabling efficient transfer between maritime, rail, and road modes. The port handles bulk, liquid bulk, container, and ro-ro traffic and serves as a key node on the TEN-T North Sea-Baltic Corridor. A new berth line (BCT), opened in 2024, has expanded terminal capacity and enhanced the port’s role in strategic and military mobility. Ventspils port is a deep-water, ice-free port capable of handling bulk, liquid bulk, and container cargo. The port provides extensive open-air and covered warehousing space. It is connected southward by rail through Jelgava and Daugavpils, providing access into Lithuania via the 1,520 mm-gauge East–West corridor. By road, Ventspils links to the national highway network via the E22 corridor, ensuring year-round multimodal accessibility. It also houses a small airport within its freeport zone. Liepāja port maintains year-round ice-free operations and handles dry and liquid bulk, ro-ro, and container traffic. The port is directly connected to the national road and rail networks, providing southward access toward the Grenctāle-Saločiai border crossing and onward into Lithuania. Further development and expansion are anticipated following the port’s acquisition by Stena Line in 2025.

Riga International Airport serves as Latvia’s principal air freight hub, operating 24/7 with full customs clearance and no night curfew. It functions as a regional gateway for express and general cargo, supported by road feeder services introduced in late 2024 to key Baltic logistics centres. In 2025, the Baltic Cargo Hub was opened, offering temperature-controlled storage, secure handling areas, and dedicated facilities for live animals and hazardous materials. Development is ongoing to integrate a Rail Baltica high-speed terminal, which will further enhance multimodal connectivity upon completion. Klaipėda Port, Lithuania’s primary maritime hub, is a deep-water, ice-free seaport operating year-round. The port has direct connections to the national rail network and the Via Baltica (E67) highway corridor, ensuring efficient multimodal access. It handles general cargo, dry and liquid bulk, ro-ro, refrigerated goods, and grain, supported by gantry cranes and specialised bulk handling equipment. Klaipėda also offers extensive open-air and covered storage areas, along with large-capacity liquid storage facilities.

Vilnius International Airport has developed a robust infrastructure including temperature-controlled storage, customs clearance, a bonded warehouse, and secure handling of perishable and high-value goods. The airport is also part of the Rail Baltica project, which aims to integrate the Baltic states into the European rail network, with plans underway to connect the airport terminals via an underground railway.

Kaunas International Airport, currently under expansion, serves as an emerging cargo hub with a strategic focus on intermodal logistics. It is connected to the Kaunas Intermodal Terminal, which facilitates transfers between the Baltic 1520 mm and European 1435 mm gauge systems. Construction is also underway to link the airport directly to the Via Baltica A5 motorway. Šiauliai International Airport combines commercial and strategic military cargo capabilities. Its dual-use infrastructure allows it to handle oversized, high-value, and sensitive shipments, including defence-related cargo, and can accommodate some of the larger aircraft used for cargo, unlike other airports in the region. Equipped with extensive storage and customs facilities, Šiauliai operates 24/7. The airport benefits from its location near the E272 road, which connects to the Via Baltica corridor, a primary transport route for the Baltic states. Additionally, it is close to two railway corridors, with plans to construct approximately 3 km of railway sidings to further enhance its rail accessibility.

In Poland, the ports of Gdańsk and Gdynia (approximately 20km from each other by road) serve as critical maritime gateways for cargo entering the North Sea–Baltic transport corridor. Gdańsk handles containers, ro-ro, vehicles, dry and liquid bulk, and ores, while Gdynia manages bulk, container, tanker, reefer, and ro-ro cargo. Both ports are integrated into Poland's national rail grid, offering efficient connections to Warsaw, Lublin, and the Ukrainian border. Gdańsk is a key node in the Baltic-Adriatic Corridor (TEN-T). The port is connected to the E65 high-speed railway line, facilitating efficient rail freight movement. Gdynia is a Category A core port in the TEN-T network and the only Polish port with a Motorway of the Sea connection to Sweden (Gdynia-Karlskrona). The port is also part of the Baltic-Adriatic Corridor. Recent investments have improved rail access, enhancing connectivity with the national rail system. The ongoing development of the Outer Port aims to accommodate larger vessels, further strengthening Gdynia's position in European logistics.

Warsaw airport offers comprehensive facilities and services for a wide range of cargo types, including perishables, pharmaceuticals, high-value goods, and dangerous materials. It is connected to the national rail system via the Warsaw airport railway station, facilitating seamless intermodal transport. Additionally, the airport is located near major highways, providing efficient road access for cargo transport. Strategically located approximately 60 miles from the Ukrainian border, Rzeszów airport has become a vital logistics point for NATO and international aid operations. Its 3,200-meter runway accommodates large aircraft, including Boeing 747s and military transport planes, facilitating the rapid deployment of humanitarian and military supplies. The airport's cargo infrastructure includes the Waimea Cargo Terminal, a modern multimodal facility situated adjacent to the airport. Spanning 6,700 square meters, the terminal offers comprehensive services such as warehousing, cold storage, and handling of special cargo types like dangerous goods, perishables, and live animals. It is equipped with advanced ground support equipment and has enhanced its connectivity through the development of a railway link to the main train station in Rzeszów.

Table 5 summarises the relevant border crossings identified in this research.

Table 5: Relevant border crossings

Country	Location	Truck	Rail
Estonia-Latvia	Ikla-Ainaži	✓	
	Valga-Valka	✓	✓
Latvia-Lithuania	Meitene- Joniškis		✓
	Grenctāle – Saločiai	✓	✓
	Daugavpils–Turmantas		✓
Lithuania-Poland	Mockava-Trakiszki		✓
	Kalvarija-Budzisko	✓	
Poland-Ukraine	Medyka-Mostyska II		✓
	Dorohusk-Yahodyn	✓	
	Korczowa-Krakovets	✓	
	Medyka-Shehyni	✓	

Ikla-Ainaži facilitates road transport and is part of the E263 route, connecting Tallinn to Riga. Customs procedures are in place for freight vehicles, with standard EU customs regulations applying.

Valga-Valka crossing supports both road and rail transport. Customs controls are applied to freight movements, ensuring compliance with EU regulations. Valga station in Estonia accommodates broad-gauge rail; Valka in Latvia accommodates standard-gauge rail. Bogie exchange facility available and trains are transhipped between gauges. Meitene-Joniškis is primarily used for rail transport. Customs procedures are conducted in accordance with EU standards. The crossing is part of the Jelgava-Meitene Railway, a 33 km line connecting Jelgava in Latvia to Meitene, which then continues to Šiauliai in Lithuania. This line is integral to the broader Rail Baltica project. The crossing involves a transition from Latvia's standard 1520 mm gauge to Lithuania's 1435 mm gauge, necessitating a bogie exchange or transshipment at the border.

Grenctāle-Saločiai serves both road and rail traffic, this crossing is a key component of the Via Baltica corridor, with customs checks in place for freight transport. Rail station in Saločiai accommodates broad-gauge rail; Grenctāle in Latvia accommodates standard-gauge rail. Bogie exchange facility available and trains are transhipped between gauges. Daugavpils-Turmantas crossing supports rail transport. Daugavpils station in Latvia accommodates broad-gauge rail; Turmantas in Lithuania accommodates standard-gauge rail. Bogie exchange facility available and trains are transhipped between gauges. While passenger services were suspended in 2020, freight operations continue under EU customs regulations.

Mockava-Trakiszki crossing handles rail transport with a transition from 1520 mm gauge in Lithuania to 1435 mm gauge in Poland. Customs procedures are conducted as per EU standards. Transhshipment and boogie exchange are possible. The crossing is part of the Rail Baltica project. Kalvarija-Budzisko supports road transport. Customs checks are applied to freight vehicles, ensuring compliance with EU regulations. The crossing is part of the Via Baltica corridor, connecting to the E67 corridor, facilitating efficient movement of goods. Medyka-Mostyska II facilitates both road and rail transport. The rail line operates on the 1520 mm gauge, with customs procedures in place for freight movements. Recent upgrades have increased capacity, allowing for more efficient processing of goods. The crossing is a vital link in the Trans-European Transport Network (TEN-T).

Dorohusk-Yahodyn serves road transport. Customs controls are applied to freight vehicles, ensuring compliance with international trade regulations. Korczowa-Krakovets facilitates both road and rail transport. The rail line operates on the 1520 mm gauge, with customs procedures in place for freight movements. Recent infrastructure developments have improved capacity and efficiency. The crossing is a significant node in the Trans-European Transport Network (TEN-T). Medyka-Shehyni supports road transport. Customs checks are applied to freight vehicles, ensuring compliance with international trade regulations. Table 6 lists the rail and road hubs identified in the Baltic region.

Table 6: Rail and road hubs in Estonia, Latvia, Lithuania and Poland

		Rail	Road
Estonia	Tallinn	✓	✓
	Tartu	✓	
	Pärnu		✓
	Paldiski	✓	✓
Latvia	Riga	✓	✓
	Jelgava	✓	
Lithuania	Siauliai	✓	✓
	Kaunas	✓	✓
	Klaipeda	✓	
	Vilnius	✓	✓
Poland	Warsaw	✓	✓
	Lublin	✓	✓
	Rzszow	✓	

Tallinn serves as Estonia's primary rail hub, situated at the convergence of the 1,520 mm gauge network and the upcoming 1,435 mm gauge Rail Baltica line. This strategic location facilitates the transfer of freight between the Russian gauge and European standard gauge systems. The Ülemiste Transport Hub, currently under construction and expected to open in 2028, will integrate rail, road, and air transport. The hub is designed to handle a variety of cargo types, including containers, general freight, and bulk goods. Tallinn is also Estonia's main road hub, connected to the E20 and E67 highways, linking it to central Estonia (Tartu and Pärnu) and Riga in Latvia. These roads support container trucks, bulk cargo vehicles, and express freight services. The road network complements the rail system, enabling seamless multimodal transport to the Port of Tallinn and to Tallinn Airport.

Tartu is a secondary rail hub in southern Estonia, connected to the 1,520 mm gauge network. While it primarily serves regional passenger traffic, it also handles limited freight operations, including general cargo and agricultural products. The city's rail infrastructure supports connections to Tallinn and other domestic destinations, facilitating the movement of goods within Estonia. Tartu is connected to the E263 highway, linking Tallinn and Tartu with southern Estonia and the Latvian border.

Pärnu is well connected by national roads and the E67 (Via Baltica), which links it north to Tallinn and south to Latvia. The road network supports container trucks, bulk cargo, and general freight, serving as the main transport route for Pärnu's logistics. Pärnu is well connected by national roads and the E67 (Via Baltica), which links it north to Tallinn and south to Latvia. The road network supports container trucks, bulk cargo, and general freight, serving as the main transport route for Pärnu's logistics. Paldiski is a significant rail terminal on the 1,520 mm gauge network, specialising in bulk cargo and rolling stock. The terminal's strategic location provides direct access to maritime transport. Paldiski is connected by the E265 highway to Tallinn and central Estonia, facilitating truck movements to the Port of Paldiski for bulk and container shipments. The road network complements the port and rail operations, providing flexibility for multimodal cargo transfers.

Riga is Latvia's central rail hub, located on the 1,520 mm gauge network. The city's rail infrastructure supports a wide range of cargo types, including containers, bulk goods, chemicals, metals, and agricultural products. Riga's strategic location facilitates connections to both domestic and international destinations, making it a key point in the Baltic logistics corridor. The ongoing Rail Baltica project aims to integrate Riga into the European standard gauge network. Riga is also the main road hub of Latvia, connected to the A1, A2, and A7 highways, which link the city north to Tallinn and south to Vilnius. The city's road network supports freight trucks, container transport, and express delivery services. Riga International Airport and the port are seamlessly integrated into these road corridors for multimodal logistics.

Jelgava sits on the 1,520 mm broad-gauge network and connects westward to Ventspils Port. East and south, it links toward Lithuania via border crossings such as Meitene-Joniškis and Grenctāle-Saločiai, allowing freight to continue along the Baltic States' network. Jelgava handles bulk agricultural products (grain, fertilisers), general freight, and some containerised cargo moving to / from Ventspils. The city is also integrated into Latvia's A8 highway, which runs from Riga to the Lithuanian border, supporting truck movements alongside rail transport. This provides multimodal flexibility for cargo heading toward Lithuania.

In Lithuania, Šiauliai sits on the 1,520 mm broad-gauge network and links northward to Latvia, including border crossings such as Daugavpils-Turmantas and Grenctāle-Saločiai. These connections allow freight to move seamlessly into Latvia and onward to ports like Riga, Ventspils, and Liepāja. Southward, Šiauliai connects to other Lithuanian cities, including Kaunas, Klaipėda, and Vilnius. The hub handles general freight, industrial goods, containers, and bulk cargo, supporting both commercial and strategic / military logistics. Šiauliai is connected to the E272 highway, linking the city to the Via Baltica (E67) corridor. This road infrastructure supports heavy truck movements and container transport, complementing rail operations. Šiauliai Airport further enhances multimodal logistics capabilities for high-value or sensitive cargo.

Kaunas is a central rail hub in Lithuania, situated on the 1,520 mm gauge network. The city is home to the Kaunas Intermodal Terminal (KIT), a key logistics centre for the Rail Baltica project and the North Sea-Baltic Sea transport corridor. The terminal facilitates the transfer of freight between rail and road transport, supporting the movement of containers, bulk goods, and general cargo. Situated in the Kaunas Free Economic Zone, the terminal benefits from proximity to major highways A1 and A6. These roads support container and bulk freight transport, integrating closely with the intermodal terminal and Kaunas Airport for air cargo operations. The adjacent Šeštokai Intermodal Terminal further enhances connectivity, especially for freight moving between Lithuania and Poland.

Klaipėda is Lithuania's primary seaport, connected to the 1,520 mm gauge rail network. The port's rail infrastructure supports the import and export of a wide range of cargo types, including containers and bulk goods. Klaipėda is connected to the Via Baltica (E67) and A1 highways, providing efficient road access for trucks transporting containers and bulk goods. Vilnius is connected to the 1,520 mm gauge rail network. Freight typically transits through Kaunas Intermodal Terminal, where cargo can be transferred or re-gauged to 1,435 mm European standard gauge before entering Poland. Vilnius is a major road hub, connected to the Via Baltica (E67) corridor and other national highways. These routes support truck freight, including containers and bulk cargo, and are integrated with Vilnius Airport for air freight. While the main E67 runs north-south through Lithuania, trucks from Vilnius can access Poland via A4 / S8 highways, heading toward Kalvarija-Budzisko (road-only border crossing) and Mockava-Trakiszki for nearby rail.

Warsaw is Poland's central rail and logistics hub, situated on the 1,435 mm European standard-gauge network. The city's rail infrastructure supports a wide range of cargo types, including containers, general freight, and industrial goods. Strategic rail connections run northward to the ports of Gdańsk and Gdynia, forming part of Poland's Baltic-Adriatic TEN-T Corridor. Warsaw's rail terminals are equipped with sidings and intermodal facilities, enabling efficient transfer between rail and road transport. These connections facilitate container shipments, bulk goods, and high-value industrial cargo between the ports and inland destinations. Warsaw is also a key road hub, connected via the S7, S8, and A2 highways, which link the city to northern ports and central/eastern Poland. The S17 and S12 highways run east from Warsaw to Lublin and Dorohusk, supporting heavy truck traffic to Dorohusk-Yahodyn. For Korczowa-Krakovets, freight is routed via S17/S19 through Rzeszów. The LS Cargo Terminal, located within the LS Cargo Park logistics park, is the largest cargo terminal in Poland, handling over 100,000 tons of cargo annually and operating 24/7. It offers direct access to Warsaw airport apron and provides full cargo warehousing services, including cold chain solutions and handling of special cargo types. State services are located on-site, ensuring efficient processing of shipments. Looking ahead, the Centralny Port Komunikacyjny (CPK), a planned mega-hub approximately 40 km west of Warsaw, is scheduled to open by 2032. CPK will feature state-of-the-art facilities and expanded cargo capacity, complementing Warsaw airport

Lublin sits on the 1,435 mm standard-gauge network, integrated into Poland's national rail freight corridors. Rail links connect Lublin toward Warsaw, providing access to northern ports like Gdańsk and Gdynia. Lublin has rail connections toward Dorohusk-Yahodyn, a major road and rail border crossing to Ukraine. While Lublin itself does not have a direct rail gauge-change facility for Ukraine, freight is routed via transshipment hubs or through Dorohusk for onward movement. Limited direct rail freight toward Lublin is well integrated into Poland's expressway network, with direct road access to Warsaw (NW)via the S17 and Rzeszów via S19, providing access to Ukrainian border crossings such as Korczowa-Krakovets and Dorohusk-Yahodyn.

Rzeszów is a critical rail hub in southeastern Poland, situated on the 1,435 mm gauge network. The city's rail infrastructure supports the movement of military supplies, humanitarian aid, and general freight. Rzeszów connects directly to Korczowa-Krakovets, supporting bulk, containerised, and military cargo. Rail also links to Dorohusk-Yahodyn via Lublin for eastbound freight. The S19 expressway connects Rzeszów north-south toward Korczowa-Krakovets and south to Medyka-Mostyska II / Shehyni.

6. ReMuNet's social use case: scenarios for pilot testing

To allow for the testing of the ReMuNet platform, two scenarios were created for the social use case. The first scenario involves the shipment of humanitarian aid from Germany to Ukraine, coordinated by a non-profit organisation, whereas the second concerns the delivery of aid from Finland by a group of volunteers. In this section, the potential scenarios are presented, along with the rationale for them. Each scenario has an identified optimal route and a possible rerouting resulting from a disruptive event. The selection of route options is further discussed, considering current conflict dynamics and available transport infrastructure.

6.1 Scenario creation rationale

For the creation of the scenarios, the aspects of origin point, destination point, transportation mode, and product were considered. Two points of origin, Helsinki and Hamburg, were chosen as they represent key nodes in the North Sea-Baltic TEN-T Corridor and are in countries that offer substantial amounts of humanitarian aid to Ukraine. In both scenarios, Dnipro was the destination, as the city is currently a hub for receiving aid, being close to the front line to ensure rapid redistribution, while still being stable and safe enough for commercial logistics providers to operate in. Transportation modes were selected based on geography and available options, given the current state of the conflict. Finally, the types of products reflect existing flows of aid from Finland and Germany. More detailed descriptions of the rationale behind these choices are given in the Table 7.

Table 7: Rationale for choices made during scenario creations

Aspect	Choice	Reasoning
Origin point	Scenario 1: Helsinki, Finland	Key city in the North Sea-Baltic TEN-T Corridor
	Scenario 2: Hamburg, Germany	Key city in the North Sea-Baltic TEN-T Corridor
Destination point	Scenario 1 and 2: Dnipro	As the delivery of goods is mainly directed eastwards, where it is needed, Dnipro serves as the midpoint between the western borders and the frontline. Major warehouses of humanitarian organisations are in the city. Until Dnipro, commercial logistics providers are very reliable, including both large international and national carriers. Cities close to the Western Ukrainian border, such as Lviv (Poland), may not accurately reflect the situation in most of the country, as they are less affected by the conflict dynamics. Cities closer to the frontline are still too volatile and are potentially unsafe for the pilot.

Transportation mode	Scenario 1: sea, road	Sea is the only direct mode of transport from Finland to the Baltic states.
	Scenario 2: rail, road	Rail is chosen for three main reasons: - the efficient infrastructure in the EU countries that are part of the route. - to highlight that even during the conflict, rail transport is still functioning in most of Ukraine. - to account for how the different rail gauges in the EU and in Ukraine can be a source of disruption. Road is considered an alternative to rail, especially in case of a disruptive event
Product	Scenario 1	Unlike items such as food and hygiene products, there is still a need to import rescue vehicles to Ukraine. Vehicles add a dynamic element to the scenario, as they are both a product that can be transported and a method of transport – i.e. in the parts of the route that are done by road, they can be driven, if there are enough people capable of doing so.
	Scenario 2	Germany is a known producer of vaccines, which adds realism to the scenario. Unlike items such as food and hygiene products, there is still a need to import vaccines to Ukraine, as the local production is not sufficient to meet the needs of the population. As some vaccines require temperature control, the element of the cold chain can be added to the scenario, adding a layer of urgency to the time dimension when considering re-rerouting options in case of disruption.

6.1.1 *Scenario 1: Finland to Ukraine*

Table 8 shows the stakeholder information for Scenario 1. Finland Ukraine Aid Volunteers Ry is a volunteer association that collects aid from Finland and sends it to Ukrainian civil society organisations and NGOs. It is focused on non-perishable food, as well as rescue vehicles, including ambulances and fire trucks. The products are collected throughout Finland, sorted at the warehouse in Vantaa, and then sent personally by volunteers to Ukraine. Once they cross the border, they are handed over to Ukrainian organizations, who are responsible for distributing the items to beneficiaries.

The first consignee, the Ukraine Aid Logistics Center, receives aid donations from abroad at a warehouse in Lviv, near the Polish border, and then distributes them to other Ukrainian civil society organisations and NGOs. In this case, three ambulances and one fire truck will be driven to a partner in Dnipro. There, they will be handed to the recipient, the Dnipro Alliance, an NGO that provides rescue services. They have a team of volunteer first responders, whom the NGO has trained.

Table 8: Stakeholder information for Scenario 1

Stakeholder	Consignor	Consignee	Recipient	Carrier 1	Carrier 2
Name	Finland Ukraine Aid Volunteers Ry	Ukraine Aid Logistics Center	Dnipro Alliance	Fin-Est Shipping Line	Bal-Pol Shipping Line
Operating area	Helsinki, Finland	Lviv, Ukraine	Dnipro, Ukraine	Vuosaari (Helsinki, Finland) – Muuga (Tallinn, Estonia)	Baltic countries and Poland
Services	Collect and sort aid items in Finland Producing the initial documents necessary for sending aid to Ukraine Transportation to Ukraine	Handling the paperwork necessary for import and customs clearance Receiving and storing the aid items brought from abroad Organizing further transportation inside Ukraine	Providing rescue services to Ukrainians in Dnipro and other nearby areas Training volunteer first responders Organizing further transportation inside Ukraine	Ferry services for containers, trailers and trucks Fast turnaround times for cargo at ports	Container and trailer shipping Backup shipping capacity
Role in the pilot	Acting as the pilot originator of goods Responsible for the delivery of goods until they enter Ukrainian territory	Receiving the aid items from Finland Organizing the transportation inside Ukrainian territory	Final recipient of part of the vehicles sent by Finland Ukraine Aid Volunteers Ry Reporting on the use of the aid received	Shipping the aid by ferry across the Gulf of Finland from Vuosaari to Muuga	Providing contingency shipping if Fin-Est Shipping Line sailings are delayed or unavailable

In this case, the optimal route identified combines road and maritime transport. It begins in Helsinki, going to Muuga, Estonia, by a commercial ferry operated by Carrier 1. After that, the Finnish volunteers drive the donated vehicles through the Baltics to Poland, crossing in Medyka-Shehyni to Lviv. At the border, the vehicles are handed over to Ukrainian drivers from the first consignee. These drivers will continue until Dnipro, where they will deliver the aid to the recipient.

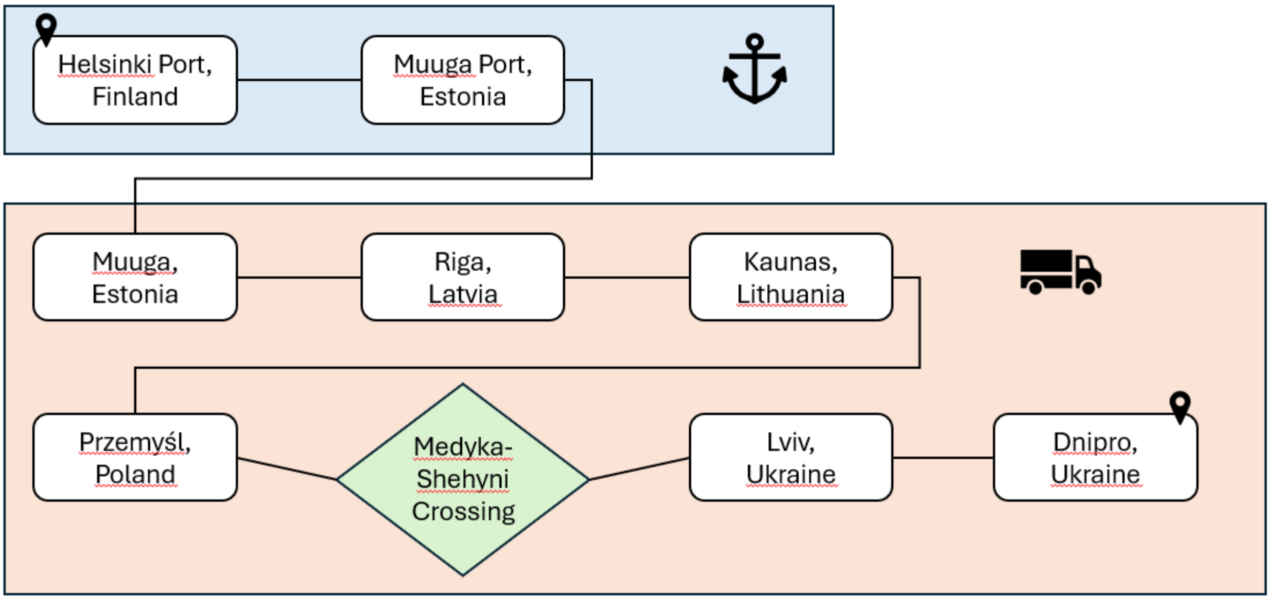

Figure 6: Optimal route from Finland to Ukraine

Nevertheless, the border between Lithuania and Poland is a significant bottleneck. If a disruptive event occurs in that location, the route cannot continue as planned. In that case, the delivery is rerouted by ferry, using the commercial service provided by Carrier 2, to Gdánsk, Poland. From there, it continues by truck to the destination in Dnipro, Ukraine.

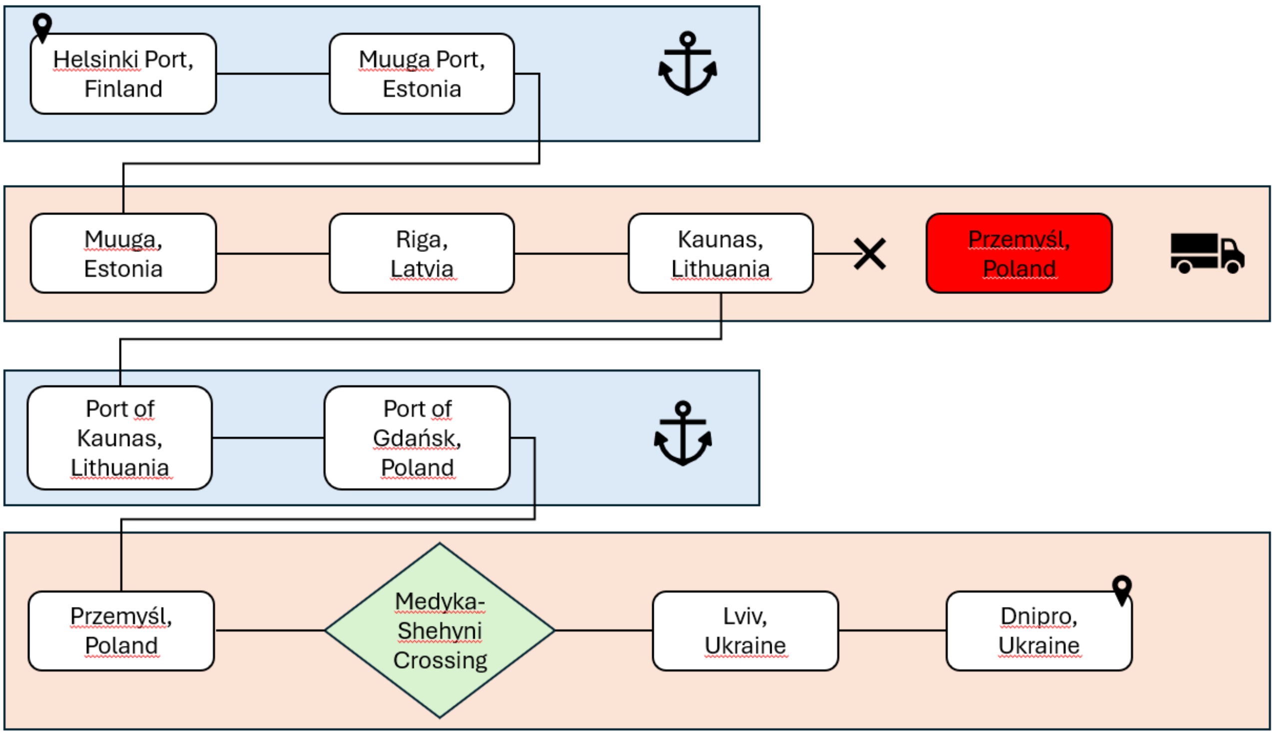

Figure 7: Rerouting due to a disruptive event at the Lithuania-Poland border

Since the consignor is personally delivering the goods, they can be more flexible to routing changes and adjustments, as their timeline may not be quite as restricted and controlled as those of commercial providers. It must be noted, however, that the drivers involved in this scenario are not professionals and may require specific documentation and authorisations to enter Ukraine. The procedure for importing humanitarian aid is also specific and must be followed, including the provision of exact information about the vehicles being donated.

6.1.2 *Scenario 2: Germany to Ukraine*

The German Coalition for Vaccines is an organisation that collects donations from German companies and citizens and procures vaccines in the country. It then uses commercial service providers to send them to Ukraine, where they have a partner NGO in Dnipro that administers vaccines to both adults and children. In this case, they are sending two batches of vaccines – one requires cold storage (between -80 and -60°C), and the other is freeze sensitive and must be kept between 2 and 8 °C. As these vaccines require specialised transport and the coalition evaluated that commercial service providers can reliably get to Dnipro, they decided to contract a logistics service provider to coordinate the aid delivery. The recipient is the Dnipro Vaccination Committee, a local branch of the Ukrainian Vaccination Committee that conducts vaccination campaigns for Ukrainian citizens affected by the war in that city. As the national committee has given its approval, the local branch can receive donations from abroad directly.

Table 9: Stakeholder information for Scenario 2

Stakeholder	Consignor	Recipient	LSP	Carrier 1	Carrier 2
Name	German Coalition for Vaccines	Dnipro Vaccination Committee	EastLink GmbH	Ger-Pol-Ukra Rail	Slava Trucking Services
Operating area	Berlin, Germany	Dnipro, Ukraine	Germany, Poland, Ukraine	Germany, Poland, Ukraine	Ukraine
Services	Collect donations and procure vaccines in Germany Producing the initial documents necessary for sending aid to Ukraine	Handling the paperwork necessary for import and customs clearance Receiving and storing the aid items brought from abroad Vaccinating the Ukrainian population	Freight forwarding coordination Multimodal transport planning Customs clearance and documentation services	Rail transport of containers, trailers and trucks	Container and trailer shipping Backup shipping capacity

Role in the pilot	Acting as the pilot originator of goods Responsible for arranging the transportation of goods from Germany to Dnipro (Ukraine)	Receiving the aid items from Germany Reporting on the use of the aid received	Planning and executing the transport chain from Berlin to Dnipro Coordinating between different carriers, shipping lines and terminals Ensuring documentation flows correctly through all checkpoints	Shipping the aid by rail from Berlin to Dnipro	Providing contingency shipping if Ger-Pol-Ukra Rail trains are delayed or unavailable

In this case, the optimal route identified is by rail, as its predictability and consistency offer guarantees that the vaccines will arrive in the appropriate condition. The route starts in Berlin, passing through Kraków, Poland, crossing at Medyka-Mostyska II. That crossing is chosen due to recent upgrades to increase its freight capacity. From there, it continues to Dnipro.

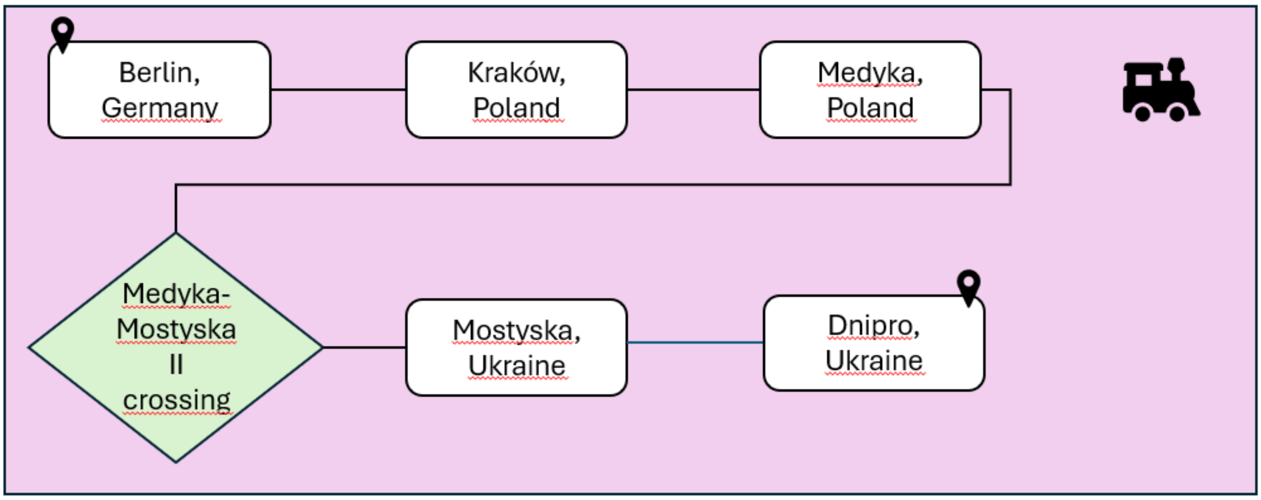

Figure 8: Optimal route from Germany to Ukraine

Nevertheless, there are many potential disruptions at the Medyka-Mostyska II crossing, from Polish citizens blocking it to protest the entry of Ukrainian agricultural products in the neighbouring country, to unexpectedly high volume of traffic, and the lack of workers in Mostyska due to conscription to gauge changes. If a disruptive event takes place at the border, especially if it would affect the temperature control required to keep the vaccine cargo from spoiling, the transport mode can be changed. The LSP can arrange for the cargo to be passed on from Carrier 1 to Carrier 2 by loading the vaccines in a truck for the remaining leg of the journey to Dnipro.

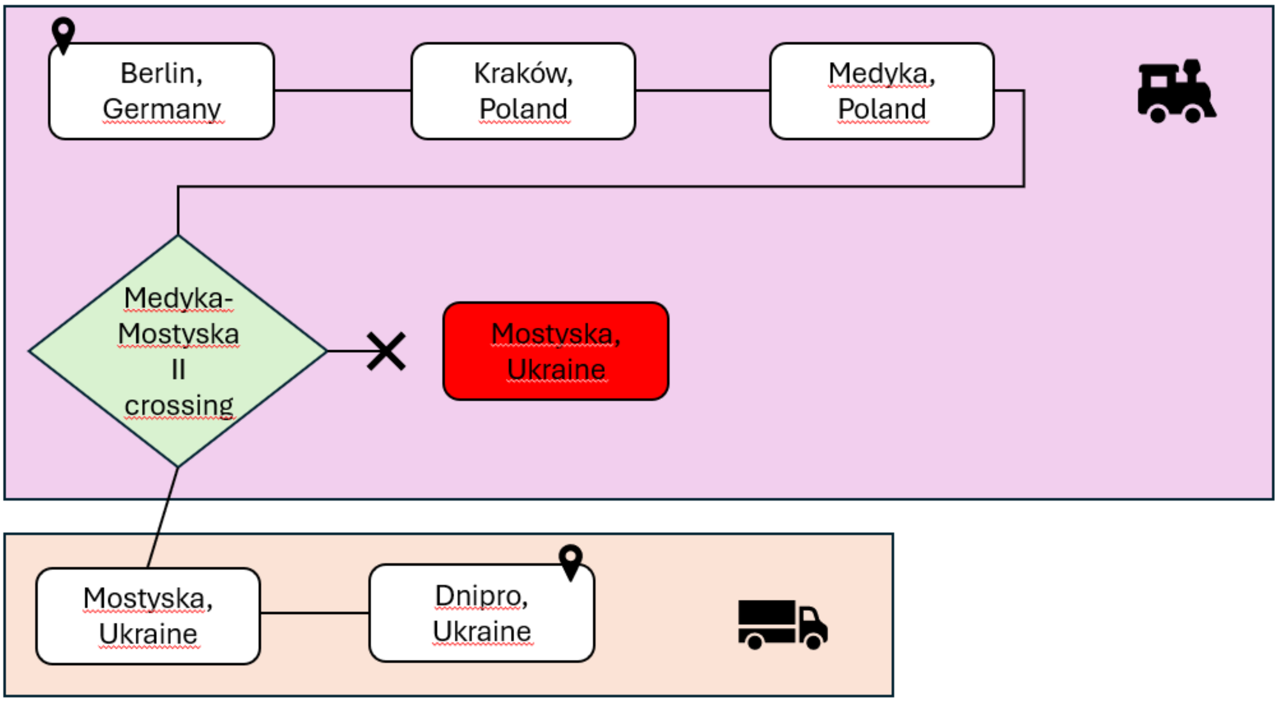

Figure 9: Rerouting due to a disruptive event at the Poland-Ukraine border

6.2 Selection of route options for the pilots

The selection of pilot nodes for this analysis has been guided by their strategic positioning within the Trans-European Transport Network (TEN-T) and their alignment with the Baltic Sea–Black Sea–Aegean Sea, North Sea–Baltic, and Baltic–Adriatic transport corridors. These corridors form the principal arteries linking northern, central, and southern Europe and are central to EU efforts to strengthen multimodal connectivity, resilience, and cross-border interoperability. The selected nodes located across Estonia, Latvia, Lithuania, and northern and western Poland were chosen because they sit along these priority axes and represent critical junctions for cargo, humanitarian, and defence-related movements between the Baltic States and the broader European network. Their inclusion ensures that the pilot scope captures both the current operational dependencies and the infrastructure prioritised for EU investment and capacity enhancement.

Several of these nodes coincide with infrastructure undergoing significant upgrade through the Rail Baltica project, designed to establish a continuous 1,435 mm standard-gauge rail link from Tallinn through Riga and Kaunas into Poland. By connecting the Baltic States to the European standard-gauge system, Rail Baltica will address one of the region's most persistent logistical constraints, the rail gauge break at the Lithuania–Poland border and introduce modern dual-gauge intermodal facilities that improve efficiency and throughput. Parallel focus has been given to nodes situated along the Via Baltica corridor, the main north–south highway linking Tallinn to Warsaw, ensuring a coordinated approach between rail and road modalities. Together, these two frameworks represent the backbone of the region's overland mobility and are central to the EU's multimodal transport resilience objectives.

A deliberate emphasis has been placed on northern and western Polish logistics hubs, including Gdansk, Warsaw, Lublin, and Rzeszów, due to their function as key interface points between the Baltic and Ukrainian networks. These hubs connect directly into Poland's standard-gauge rail grid, high-capacity motorways, and established airport and intermodal infrastructure, allowing efficient routing of cargo and humanitarian flows from the Baltic region toward Ukraine. Their proximity to principal border crossings such as Dorohusk-Yahodyn and Medyka-Mostyska II further supports their selection as pilot sites. Concentrating analysis on these locations provides a realistic operational framework for continuity planning: each is integrated into existing EU policy frameworks; forms part of both civilian and defence mobility corridors and possesses the scalability to manage surge demand under crisis or evacuation conditions.

6.2.1 *Impact of disruptive events on the chosen routes*

The north–south corridor running from Estonia through Latvia and Lithuania into north-western Poland forms the backbone of the Baltic region's overland connectivity to Central and Western Europe. However, this corridor is geographically constrained and offers relatively few alternate routings inside the Baltic States. The route's vulnerability is compounded by mixed rail gauges (1,520 mm in the Baltics and 1,435 mm in Poland) and by the narrow land bridge at the Lithuania-Poland border, which is situated between the Russian exclave of Kaliningrad and Belarus. This geography creates a single point of failure: the closure or restriction of any major node along this axis would have immediate and significant implications for regional cargo, humanitarian, and civilian evacuation movements.

The Lithuania-Poland border is particularly exposed. Its short distance to both Belarus and Kaliningrad places it within a zone of elevated strategic risk. In the event of closure or sustained disruption, the principal north-south road and rail arteries linking the Baltic States to Poland and the wider European network would be immediately constrained. Freight and humanitarian movements would be forced to reroute via maritime or air options. Compounding this vulnerability is the technical barrier of differing rail gauges, an enduring chokepoint that limits through-rail freight capacity and complicates rapid redeployment of rolling stock without transshipment or bogie exchange.

The ongoing Rail Baltica project represents the most significant step toward mitigating these limitations. Designed to establish a continuous 1,435 mm standard-gauge rail link from Tallinn through Riga and Kaunas to Poland, Rail Baltica will integrate the Baltic States into the wider European rail system. When completed, it will dramatically improve interoperability, eliminate the current gauge discontinuity, and create a modern, high-capacity corridor for both passenger and freight operations. In addition to new dual-gauge intermodal terminals and upgraded logistics hubs, the project will strengthen resilience by providing a standardised, multimodal link between the Baltic capitals, Poland, and beyond. Nevertheless, full freight operational capacity and cross-border integration depend on continued investment in terminals, customs harmonisation, and interconnection with existing national rail networks. These factors mean the system's resilience benefits will not be fully realised for several years.

Should the Lithuania-Poland border become impassable, short-sea and feeder operations from Lithuanian and Latvian ports would provide the most immediate alternative routing options. Cargo could be redirected from Klaipėda, Riga, Ventspils, and Liepāja to Polish and German ports via the Baltic Sea. Container and ro-ro freight could be transferred directly to Gdańsk and Gdynia, which are integrated into Poland's standard-gauge rail and high-capacity road networks and included as part of this report. These ports offer direct maritime-to-land transfer without gauge-change constraints, supported by extensive intermodal network connections to Warsaw, Lublin, and Rzeszów. For larger-scale diversion or to reduce congestion on Polish infrastructure, further westward alternatives, such as Lübeck and Travemünde in Germany, could receive short-sea feeders and leverage the dense German rail and autobahn networks for onward distribution into central Europe. However, such western alternatives fall outside the immediate operational scope of this analysis.

Several critical constraints must be considered in any contingency scenario. First, Baltic ports are relatively modest in capacity compared with major northern European terminals and could be overwhelmed quickly if required to handle simultaneous flows of commercial cargo, evacuees, humanitarian shipments, and military logistics. Second, maritime rerouting introduces additional transshipment stages, each creating potential bottlenecks at berths, container yards, reefer plug points, and customs inspection areas. Third, until Rail Baltica becomes fully operational, the rail-gauge discontinuity will continue to necessitate time- and labour-intensive transfers at intermodal nodes such as Kaunas Intermodal Terminal, further straining logistics chains during surge conditions.

Customs and border management policies will likely determine throughput more than physical infrastructure alone. To ensure efficiency, ports and terminals in Lithuania and Latvia will require pre-cleared “green lane” corridors, extended operating hours, and advanced electronic documentation systems to minimise dwell times. Polish and German receiving ports, in turn, must prepare for sudden increases in volume by designating priority lanes for humanitarian and evacuation cargo. Inland logistics nodes, particularly Kaunas Intermodal Terminal, Mockava-Trakiszki crossing, and major Polish distribution hubs at Warsaw, Lublin, and Rzeszów, will become pivotal chokepoints for onward movement. Expanding siding capacity, pre-positioning mobile cranes, and identifying temporary storage zones will be critical to maintaining operational flow and avoiding systemic delays.

Given these systemic vulnerabilities, diversification of access routes becomes essential. Alternative corridors via Helsinki and Nordic ports reduce reliance on the Baltic route and add strategic redundancy, but they require separate analysis (ice patterns, short-sea lift, road congestion in Sweden-Finland, ferry capacities) and hence have been excluded from this immediate resilience plan.

7. Pilot Scenario Operationalisation and Order Dataset Design

This section documents the operational preparation of the order dataset used to simulate the Finland-Ukraine and Germany-Ukraine humanitarian corridors within the ReMuNet platform. Rather than presenting final routing outputs, the focus here is on the experimental translation of empirical humanitarian flows into structured, time-sensitive transport orders suitable for synchromodal testing. The dataset is derived from historical humanitarian shipment records, primarily provided by the DRC and associated partners. These empirical flows were anonymised and reformulated into hypothetical but operationally realistic transport orders. The transformation preserved core characteristics such as cargo categories, shipment volumes, and modal relevance, while introducing controlled temporal and prioritisation variables required for platform evaluation. The purpose of this operationalisation is twofold. First, it ensures that the pilot scenarios reflect realistic humanitarian logistics conditions rather than abstract routing problems. Second, it enables systematic testing of the platform’s ability to manage heterogeneous service requirements, overlapping time windows, and competing urgency levels within a shared multimodal network.

7.1 Urgency-Based Time Structuring

Humanitarian logistics is inherently differentiated by time criticality. Some shipments, such as vaccines or temperature-sensitive medical supplies, require immediate and tightly controlled delivery. Others, such as non-perishable goods or standard equipment, allow greater flexibility in scheduling and mode selection. To reflect this operational reality, the dataset incorporates three urgency classes that function as structural routing constraints rather than descriptive labels.

The urgency categories are defined as follows:

- **URGENT**: time-critical shipments such as vaccines or cold-chain goods, where speed and reliability are prioritised.
- **STANDARD**: typical humanitarian goods, equipment, or vehicles with moderate delivery sensitivity.
- **FLEX**: low-criticality or non-perishable goods where cost efficiency may take precedence over speed.

Each urgency class is associated with differentiated pickup windows, order creation timing, and delivery constraints (detailed in Section 6.2). By embedding urgency into the temporal architecture of the orders, the platform is required to evaluate trade-offs between cost, speed, and feasibility across modes. This structuring ensures that the pilot does not merely test route optimisation, but prioritisation logic under heterogeneous service-level expectations.

7.2 Temporal Logic by Urgency

To simulate operational realities within humanitarian logistics, the order dataset incorporates differentiated temporal parameters linked to urgency classification. Rather than assigning uniform pickup and delivery constraints to all shipments, time sensitivity is treated as a structured experimental variable. This allows the platform to encounter heterogeneous service requirements and to evaluate routing feasibility under varying degrees of temporal rigidity.

Pickup Window Width

Pickup window width determines the degree of scheduling flexibility available at the origin node. In the dataset, urgent shipments are assigned a narrow six-hour pickup window, reflecting operational conditions such as vaccine dispatches or cold-chain goods that require precise coordination. Standard shipments are given an 18-hour window, representing typical humanitarian freight with moderate scheduling flexibility. Flexible shipments are assigned a 48-hour pickup window, simulating low-criticality goods where consolidation or delayed dispatch is acceptable. By varying pickup window width, the dataset introduces differentiated pressure on terminal coordination and mode selection. Narrow windows constrain the range of feasible departure options, potentially eliminating slower modes or multi-transfer solutions. Wider windows increase the platform’s solution space, allowing cost-optimised or capacity-balancing strategies.

Order Creation Lead Time

The dataset also varies the time between order creation and pickup, thereby modelling differences in planning horizon. Urgent shipments are created one to two days prior to pick up, simulating reactive emergency response. Standard shipments are introduced three to six days in advance, while flexible shipments may appear five to ten days before dispatch. This staggered creation timing allows the platform to encounter both short-notice orders and longer-term planning scenarios. It tests the system’s ability to integrate newly created urgent shipments into an already evolving routing landscape, potentially requiring reprioritisation or reallocation of modal capacity.

Delivery Windows

Delivery windows further differentiate service expectations. Urgent shipments are assigned earliest arrival times approximately two days after pickup and latest delivery limits within four to six days. Standard shipments allow broader windows, typically four to ten days. Flexible shipments extend the acceptable delivery horizon up to fourteen to sixteen days. These differentiated delivery constraints create measurable trade-offs between speed, cost, and reliability. For urgent shipments, slower rail–road combinations or cost-efficient maritime options may be infeasible, whereas flexible shipments allow the platform to explore lower-cost multimodal chains with longer transit times. The variation therefore enables evaluation of how synchromodal logic adapts under tightening temporal constraints.

Analytical Implication

Taken together, these temporal parameters transform urgency from a descriptive label into a structural constraint embedded in the routing problem. The dataset therefore enables testing of:

- feasibility filtering under constrained time windows,
- dynamic prioritisation across concurrent orders,
- mode selection trade-offs between cost and speed,
- and rerouting behaviour as delivery windows narrow.

Rather than merely generating route outputs, the temporal logic is designed to expose how the platform handles differentiated service-level expectations within a shared multimodal network.

7.3 Order Staggering and Scenario Timing

To further simulate realistic operational dynamics, orders were not generated as a single synchronised batch. Instead, they were deliberately staggered within each scenario month, March 2024 for the Finland corridor and April 2024 for the Germany corridor. This staggering introduces variability in temporal overlap. Some orders coexist within identical planning horizons, creating competition for modal capacity or terminal handling. Others emerge sequentially, requiring the platform to integrate new shipments into an already evolving routing landscape. This design reflects the non-linear arrival of humanitarian demands, which are triggered by changing needs on the ground rather than fixed scheduling cycles.

The staggered structure enables observation of how the platform handles:

- concurrent urgent and flexible shipments,
- capacity conflicts across modes,
- prioritisation under constrained delivery windows,
- and potential rerouting behaviour when previously feasible options become temporally infeasible.

By avoiding artificial synchronisation, the dataset reproduces the complexity of real humanitarian flow patterns and enhances the robustness of the platform evaluation.

7.4 Platform Capabilities Targeted by the Dataset Design

Although final routing outputs are pending, the dataset has been intentionally structured to activate key analytical capabilities within the ReMuNet platform.

The differentiated urgency classes and temporal constraints are designed to test:

- **Feasibility filtering**, particularly under narrow pickup and delivery windows.
- **Mode selection trade-offs**, where faster but costlier modes compete with slower multimodal combinations.
- **Priority handling**, when urgent shipments coexist with flexible cargo.
- **Dynamic reallocation**, in cases where tightening delivery windows reduce the feasible solution space.
- **Synchromodal switching behaviour**, especially under urgency pressure or capacity constraints.

Importantly, the dataset allows the platform to demonstrate adaptive behaviour rather than static optimisation. The objective is not solely to identify the shortest path, but to evaluate how routing logic responds when time sensitivity, cost considerations, and modal availability interact dynamically.

7.5 From Humanitarian Logistics Observation to Platform Experimentation

Within the analytical progression outlined in the Introduction, the order dataset represents the operational bridge between contextual analysis and platform-level evaluation. Earlier sections examined how the evolving conflict environment reshaped corridor accessibility and exposed structural vulnerabilities within the multimodal transport network. They further analysed how humanitarian actors adapted through route reconfiguration, modal substitution, and flexible coordination mechanisms. This section translates those empirical observations into structured experimental parameters. By embedding differentiated urgency classes, temporal constraints, and staggered order generation into the dataset, the stress characteristics identified in the conflict environment are reproduced in a controlled simulation setting. The dataset therefore enables the transition from descriptive analysis to platform testing, allowing the ReMuNet routing logic to be evaluated against realistic and heterogeneous service requirements.

The humanitarian-focused social use case, thus, functions as a structured experimental environment rather than a standalone case description. It operationalises the resilience challenges identified earlier in the report and prepares them for systematic evaluation within the synchromodal routing architecture. The structured order dataset does not only represent a set of hypothetical shipments but also defines the operational conditions under which the ReMuNet platform is expected to perform. By introducing differentiated urgency levels, constrained time windows, and overlapping shipment requests, the dataset requires the routing logic to evaluate trade-offs between speed, cost, and feasibility across multiple transport modes. In this sense, the dataset functions as a controlled environment for testing how the platform responds to disruption-related constraints observed in real-world humanitarian logistics.

7.6 Dataset Limitations and Simplifications

The dataset design described above provides a structured basis for platform testing. However, it necessarily involves certain simplifications compared to real-world operations. While the structured order dataset provides a realistic representation of humanitarian logistics conditions, it necessarily involves several simplifications compared to real-world operations.

First, the empirical shipment data used in this study covers the period March 2022 to April 2023, reflecting the early phase of the conflict. Since then, both the composition of aid and the operational environment have evolved. The dataset therefore combines historical data with research-based assumptions and interview insights to approximate current conditions. Second, shipment urgency is treated as static throughout the transport process. In practice, urgency may change dynamically due to evolving needs, delays, or changing conditions on the ground, which is not captured in the current dataset. Third, the dataset represents a simplified set of shipment types and does not fully capture the diversity and variability of goods in real humanitarian operations, where cargo characteristics may influence routing and handling decisions.

These simplifications are intentional and reflect the objective of this deliverable, which is to construct a structured and reproducible experimental framework for evaluating routing logic, rather than to replicate the full complexity of real-time humanitarian operations.

8. Discussion: Generalisable insights from the social use case and implications for ReMuNet

Humanitarian logistics in conflict conditions represent an extreme operational environment. However, extreme cases often illuminate structural weaknesses and hidden dependencies that remain invisible under normal circumstances. The patterns observed in this study: modal elasticity, chokepoint amplification, distributed coordination, and corridor rebalancing, are not unique to war settings. They are intensified manifestations of dynamics present in all freight systems. By incorporating lessons from this humanitarian pilot, the ReMuNet platform can strengthen its robustness not only for crisis response but also for everyday freight operations facing weather disruptions, labour shortages, or infrastructure constraints.

The humanitarian pilot examined in this report represents an extreme but analytically valuable operational environment. While the preceding sections focused on conflict-induced disruption, adaptive logistics behaviour, and the operationalisation of structured pilot scenarios, this section distils the broader lessons that can inform ReMuNet's platform development. The objective is not to derive case-specific conclusions limited to Ukraine, but to extract structural insights into multimodal resilience, corridor fragility, and synchromodal decision-making under compound disruption. These insights are transferable to a wide range of crisis and non-crisis freight contexts across Europe.

In the context of active conflict, resilience extends beyond simple redundancy. It involves the capacity of a multimodal transport ecosystem to reorganise flows dynamically while maintaining continuity of essential deliveries. This includes the ability to shift between modes, reroute around damaged infrastructure, reallocate terminal capacity, and manage fluctuating border conditions. The humanitarian case demonstrates that resilience is not solely a property of infrastructure but emerges from coordinated interactions among actors, platforms, and modal interfaces. For ReMuNet, this reinforces the importance of ecosystem-level orchestration rather than isolated route optimisation.

8.1 Designing for crisis, benefitting all

The ReMuNet platform includes multiple interactive features that alert drivers and operators of potential disruptions along their route. The platform also allows users to report disruptions they have encountered for the benefit of other users. This section explores additional features that may be included in the platform for humanitarian-specific applications.

Apart from the rerouting and multimodality features of the ReMuNet platform, the humanitarian users have some special requirements:

1. Prioritizing safety and speed: The trade-off between speed and safety can be quite complex in humanitarian contexts. Users could be allowed to change the priorities. For emergency response, speed could have a higher priority, while safety would be more important in most other scenarios.
2. Coordination support: An important aspect of the humanitarian flows is the coordination among multiple actors. The platform could facilitate communication between these actors to improve coordination.

3. Traceability and accountability: For humanitarian aid, the traceability of shipments is crucial information for donors and regulating authorities. The platform could help support these efforts, which are often manual or paper based.

Now, we propose some alerts or notifications that could have special importance in humanitarian applications. The alerts are grouped into three categories: safety, operational, and coordination alerts. The safety-related alerts allow users to share updated information regarding safe corridors. The operational alerts allow actors to share real-time updates on the status of the infrastructure. Finally, the coordination alerts allow the stakeholders to communicate and track the cargo throughout its flow. Table 10 lists these ideas.

Table 10: Alerts and notifications for the humanitarian applications

Safety alerts	Operational alerts	Coordination alerts
Avoiding high-risk areas	**Prevent loss of time**	**Improve predictability and efficient**
Conflict zone proximity	Border crossing times, corridor updates	Status update on shipments
Curfew and restricted zone	Bottlenecks	Inter-agency coordination
Safe corridor updates	Damaged infrastructure	Verification of information
Shelter points	Fuel availability and fuelling points	Local restrictions
Weather alerts	Available capacity at logistics hubs	

The incorporation of such features would not only enhance humanitarian operations but would also improve the platform's performance in commercial freight contexts. Weather disruptions, labour shortages, infrastructure maintenance, and sudden demand spikes similarly require rapid information exchange, prioritisation adjustments, and dynamic rerouting. By embedding crisis-informed coordination and alert mechanisms into the platform architecture, ReMuNet strengthens its capacity to function as a disruption-aware orchestration tool across diverse operational environments.

8.2 Cross-sector benefits of humanitarian pilots

The humanitarian scenario analysed in this report illustrates the structural interdependence of civilian freight systems, crisis-response logistics, and strategic mobility planning. The corridors examined, particularly along the Baltic-Poland-Ukraine axis, serve not only commercial supply chains but also humanitarian flows and broader European strategic transport objectives. Under conditions of disruption, these roles converge, exposing shared dependencies on border crossings, intermodal terminals, and multimodal flexibility. By testing routing logic within a humanitarian stress environment, the ReMuNet platform engages with infrastructure segments that are inherently dual use. Ports, rail hubs, and road corridors that handle everyday commercial cargo must also absorb crisis-driven surges, reconfigurations of flows, and heightened coordination demands. Insights derived from humanitarian routing scenarios therefore contribute to strengthening infrastructure resilience across sectors. Furthermore, humanitarian logistics often involves coordination among heterogeneous actors, including non-governmental organisations, freight forwarders, public authorities, and infrastructure operators. These actors operate with differing planning horizons, information systems, and prioritisation criteria. A disruption-aware routing platform capable of integrating differentiated urgency levels, dynamic time constraints, and modal feasibility assessments can support more coherent decision-making across such actors.

In this sense, humanitarian pilots serve as controlled environments for testing digital coordination under complexity. The lessons extend beyond the immediate case study and contribute to broader European objectives related to crisis preparedness, supply chain robustness, and strategic transport resilience.

8.3 Humanitarian use case: strengths and limitations for platform development

The humanitarian use case examined in this report provides a valuable but inherently specific perspective on multimodal transport systems under disruption. As an extreme operational environment, it exposes structural constraints, coordination challenges, and the need for rapid adaptation. At the same time, humanitarian logistics differs fundamentally from commercial freight operations in terms of objectives, stakeholders, and decision-making processes. This creates both opportunities and limitations when using such a case to inform broader platform development.

8.3.1 *Strengths of the humanitarian use case*

The humanitarian context offers several advantages as a test environment for multimodal routing systems. First, it represents an **extreme disruption scenario**, where infrastructure damage, border congestion, and modal restrictions make system vulnerabilities clearly visible. Second, it highlights the **redistribution of transport flows under pressure**, revealing critical nodes and chokepoints that may remain less apparent in stable conditions. Third, it emphasises **the importance of flexibility**, as logistics operations rely on rerouting, modal substitution, and coordination across multiple actors. Together, these characteristics make the humanitarian case particularly suitable for stress-testing routing approaches and identifying structural weaknesses in multimodal networks

8.3.2 *Limitations and transferability considerations*

At the same time, the humanitarian use case presents limitations when considered as a basis for general platform development. Humanitarian logistics operates under **different optimisation objectives**, where speed, accessibility, and reliability often take precedence over cost efficiency. In contrast, commercial logistics typically balances cost, time, and service levels. The **operational context is also more specialised**, involving distinct coordination mechanisms, institutional actors, and decision-making processes. As a result, routing behaviour in humanitarian settings is often **reactive and context-driven**, rather than based on systematic optimisation. These differences raise important considerations regarding the extent to which a single platform can effectively support both humanitarian and commercial use cases without introducing trade-offs between flexibility and efficiency.

8.3.3 *Implications for platform development*

Rather than representing a limitation, these differences can be interpreted as a design challenge. The humanitarian use case highlights the need for routing systems that are adaptable to varying objectives, constraints, and decision-making contexts. This suggests that platform development should prioritise flexibility and configurability, enabling different operational logics to coexist within a common framework. In this sense, the humanitarian case contributes to expanding the design space for multimodal routing systems within ReMuNet.

8.4 Mapping humanitarian use case to platform functionalities

The humanitarian use case analysed in this report highlights several operational characteristics of freight transport under disruption. These include shifting corridor availability, border congestion, terminal dependency, and varying levels of urgency across shipments. Together, these factors define the types of conditions under which routing decisions must be made. While the detailed design of platform functionalities lies outside the scope of this deliverable and are addressed in deliverables 3.7 and 3.8, the empirical observations and the structured dataset developed in this study allow us to identify key functional requirements for disruption-aware routing systems. The following section and Table 11 map selected characteristics of humanitarian logistics operations to the types of capabilities that a platform such as ReMuNet would need to support.

Table 11: Mapping of humanitarian characteristics with platform functionalities

Category	Humanitarian logistics characteristic	Evidence from case	Implication for routing decisions	Platform-relevant functionality
Network constraints	Border congestion and variability	Recurrent delays at Poland–Ukraine border crossings; queueing and processing uncertainty	Route feasibility depends on border conditions, not just distance or cost	Dynamic feasibility evaluation incorporating border delays and uncertainty
	Terminal dependency and capacity constraints	Intermodal hubs and border terminals act as bottlenecks under high demand	Routing must account for node capacity and transfer delays	Integration of node capacity constraints and bottleneck-aware routing
	Corridor shifting under disruption	Changing accessibility due to security conditions and infrastructure damage	Predefined routes are unreliable; alternatives must be continuously evaluated	Dynamic corridor assessment and alternative route generation

Operational dynamics	Modal constraints and substitution	Restricted air/sea routes; increased reliance on rail and road corridors	Routing must allow flexible switching between modes	Synchromodal routing with dynamic mode selection
	Uncertainty in travel times	High variability in transport times across corridors and borders	Deterministic routing is insufficient; robustness is required	Incorporation of time variability and robustness in routing evaluation
	Cross-border coordination complexity	Multiple actors coordinating across countries and organisations	Routing is influenced by coordination constraints, not just infrastructure	Support for multi-actor coordination and shared operational visibility
Decision complexity	Urgency-driven shipment prioritisation	Differentiation between urgent, standard, and flexible shipments	Routing must prioritise time-critical deliveries over cost efficiency	Priority-aware routing incorporating urgency and delivery windows
	Overlapping and competing shipments	Staggered orders with overlapping time windows in dataset	Routing must allocate limited capacity across competing demands	Handling of concurrent shipments and optimisation under competing constraints
	Evolution of aid types over time	Shift from basic goods (2022) to specialised goods (later phase)	Routing requirements vary depending on cargo characteristics	Adaptive routing based on shipment type and operational requirements

8.5 Future platform improvements: leveraging humanitarian scenarios

The structured operationalisation of the humanitarian pilot provides a foundation for identifying targeted enhancements to the ReMuNet platform. While final routing outputs remain pending, the design of differentiated urgency classes, staggered order creation, and constrained delivery windows reveals specific areas where disruption-aware logic can be further refined.

First, the prominence of border crossings as systemic bottlenecks under conflict conditions highlights the value of incorporating probabilistic delay modelling and dynamic capacity scoring at corridor interfaces. Integrating real-time or scenario-based border performance indicators would strengthen the platform’s ability to assess fragility at critical nodes. Second, the role of intermodal terminals as consolidation and transfer points suggests the need for dynamic weighting of terminal criticality. Incorporating throughput concentration, modal dependency, and alternative access availability into routing evaluation could enhance robustness assessments. Third, the urgency-based time structuring introduced in the pilot dataset demonstrates the importance of adaptive optimisation parameters. As delivery windows narrow or new urgent shipments enter the system, the platform should be capable of recalibrating feasible mode sets and reprioritising existing routes in real time.

Additional enhancement pathways include the integration of seasonal weather constraints, disruption event feeds, and scenario simulation tools that allow stress-testing under compound disruptions affecting multiple nodes simultaneously. Several open-source humanitarian platforms could be integrated into ReMuNet to serve as critical data sources. In the table below, platforms that track the conflict and potential sources of disruption in Ukraine are shown in Table 12 below.

Table 12: Conflict-tracking platforms

Platform name	Description
ACAP's Humanitarian Access Event	The dataset documents events related to access of people in need to aid, access of humanitarian actors to affected populations, as well as physical and security constraints. From the beginning of the dataset, in February 2024, to September 2025, more than 13.000 such events were recorded. Events labelled as "ongoing insecurity", "presence of mines and explosive devices" and "environmental constraints" (from rainy season to severe disruption of infrastructure and scarcity of fuel), especially, are aligned to ReMuNet's typology of disruptive events. As they are reported with precise locations, and an API is available to access the dataset, they could be a source of data for the project's app.
ACLED's Ukraine Conflict Monitor	The platform provides near real-time information on political violence events in the country, including violence against civilians, air and drone strikes, armed clashes, shelling events, and instances in which control of portions of the territory switches. Crucially, it also maps attacks on infrastructure, including energy infrastructure, which can have a direct impact on the distribution of humanitarian aid.
OCHA's Humanitarian Access Snapshots	The platform map access incidents by oblast, including types, severity, and affected organisations. They are released monthly, but even if they are not a potential source of near-real-time data for the ReMuNet platform, insight can still be derived from them, especially when identifying patterns of weather-related disruptions.

Incorporating additional data sources, especially those with real- or near-real-time updates, could enhance the platform's accuracy and reliability. In scenarios of high uncertainty, where changes can happen suddenly and without warning, these updates are critical. If not present, users on the ground, such as drivers and humanitarian field actors, may abandon the platform and revert to manual decision-making. If possible, the platform should also allow users to manually input the disruption they see and reroute based on it. This would help not only the user in question but also others in the same area using the tool.

By embedding these capabilities into the platform architecture, ReMuNet can evolve from a route optimisation tool toward a comprehensive disruption-aware orchestration system. The humanitarian pilot illustrates that resilience emerges from adaptive prioritisation, multimodal flexibility, and informed coordination rather than static redundancy alone. Leveraging humanitarian scenarios for continued tool refinement therefore strengthens the platform's applicability across both crisis-response and routine freight operations. Together, the shipment data and corridor mapping reveal how freight flows reorganise across the multimodal network under crisis conditions.

8.5.1 *Role of ReMuNet in humanitarian logistics*

An additional consideration relates to the potential role of the ReMuNet platform in supporting humanitarian logistics beyond structured pilot scenarios. While the platform is primarily designed for multimodal freight routing within commercial and institutional contexts, the question arises whether similar capabilities could be extended to support humanitarian or volunteer-based logistics coordination. In its current form, ReMuNet is not designed as an open-access coordination platform for humanitarian actors or volunteers. Such applications typically require different governance models, higher levels of data sharing, and open participation mechanisms, which differ from the controlled and commercially oriented environment in which ReMuNet operates. Moreover, specialised tools and coordination platforms already exist within the humanitarian sector, such as those used by logistics clusters and international organisations. Nevertheless, there is potential for complementary integration. Rather than replacing existing humanitarian systems, ReMuNet could provide additional value by supporting specific functions, such as evaluating multimodal routing options, identifying alternative corridors, or incorporating sustainability considerations into routing decisions. In particular, the platform could facilitate collaboration between humanitarian organisations and commercial logistics providers, for example by enabling the use of available transport capacity or supporting hybrid operational models. These considerations suggest that the role of ReMuNet in humanitarian contexts may lie not in direct platform substitution, but in interoperability and targeted support functions, which could be explored further in future development work.

9. Conclusions and future directions

This report has explored the delivery of humanitarian assistance to Ukraine as a demanding real-world case for testing multimodal transport resilience within the ReMuNet project. By examining how aid flows operate under sustained armed conflict, the study highlights how transport networks respond when multiple constraints occur simultaneously: damaged infrastructure, restricted air and sea access, border congestion, and ongoing security risks. In Scenario 1, the vulnerability of the Lithuania-Poland border was highlighted. Considering how short that border is, any disruptive event along it, whether due to a natural disaster, such as flooding, or a man-made one, such as military conflict, will likely have a high impact and require substantial rerouting by sea. The Poland-Ukraine border, in turn, was investigated in Scenario 2, where it was noted that political decisions and social movements, such as workers' protests, can affect its capacity. In both scenarios, the possible transport modes were restricted from the start by considerations such as the impossibility of accessing Ukrainian airspace for security reasons and gauge changes on the railway lines between Poland and Ukraine. These disruptions are among the many that can occur, with varying probabilities, during transport from the respective origin countries (Finland and Germany) to the destination in Ukraine. They show that companies and humanitarian organisations involved should not only be aware of multiple types of disruptions but also be prepared to respond by rerouting cargo.

The analysis shows that resilience is not simply a matter of having alternative infrastructure in place. Instead, it emerges through continuous adaptation: shifting between modes, rerouting across corridors, reorganising warehouse locations, and managing border crossings under pressure. The war has altered freight patterns across the Baltic–Poland–Ukraine axis, increasing reliance on rail and road corridors and placing particular strain on intermodal terminals and key border points. These locations often act as system bottlenecks, where capacity limitations can cascade backward through the network.

The empirical assessment of DRC shipment data, combined with corridor mapping and expert validation, provided a grounded understanding of how humanitarian supply chains functioned in practice. These insights informed the design of two pilot scenarios – Finland to Ukraine and Germany to Ukraine – and the construction of a structured order dataset for platform testing. By embedding differentiated urgency levels, staggered time windows, and competing service requirements, the dataset creates realistic operating conditions for evaluating synchromodal routing logic within ReMuNet. Several recurring patterns are evident. Border capacity consistently shapes overall corridor performance. Rail–road interoperability, especially where gauge changes occur, is both a constraint and a source of flexibility. Intermodal hubs serve as critical adjustment points when other modes become unavailable. Most importantly, disruption redistributes pressure within the network, revealing dependencies that remain largely invisible in stable conditions. As corridors shift and capacity constraints emerge at different nodes, the functional geography of the transport system changes dynamically. This reinforces a key insight for ReMuNet: transport resilience cannot be understood as a static property of infrastructure alone but must be evaluated in relation to evolving disruption patterns across the network.

For ReMuNet, these findings reinforce the need for routing models that account for dynamic disruption patterns rather than static infrastructure maps. Effective resilience modelling must incorporate time sensitivity, modal substitution, urgency-based prioritisation, and corridor-level constraints. Among these factors, the role of urgency is particularly significant. As demonstrated through the structured order dataset, different shipments may require fundamentally different routing strategies depending on their priority, time sensitivity, and operational constraints. In practice, this introduces an additional layer of complexity, as routing decisions must balance competing demands across shipments with varying urgency levels. While the current work incorporates urgency as a predefined attribute within the dataset, its dynamic management represents an important direction for future platform development. In real-world operations, priorities may evolve over time in response to delays, changing needs, or external conditions. Supporting such adaptive prioritisation within routing logic would further enhance the platform's ability to operate effectively under disruption.

The humanitarian case demonstrates how evolving operational realities can be translated into structured inputs for platform design. Although the pilot simulations are ongoing, the preparatory work documented in this deliverable establishes a clear link between empirical observation and digital experimentation. These findings are clearly generalisable for several reasons. The first is that although the delivery of humanitarian aid may seem exceptional, it is still largely handled by logistics companies, and considerable portions of the routes are in non-conflict areas, thus subject only to "regular" potential disruptions. The same transport rationality used in commercial operations, therefore, is applicable to most of humanitarian logistics. Even within a country under conflict, there are still areas that operate almost normally, as seen in western Ukraine. Once within areas of active conflict, the types of disruptions may differ and be more frequent, but they continue to require the same tools to be bypassed: real or near-real time updates, the possibility of sharing information with partners, and reliable rerouting options based on each case's priority, be it delivery time, security, cost, or sustainability. The humanitarian use case thus contributes not only to understanding aid delivery under conflict, but also to strengthening broader European multimodal freight resilience in the face of complex and layered disruptions.

An additional aspect relevant to multimodal transport operations, but not explicitly addressed in this study, relates to the handling and digitalisation of transport documentation. Both commercial and humanitarian logistics rely on a wide range of documents, including customs declarations, waybills, and compliance-related information, often involving multiple stakeholders across jurisdictions. In humanitarian contexts, documentation requirements may be further shaped by donor conditions, regulatory frameworks, and coordination mechanisms with national authorities. The digital exchange of such information is widely recognised as a challenge, particularly in multimodal and cross-border settings. While the ReMuNet platform focuses on routing and disruption-aware decision-making, the efficiency of such systems may ultimately depend on the availability and interoperability of underlying data and documentation flows between stakeholders. Although the integration of transport documentation lies outside the scope of this deliverable, it represents a potential area for future development, particularly in relation to improving data sharing, coordination, and end-to-end visibility across multimodal transport chains.

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10. Appendix

10.1 Interview questions

The questions used as a guiding structure for the interviews with humanitarian experts are presented in the following table. The interviews were semi-structured, and the questions served as a guiding template.

	Questions
1	Can you describe your role and experience in the humanitarian response to the Ukraine conflict?
2	What major conflict dynamics within Ukraine have had the greatest impact on humanitarian logistics operations?
3	Which aspects of humanitarian logistics (e.g., procurement, warehousing, distribution) have been most affected by these conflict dynamics, and in what ways?
4	How have you or your organisation navigated these challenges?
5	In your view, has the humanitarian logistics response adapted as a direct result of these conflict dynamics? If so, how?
6	Have any unexpected conflict-related factors emerged that significantly disrupted humanitarian logistics? Can you provide specific examples?
7	How has the evolving nature of the conflict (e.g., shifts in frontlines, changing control of territories) affected long-term logistics planning and operations?
8	What have been the biggest constraints in terms of infrastructure (roads, ports, warehouses) due to the conflict?
9	Did seasonal changes affect the logistics? Any additional challenges during winter, for example?
10	What modes of transport were most common? Was it mostly freight or were there other modes?
11	What were some disruptions (apart from the conflict) that you planned for, from previous experience?
12	What other disruptions did you encounter (other than conflict-related)?
13	How did you plan for resilience? Any backup options against known disruptions?
14	What do you envision as the challenges ahead?
15	When did your organisation start to work with the response in Ukraine?

16	How were the first weeks of the response in your organisation – for instance, what type of assistance were you providing and where?
17	Has the type and location of assistance you provide changed over the course of your work in Ukraine? If so, when and how?
18	What types of local partners do you work with? How is your relationship with them?
19	When you work with them, what types of roles do they play?
20	Has your relationship with local changed during the time your organisation has worked in Ukraine?
21	Do you provide support for local partners? If so, what type?

Table 13: Interviewee details at a glance

S.No	Code	Role	Sector	Country
1	01-131023	Technical director	Combined transport	Belgium
2	02-161023	Member of management board	Terminal operator	Estonia
3	03-171023	Founder	Road freight relay	Germany
4	04-181023	Manager	Network planning	Germany
5	05-201023	Head, digitalisation	Air freight	Switzerland
6	06-231023	Managing director	Terminal operator	Austria
7	07-231023	Transport consultant	Combined transport	Lithuania
8	08-251023	Head of sales	Network planning	Germany
9	09-271023	Senior project manager	Combined transport	Germany
10	010-271023	Managing director	Combined transport	Germany
11	011-011123	Logistics development manager	Government transport agency	Finland
12	012-021123	Sales manager, specialist	Terminal operator	Finland
13	013-021123	Consultant	Humanitarian logistics	Denmark
14	014-031123	Founder	Combined transport	Germany
15	015-101123	Consultant	Maritime shipping	Estonia
16	016-201123	Data manager	Terminal operator	Finland
17	017-211123	Project manager	Combined transport	Germany
18	018-011024	Member of advisory board	Humanitarian Logistics Association	Finland
19	019-030925	Head of operations	Humanitarian Logistics	Ukraine
20	020-111024	Researcher	Humanitarian Logistics	Ukraine

10.2 Orders data

Below is a sample of the orders data that was created.

	DeliveryConsignor (string)	DeliveryConsignee (string)	CargoDescription (string)	ContainerType (string)	DecisionPoint (string)	CreationDate (Datetime)	External Unique reference ID (string)	Weight (kg, integer)	EarliestPickupTime (float)	LatestPickupTime (float)	EarliestDeliveryTime (float)	LastestDeliveryTime (float)
2	Finland Ukraine Aid Volunteers ry	Dnipro Alliance (NGO, first responder services)	Non-perishable food (palletised)	Palletised cargo	URGENCY=FLEX | Route chosen to minimise	2024-03-05 08:00	DEM_S1_ROUTE1_001	8000	45361,33333	45363,33	45366,33333	45375,33333
3	Finland Ukraine Aid Volunteers ry	Dnipro Alliance (NGO, first responder services)	Ambulance 1	Vehicle	URGENCY=STANDARD | Route chosen to min	2024-03-07 10:00	DEM_S1_ROUTE1_002	6000	45362,45833	45363,21	45366,70833	45370,95833
4	Finland Ukraine Aid Volunteers ry	Dnipro Alliance (NGO, first responder services)	Ambulance 2	Vehicle	URGENCY=STANDARD | Route chosen to min	2024-03-07 12:00	DEM_S1_ROUTE1_003	6000	45363,58333	45364,33	45368,08333	45372,58333
5	Finland Ukraine Aid Volunteers ry	Dnipro Alliance (NGO, first responder services)	Ambulance 3	Vehicle	URGENCY=STANDARD | Route chosen to min	2024-03-04 14:00	DEM_S1_ROUTE1_004	6000	45361,70833	45362,46	45365,70833	45371,20833
6	Finland Ukraine Aid Volunteers ry	Dnipro Alliance (NGO, first responder services)	Fire truck	Vehicle	URGENCY=STANDARD | Route chosen to min	2024-03-08 04:00	DEM_S1_ROUTE1_005	8000	45362,33333	45363,08	45366,58333	45370,33333
7	German Coalition for Vaccines	Dnipro Vaccination Committee	Vaccines requiring -80 to -60°C cold chain	Ultra-cold chain container	URGENCY=URGENT | Rail chosen for predict	2024-04-04 06:00	DEM_S2_ROUTE2_001	500	45387,25	45387,5	45389,25	45391,25
8	German Coalition for Vaccines	Dnipro Vaccination Committee	Vaccines requiring -80 to -60°C cold chain	Ultra-cold chain container	URGENCY=URGENT | Rail chosen for predict	2024-04-04 08:00	DEM_S2_ROUTE2_002		45388,375	45388,63	45390,625	45392,875
9	German Coalition for Vaccines	Dnipro Vaccination Committee	Vaccines requiring +2 to +8°C (freeze-sensitive) 1	Refrigerated medical container	URGENCY=URGENT | Rail chosen for predict	2024-04-06 10:00	DEM_S2_ROUTE2_003	800	45389,5	45389,75	45392	45394,5
10	German Coalition for Vaccines	Dnipro Vaccination Committee	Vaccines requiring +2 to +8°C (freeze-sensitive) 2	Refrigerated medical container	URGENCY=URGENT | Rail chosen for predict	2024-04-06 12:00	DEM_S2_ROUTE2_004	800	45390,625	45390,88	45392,625	45396,125
11	German Coalition for Vaccines	Dnipro Vaccination Committee	First aid kits 1	20000 units	URGENCY=URGENT | Prioritize speed of deli	2024-04-08 02:00	DEM_S2_ROUTE2_005	3720	45391,25	45391,5	45393,5	45395,25
12	German Coalition for Vaccines	Dnipro Vaccination Committee	First aid kits 2	20000 units	URGENCY=FLEX | Prioritize low cost	2024-03-31 04:00	DEM_S2_ROUTE2_006	3720	45392,375	45394,38	45397,875	45406,875
13	German Coalition for Vaccines	Dnipro Vaccination Committee	Hygiene kits 1 (Ukraine Specs)	2079 units (33 pallets)	URGENCY=FLEX | Prioritize low cost	2024-04-06 12:00	DEM_S2_ROUTE2_007	17784	45393,5	45395,5	45398,5	45408,5

Figure 10: Sample of orders data created

10.3 Routing data from desk research

Below is a sample from the routing data collected through desk research on some of the possible routes along the North-Sea Baltic corridor serving Ukraine.

Entry points			
Country	Location	Port	Airport
Estonia	Tallinn	✓	✓
Estonia	Paldiski	✓	
Estonia	Muuga	✓	
Latvia	Riga	✓	✓
Latvia	Ventspils	✓	
Latvia	Liepaja	✓	
Lithuania	Siauliai		✓
Lithuania	Vilnius		✓
Lithuania	Kaunas	✓	✓
Lithuania	Klaipeda	✓	
Poland	Warsaw		✓
Poland	Rzeszow		✓
Poland	Gdansk	✓	
Poland	Gdynia	✓	
Ukraine	Lviv		✓
Ukraine	Kyiv		✓
Ukraine	Dnipro		✓
Ukraine	Odesa	✓	
Ukraine	Chornomo	✓	
Ukraine	Pivdennyi	✓	
Ukraine	Mykolaiv	✓	

Crossings

		Truck	Rail
Estonia-Latvia	Ikla-Ainazi	✓	
Estonia-Latvia	Valga-Valka	✓	✓
Latvia-Lithuania	Meitene-Joniskis	✓	✓
Latvia-Lithuania	Grenctāle–Saločiai	✓	✓
Latvia-Lithuania	Daugavpils–Turmantas	✓	✓
Lithuania-Poland	Mockava-Trakiszki	✓	✓
Lithuania-Poland	Kalvarija-Budzisko	✓	
Poland-Ukraine	Medyka-Mostyska II		✓
Poland-Ukraine	Dorohusk-Yahodyn	✓	
Poland-Ukraine	Korczowa-Krakovets	✓	
Poland-Ukraine	Medyka-Shehyni	✓	

Hubs		Rail
Estonia	Paldiski	✓
Estonia	Tallinn	✓
Estonia	Tartu	✓
Latvia	Riga	✓
Latvia	Jelgava	✓
Lithuania	Siauliai	✓
Lithuania	Kaunas	✓
Lithuania	Klaipeda	✓
Lithuania	Vilnius	✓
Poland	Rzeszow	✓
Poland	Warsaw	✓
Poland	Lublin	✓
Ukraine	Lviv	✓
Ukraine	Kyiv	✓

Figure 11: Sample routing data collected from desk-research

10.4 Humanitarian aid findings

As explained by the interviewees, the DRC, as a national society of the Red Cross and Red Crescent, is only permitted to operate abroad upon receiving a request. That request can be made either by the national RC society of a particular country, or by the International Committee or the International Federation of the Red Cross (ICRC or IFRC). In the case of Ukraine, the DRC had been present since 2014. Its work is always meant to support and complement that of the local Red Cross. (Interview 13, 19).

“Since February last year, Ukraine has been by far the biggest operation we have been engaged in. Also, because we as Danish Red Cross, were already in Ukraine helping or assisting capacity-building with the Ukrainian Red Cross Society. We were actually the first Red Cross national society in Ukraine partnering up with the Ukrainian Red Cross.” (Interview 13)

When providing humanitarian assistance in Ukraine in the form of physical goods, it utilised reception and distribution hubs in Romania. During Ukraine Phase 1, the primary type of aid delivered was in the form of blankets and sleeping items, food, hygiene kits, and medicine (Source: Mobilisation table DRC Ukraine).

From a logistics perspective, items were sent from China, Bulgaria, Spain, Denmark, Hungary, Poland, Belgium, and India, with some being acquired locally in Dornești. The modes of transportation used include air, sea and road, and the transport cost is shown in the figure below.

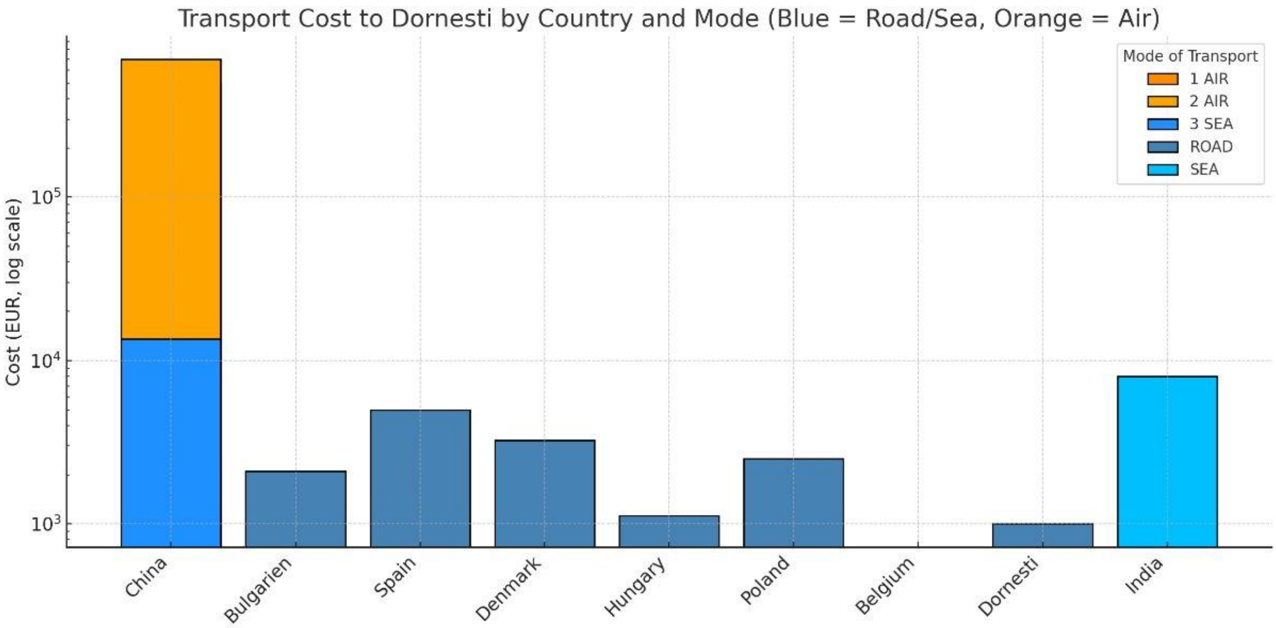

Figure 12: Transport cost to Dornesti by country and mode

Interviews have indicated that the DRC uses commercial logistics providers to transport goods to Ukraine. Following a tendering process, the organisation contracts with freight forwarders, who are responsible for the shipments. The DRC receives updates on the goods’ location and ETA predictions. They confirm the document data regarding the transport modes:

“Primarily, it would be vessels, trucks, and air. For instance, in vessels, for example, when we have imported, when we have equipment or items delivered from China, India, of course, it would be shipped from China, India to, let's say, Ukraine. It was shipped to Constanta in Romania, and then it was offloaded onto trucks and taken via Romania into Ukraine. So that is one very normal mode. So, there's vessels, trucks. And then you have, of course, you have the, the, the last mile from the distribution to the beneficiaries, which is, will also be done by trucks, most likely.” (Interview 13)

The estimated time of departure from the point of origin and the estimated time of arrival in Dornesti are reported in the documentation (Source: Pipeline 13-04-2023) and, with those dates, the average shipping transit time by country was calculated. The results are shown in the figure below.

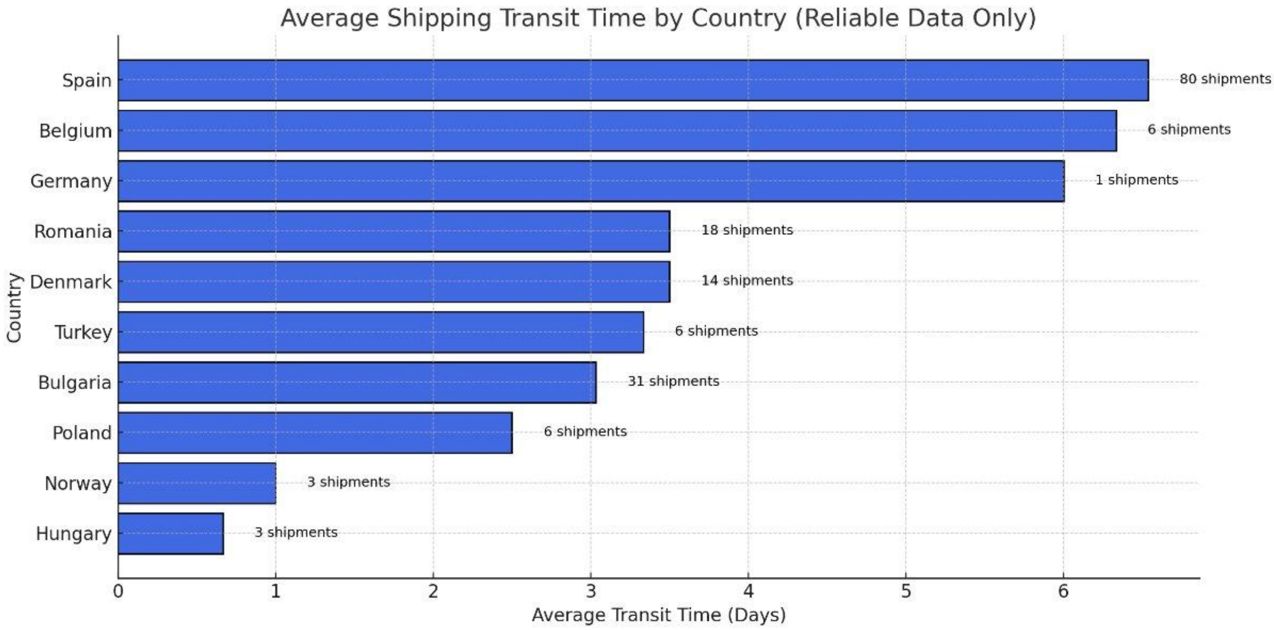

Figure 13: Average shipping transit time to Dornesti by country

In the interviews, the challenge of transporting goods in a conflict setting, prone to multiple types of disruptions, was highlighted. Border crossings were noted as the most challenging part of the delivery process (Interview 13, 19):

"One thing is to actually buy it, another thing is to get it across the border into Ukraine. And this is where you can say that you have a good example of disruption, because you never really know, for political reasons, what will stop a truck at the border crossing. So, to get around this, we had to equip all our trucks with Red Cross logos, either Danish Red Cross logos or Ukrainian Red Cross logos, so we could bypass this 20-kilometre-long queue of trucks waiting to cross the border. So, you have to find these workarounds and now you have a new disruption at the border because Poland and Romania and Bulgaria and all the neighbouring countries of Ukraine for political reasons, because of the price of grain is going down, which hits the agricultural production in Poland. They have shut down trucks from Ukraine to go out, meaning you now have 40 kilometers of queues of trucks on both sides, simply for political reasons, because the Polish farmers, they are losing money on the price of grain. So, this is like the current eruption where you have no control, and where political diversities or differences change the whole game." (Interview 13)

The weight of cargo received by the Ukraine Red Cross Society in each of its three warehouses near the Romanian border was calculated (Source: The Movement reporting to Tjernivtsi document). The dates of June 20 and 21 were excluded from the monthly graph, as there was so much cargo received on those days that they distorted the visualization, as shown in figures 7 and 8 below.

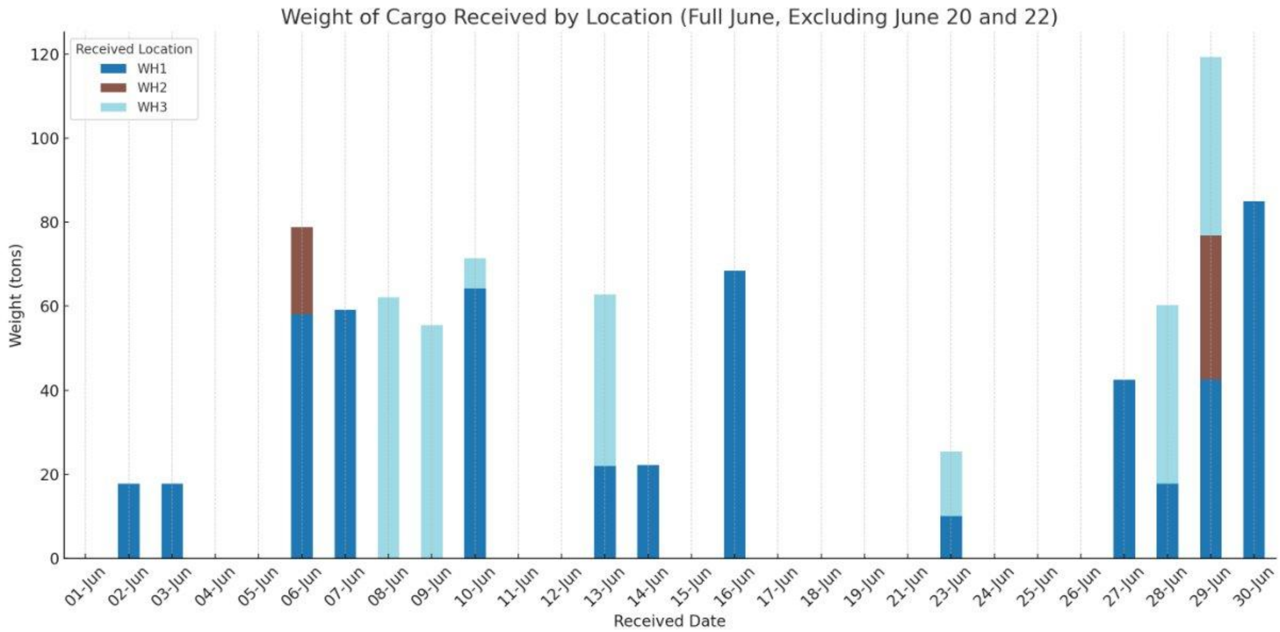

Figure 14: Weight of cargo received by warehouse in Chernivtsi

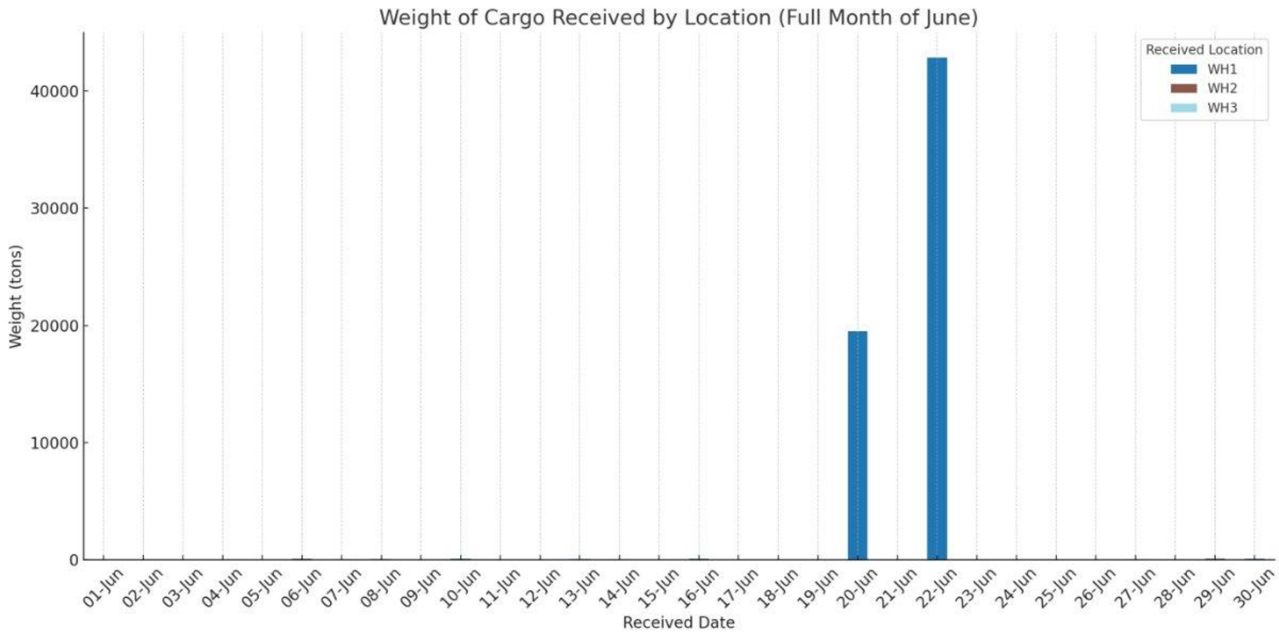

Figure 15: Weight of cargo received by warehouse in Chernivtsi on June 20 and 22

The senders and final recipients of different shipments during the month of June are also indicated (Source: The Movement reporting to Tjernivtsi document). After the necessary data was identified in the spreadsheet, a table containing sender, recipient and respective weight of cargo was compiled. The filtered data was then used to create a Sankey diagram, showing the flows of aid, from the beginning to the last mile of the humanitarian supply chain in Ukraine. The diagram is depicted in the figure below.

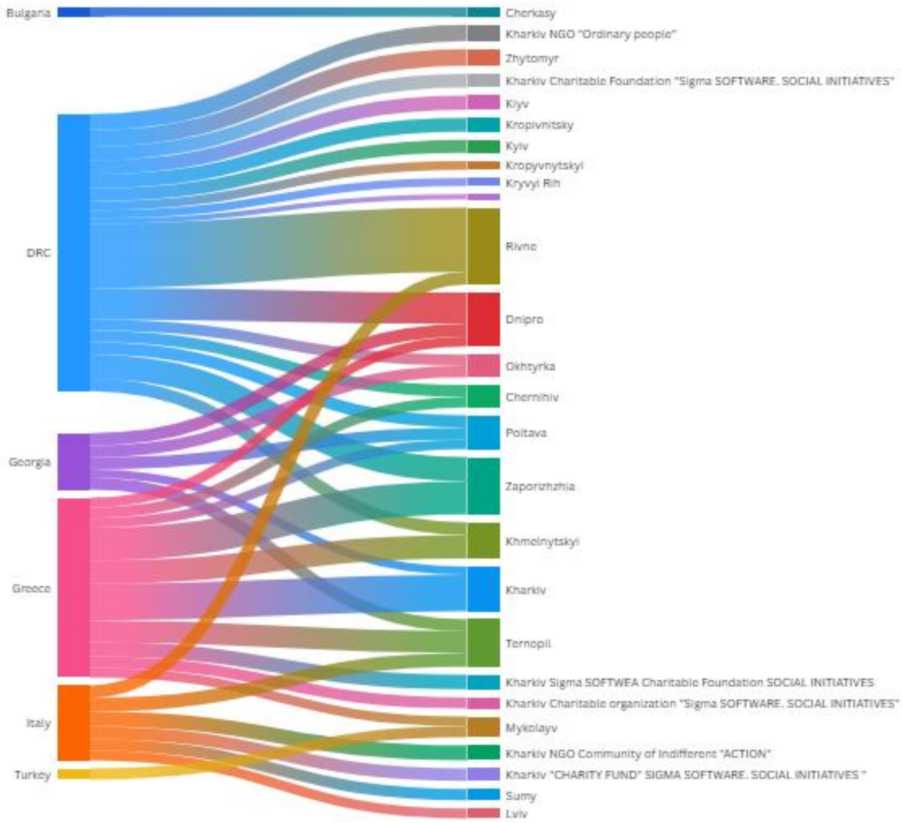

Figure 16: Sankey diagram showing senders and recipients of humanitarian aid in Ukraine, with the flow representing the weight of cargo transported

The data received from the DRC, together with interviews conducted with their staff, help build an understanding of how humanitarian supply chains delivering aid to Ukraine are organised. The DRC dataset covers the period March 2022 to April 2023 and reflects the types of goods delivered during the early phase of the conflict. As noted by interviewees, however, the composition of aid has evolved since then (Interview 19). As the frontline stabilised and parts of the Ukrainian market resumed production, some items that were widely delivered in 2022 – such as blankets, food, and hygiene products – increasingly became available locally. As a result, more specialised items that cannot be produced locally continue to be imported. Because the 2022 shipment data do not fully reflect the current composition of aid deliveries, these product categories were not used directly in the construction of the pilot scenarios. Instead, the scenarios draw on insights from the interviews to identify representative goods currently delivered. The DRC data was nevertheless used to provide realistic shipment volumes and operational parameters for platform testing.

The project

ReMuNet identifies and signals disruptive events and assesses their impact on multimodal transport corridors. It reacts quickly and seamlessly upon disruptive events in real-time. It supports TMS providers to improve route planning resilience. ReMuNet communicates alternative, pre-defined, multimodal transport routes to logistics operators and subsequently to truck drivers, locomotive drivers and barge captains. Through this, it enables a faster and adaptive multimodal network response. ReMuNet orchestrates route utilization, suggests transshipment points and optimizes capacity allocation, minimizing damage and shortening the recovery time. What is ReMuNet's core objective? As trailblazer for the Physical Internet, ReMuNet pursues the vision to enable and incentivize synchro-modal relay transport on European rail, road, and inland waterways to increase the holistic network resilience. It significantly reduces emissions and boosts freight transport corridor efficiency in case of disruptive events. stakeholders to ensure Europe-wide practicability and acceptance.

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