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AUTOSUP

Preparing the ground for AUTOnomous Multimodal SUPply Chains

Grant Agreement Number: 101147468

D3.2. COST-BENEFIT ANALYSIS

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Executive Summary

This deliverable presents the Cost-Benefit Analysis (CBA) conducted within the AUTOSUP project, as part of Work Package 3 “New Operational Models for Automation-driven Multimodal Freight Transport validated in Living Hubs.” It provides a methodological framework for evaluating the financial, operational, and environmental impacts of automation solutions implemented in multimodal freight transport hubs. The document lays the foundation for integrating the CBA model into the AUTOSUP Decision Support System (DSS) and supports subsequent work.

The objective of Deliverable D3.2 is to assess the feasibility, costs, and benefits of automation-driven innovations to be tested within the Living Hubs (L-Hubs) of Trieste and Antwerp-Bruges. The analysis quantifies the financial, operational, and environmental impacts of six Use Cases, covering rail, port, and multimodal automation scenarios. These include predictive maintenance of intermodal rail wagons, automated management of multimodal slots and last-mile routes, cross-border roll-on/roll-off transshipment, port automation coordination, shipper-port collaboration for modal shift, and integration of automation systems across transport modes.

Methodologically, the deliverable develops a logic model to compare AS-IS and TO-BE scenarios, capturing the incremental value of AUTOSUP interventions, namely the selected automation-driven solutions. The model applies standard EU economic appraisal techniques (e.g., a 4% discount rate, 25-year time horizon, and 20 % sensitivity variation) to compute the Net Present Value (NPV), Return on Investment (ROI), and environmental externalities across Use Cases, and quantifies the outcomes.

The results indicate that automation solutions can yield significant efficiency and environmental gains, particularly in Use Cases involving process digitalization, predictive maintenance, and multimodal coordination. For example, the automated management of multimodal slots and last-mile routes (UC2) achieves a positive ROI of 18,6 %, demonstrating the economic viability of digital integration and intelligent decision support. Large-scale applications, such as automated roll-on/roll-off transshipment (UC3), demonstrate substantial system-level benefits in reducing emissions, improving throughput, and facilitating a modal shift from road to rail, despite incurring high initial capital expenditures.

Beyond financial analysis, the deliverable incorporates an environmental dimension by quantifying the avoided CO_2 emissions, reductions in air pollution, and externalities associated with the adoption of automation. These insights contribute to the European Green Deal’s objectives by promoting automation as an enabler of sustainable, multimodal, and interconnected multimodal freight transport.

The methodological framework developed in this deliverable will feed into the DSS-based evaluation tools for scalability. This integration will enable partners and external stakeholders to conduct scenario-based assessments of automation investments in the AUTOSUP project’s L-Hubs.

By linking quantitative economic assessment with technological and policy insights, this deliverable provides the analytical foundation to guide investment prioritization, risk evaluation, and strategic deployment of automation solutions across European multimodal freight corridors. It ensures that AUTOSUP innovations are not only technically advanced but also economically sound, environmentally sustainable, and aligned with automated supply chain networks.

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Glossary & Acronyms

Table 0-1: Glossary

TERM	DEFINITION
Cost-Benefit analysis	A systematic quantitative assessment method enables the identification and assessment of long-term financial and environmental consequences of decisions.
Sensitivity indicator	A measure that indicates how responsive a system or process is to changes in certain factors.
Costs of goods sold	The direct cost of producing a service includes the costs of the materials and labor used to create it.
Net Present Value	A financial metric that measures the profitability of an investment by discounting all future cash flows to their present value.
Return on investments	A profitability metric that measures the performance of an investment by comparing its net profit to its cost.
Sensitivity analysis	Analysis of how the CBA results change as an assumption changes.

Table 0-2: List of Acronyms

ACRONYM	DEFINITION
CBA	Cost-Benefit analysis
DSS	Decision support system
SI	Sensitivity indicator
COGS	Costs of goods sold
NPV	Net Present Value
ROI	Return on investments
UC	Use Case
T	Task
ST	Sub-task
D	Deliverable
SC	Supply chain
POC	Proof-of-concept

1 Introduction

Deliverable D3.2 is part of Work Package 3 "WP3 New Operational Models for Automation-driven Multimodal Freight Transport validated in Living Hubs," and represents the final output of Task 3.1 "T3.1 Cost Benefit Analysis (CBA) - Strategies to reduce the investment cost". This task examines the financial feasibility and strategic alignment of the Living Hubs use cases through a Cost-Benefit Analysis (CBA). The CBA calculations will be based on the scope and objectives of the use cases as defined in tasks T1.3, T2.1, and T2.2. The CBA identifies and quantifies the potential benefits from the adoption of automation technologies and innovations in multimodal hubs and networks of port of Trieste and Antwerp-Bruges such as a) improved efficiency - reduced transit times, optimized routing, streamlined operations; b) cost savings - lower transportation costs, reduced inventory holding costs; c) increased throughput - higher capacity utilization, faster turnaround times, d) enhanced connectivity to transportation modes, e) environmental impact - reduced emissions, energy savings. The next step is assigning monetary values to costs and benefits by estimating expenses based on market research, vendor quotes, and historical data.

The CBA modelling process will involve methodological steps as follows: a) the definition of the cost parameters pertinent to automation investments per mode and node (on-site technologies, operations centers as well as process automation), indicating a range of values in line with global market trends, b) this input is tailored per use case with real-world data obtained from recorded offers to logistics service providers, port authorities and carriers from automation service providers. The costs associated with establishing and operating the multimodal hub scenario have been estimated, including a) infrastructure development or modifications - construction, new land acquisition, facilities, equipment, b) technology and automation - automated systems, sensors, robotics, software, c) labor - employee training, d) regulatory compliance - Permits, licenses, legal fees, e) maintenance and upkeep - upgrades, replacement, f) energy and utilities -electricity, water, heating, cooling, g) operating expenses - administrative costs, insurance, taxes. Qualitative KPIs will be estimated using projections and industry benchmarks. The Net Present Value (NPV) and Return on Investment (ROI) indicators have been calculated. Non-monetary factors, such as strategic benefits and long-term sustainability, have also been considered.

Further in the project, the CBA model will be used in autonomous SCs feasibility analysis and decision-support systems. The CBA model will be generalized and integrated into the AUTOSUP DSS to reflect sub-task 3.1.2, "ST3.1.2 CBA Model Generalisation and Sensitivity Analysis", enabling the performance of sensitivity analysis to assess the impact of changes in variables (such as costs, benefits, or external factors) on the analysis.

1.1 Addressing the AUTOSUP Description of Action

This table describes how the deliverable aligns with the work package and task requirements, specifically how it addresses the deliverable and relevant task requirements outlined in the GA.

Table 1-1: Mapping the work package and task requirements

AUTOSUP GA Item/Requirement	Description of the item/requirement	Deliverable chapter(s)	Brief description
D3.1 Cost-benefit analysis	CBA analysis examining the feasibility of multimodal logistics operational automation models for	Chapters 1, 2	These chapters present generalised CBA model - methodological framework for evaluating

	freight logistics innovators and financial sustainability.		the financial, operational, and environmental impacts of automation solutions implemented in multimodal freight transport hubs.
ST3.1.1 Cost-Benefit Analysis (CBA) per use case	Perform a cost-benefit analysis for the multimodal hub use cases to evaluate the potential costs and benefits of establishing and operating automated hubs and SCs. The analysis will support decision-makers in assessing whether the benefits outweigh the costs and whether the investment is financially viable.	Chapters 3, 4, 5, 6, 7, 8	These chapters present the CBA results for six Use Cases by identifying and quantifying the potential benefits of adopting automation technologies and innovations in multimodal hubs.
ST3.1.2 CBA Model Generalisation and Sensitivity Analysis	The CBA model will be generalised and integrated into the DSS to perform sensitivity analysis, assessing the impact of changes in variables (such as costs, benefits, or other external factors) on the analysis.	Chapter 9	This chapter supports DSS and presents the integration of the CBA model components into DSS.

1.2 Overview and Structure of the Document

The document consists of ten chapters. The second chapter presents the CBA Conceptual model. The third-eight chapters present the CBA analysis for six Use Cases:

UC1 [Trieste]	**Automated maintenance and management of intermodal rail wagons**
UC2 [Trieste]	**Automated management of multimodal slots and last-mile routes**
UC3 [Trieste]	**Automated cross-border roll-on/roll-off (Ro-Ro) transhipment**
UC1 (UC4) [AB]	**Port automations coordination and environmental performance**
UC2 (UC5) [AB]	**Port-Shipper collaboration towards increased modal shift**
UC3 (UC6) [AB]	**Port – Transport Mode Automation-systems integration**

For each Use Case, CBA analysis is presented using Use case objectives and scope, Innovation components to be implemented (physical infrastructure, software, hardware, etc.), Cost estimates (related to investments, operational), Revenue estimates (services, demand, pricing) for wider impact (optional), Financial analysis, Environmental considerations, and Sensitivity analysis. The document concludes with CBA generalization and integration in the DSS (Chapter 9), conclusions and a description of future work (Chapter 10), and annexes.

2 CBA logic model for impact evaluation

2.1 General principles

The adoption of automation in multimodal freight transport represents a strategic transition from traditional, labour-intensive operations to digitally integrated, autonomous, and data-driven logistics networks. However, such a transition involves complex investment decisions, multiple stakeholders, and long-term impacts that extend beyond immediate financial returns. The application of Cost-Benefit Analysis (CBA) provides a structured and transparent methodology to evaluate the overall feasibility, efficiency, and sustainability of automation-based innovations within the AUTOSUP Living Hubs (L-Hubs).

Automation solutions, such as predictive maintenance, automated slot management, and digital decision-support platforms, require significant upfront investment in technology, infrastructure adaptation, and training. The rationale for CBA is grounded in its incremental assessment approach, comparing the baseline (AS IS) condition of current logistics operations with the projected (TO BE) condition enabled by automation.

This allows stakeholders to isolate the marginal benefits attributable solely to automation, such as faster transshipment, reduced idle times, or enhanced reliability, while controlling external factors.

The approach ensures that automation impacts are measurable, verifiable, and transferable, enabling a realistic understanding of potential performance improvements at the system level (e.g., port-terminal, transport corridor, or delivery chain).

The CBA impact assessment from the project time horizon perspective has been conducted up to the 18th month of the project, including a period for sufficient data generation to evaluate costs against benefits properly.

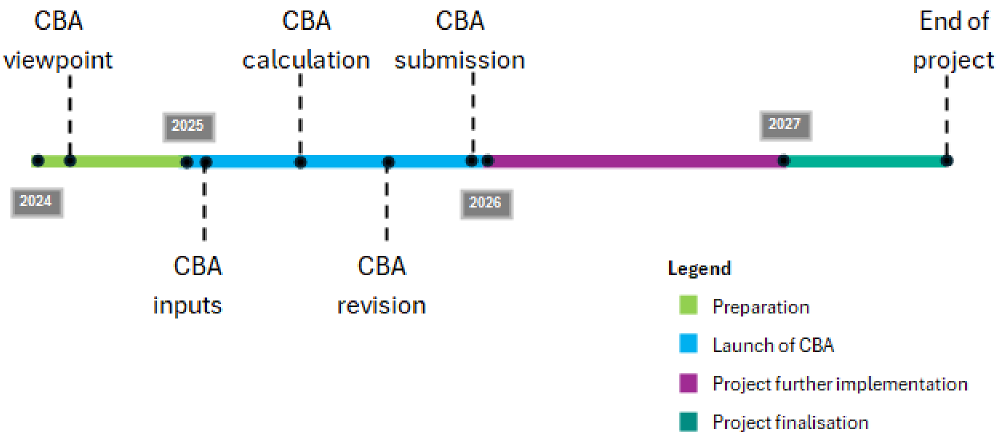


Figure 2-1: Timeline

Three phases can be highlighted in the time horizon:

- A preparation phase, which includes investigation activities. It started and continued in 2024.
- A launch and start-up phase. It occurs in 2025, when AUTOSUP is testing use cases.

- The project's further implementation phase will span from 2026 to the project's completion.

Table 2-1 visualizes the added value of AUTOSUP in a scenario without it. Column 1 of Table 2-1 reports the magnitude of the impact, Column 2 shows the associated costs and benefits, and Column 3 shows the theoretical added value for each magnitude of the impact. The latter, the more integrated and coordinated the service offered (thus the effect of decreasing the cost of access), the higher the efficiency gain in terms of avoided costs (either time or financial cost savings) generated by AUTOSUP. Of course, the added value is also maximum when permission to access is reached, and users request to expand the services further to maximize benefits.

Beyond the calculation of the efficiency gain, the added value of AUTOSUP is also linked to the number of users it will be able to attract. Accordingly, Column 4 of Table 2-1 reports the number of users influenced. It is also expected that some users' experience will be small or null because they will not access the solutions; otherwise, no services will be provided without solutions presented in the use cases accessibility.

All other services (e.g., integration, data collection, training, testing, etc.) are new as compared to a situation without AUTOSUP, so in this case, the base scenario is a 'do nothing' scenario, i.e., the impact of these greenfield services is entirely attributable to AUTOSUP.

The analysis adopts an incremental approach, i.e., it compares a scenario with the project (TO BE Scenario) against a base scenario without the project (AS IS Scenario). The 'what if' assumptions allow us to calculate the concrete impacts of the project.

Table 2-1: Base scenario: the added value of AUTOSUP

Net impact	Costs and benefits	Added value (AUTOSUP - Base scenario)	% of users by type of impact	
			TRIESTE	ANTWERP – BRUGES
Null	$B_U = B_A$ $C_U = C_A$	$(B_U - C_U) – (B_A - C_A) = 0$	50%	50%
Medium-low	$B_U > B_A$ $C_U = C_A$	$(B_U - C_U) – (B_A - C_A) = (B_U - B_A) = X$ $X>0$	25%	25 %
Medium-high	$B_U > B_A$ $C_U < C_A$	$(B_U - C_U) – (B_A - C_A) = Y$ $Y>X$	15%	15%
High	$B_{UI} > B_A$ $C_U < C_A$	$(B_{UI} - C_U) – (B_A - C_A) = Z$ $Z>Y$	10%	10%
TOTAL			**100%**	**100%**

Source: experts' insights. B_U – benefits of AUTOSUP; B_{UI} – benefits of AUTOSUP generated by integrated access; B_A – benefits of base scenario; C_U – costs of AUTOSUP; C_A – costs of base scenario; Z, Y, X – added value.

The level of integration, along with the improvement of services, will create added value for AUTOSUP. This report distinguishes six Use Cases reflecting six aspects of impact. Each impact is associated with a specific use case-based scenario.

2.2 Key assumptions

Future values must be forecasted according to realistic considerations:

- The time horizon of the CBA spans from 2025 (i.e., the base year, including the number of years required for technology implementation) up to the reference period corresponding to the project's economic life.
- Future monetary flows are discounted using a financial discount rate of 4% (European Commission, 2021). For discounting purposes, we assume that the discount rate remains stable over the reference period.
- Sensitivity analysis follows a 20 % variation of inputs test seeking to revise if an increase of inputs by 20 % does not mean that NPV is equal to zero, showing that the project is too risky (European Union, "2015).
  We will use a sensitivity indicator for sensitivity analysis, which description is presented in the table below.

Table 2-2: Use of Sensitivity Indicator

Key aspects	Explanation of the sensitivity indicator (SI)
Definition	Towards the Net Present Value Compares percentage change in NPV with percentage change in a variable or combination of variables.
Expression	Towards the Net Present Value $SI = \frac{(NPVb - NPV1) / NPVb}{(Xb - X1) / Xb}$ where: Xb – value of variable in the base case X1 – value of the variable in the sensitivity test NPVb – value of NPV in the base case NPV1 – value of the variable in the sensitivity test
Interpretation	Percentage change in NPV, respectively
Characteristic	Indicates which variables the project result is or is not sensitive to and suggests further examination of the change in the variable.

When projecting future values, it is always sensible to consider the inherent uncertainty of the exercise. For this reason, a realistic scenario has been identified to forecast future costs and benefits. A scenario analysis is then performed to assess how the alternative future developments of AUTOSUP can impact the future performance of Trieste and Antwerp-Bruges Hubs.

AUTOSUP Living Hubs' partners validate the costs and values used to calculate benefits (e.g., the number of users), considering scenarios discussed in depth with AUTOSUP management and the project partners at several meetings. The next sections present the realistic scenario's costs and benefits (impact).

As the project includes assets with varying lifespans, we set the reference period as the value-weighted average lifetime of these assets, which will be provided in Table 1 presented in each Use Case description.

2.3 Conceptual model

CBA conceptual model is developed for impact evaluation to assess how AUTOSUP innovations generate measurable financial, operational, and environmental value. It ensures that every automation initiative is evaluated within a consistent, evidence-based framework, connecting the technical performance of the Living Hubs. The model translates technological interventions within the Living Hubs into quantifiable impacts through a structured sequence of analytical stages.

Inputs feed into operational activities, describing how AUTOSUP innovations are applied, including:

- Installation, integration, and testing of automation systems
- Operational reconfiguration within terminals and intermodal nodes
- Digitalisation of data exchange and coordination between stakeholders

This stage captures the transition from baseline (AS IS) to automated (TO BE) conditions, forming the basis for incremental analysis. Outputs translate into medium and long-term outcomes, measured through:

- Financial effects: lower transportation and maintenance costs, and improved asset utilization
- Operational effects include a modal shift from road to rail and improved services
- Environmental effects: reduced CO_2 emissions, lower fuel and energy consumption, and improved air quality.

The environmental outcomes are monetized using EU-standard appraisal tools (e.g., Economic Appraisal Vademecum 2021-2027) and other guidebooks.

Figure 2-2 summarises the cost-benefit logic model used to evaluate AUTOSUP 6 Use Cases. Starting from key input indicators (left-hand side), such as the number of assets, transactions, trips, distances, and baseline/what-if scenarios with fuel and energy prices.

On the costs side, cost categories were selected to reflect both capital and operating expenditures. The core activities generate three main cost blocks: (i) upfront investments and one-time implementation costs, (ii) data collection and transmission costs, and (iii) technology maintenance and replacement costs.

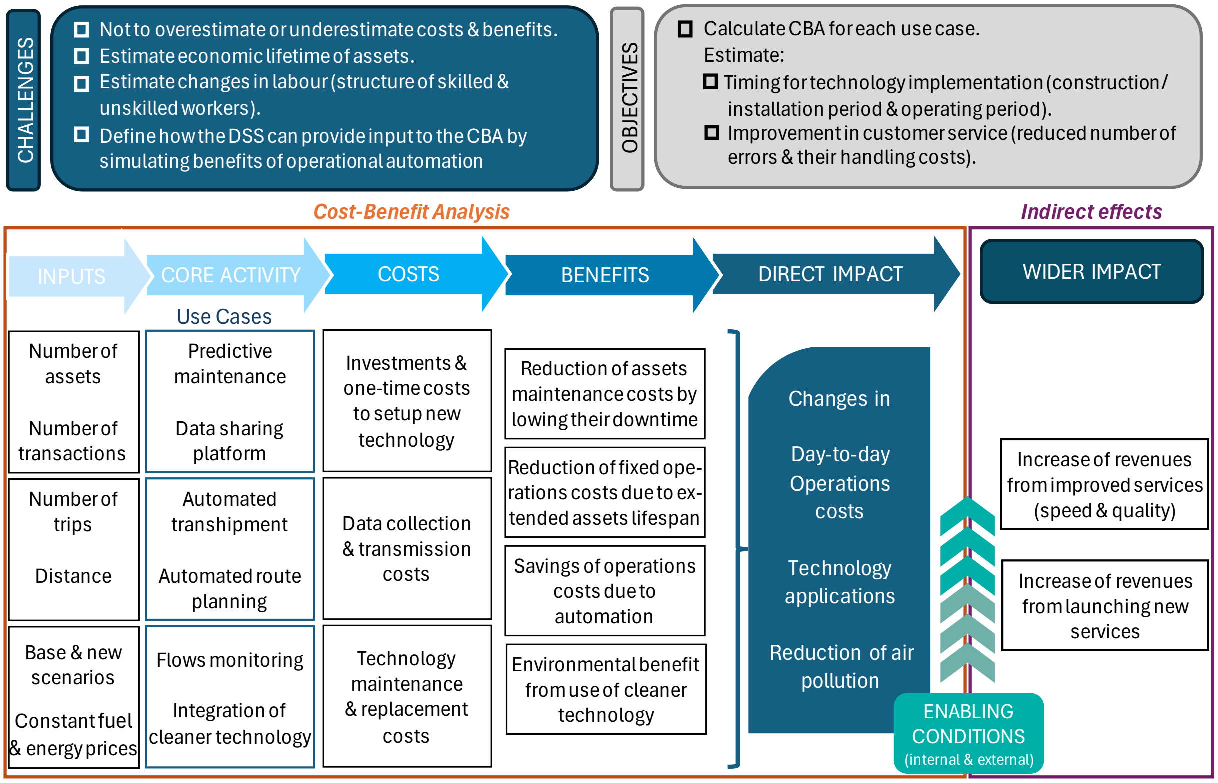
On the benefits side, the Figure 2-2 explicitly captures reductions in asset maintenance costs through lower downtime, reductions in fixed operating costs via extended asset lifetimes, operational savings from automation, and environmental gains from cleaner technologies.

The right-hand side of Figure 2-2 distinguishes between direct impacts and wider impacts/externalities:

- direct impacts are realised as changes in day-to-day operating costs, in the deployment and utilisation of technology applications, and in reduced air pollution,
- wider impacts capture revenue-side effects: higher income from improved service speed and quality and additional revenues from launching new services.

The arrows at the bottom underline that these outcomes materialise only under appropriate internal and external enabling conditions (e.g. regulatory support, organisational readiness, skills).

Together, Figure 2-2 provides a concise visual roadmap from inputs, through costs and benefits, to both direct and wider impacts.



CHALLENGES

- ☐ Not to overestimate or underestimate costs & benefits.
- ☐ Estimate economic lifetime of assets.
- ☐ Estimate changes in labour (structure of skilled & unskilled workers).
- ☐ Define how the DSS can provide input to the CBA by simulating benefits of operational automation

OBJECTIVES

- ☐ Calculate CBA for each use case.

  Estimate:
  - ☐ Timing for technology implementation (construction/ installation period & operating period).
  - ☐ Improvement in customer service (reduced number of errors & their handling costs).

Figure 2-2: CBA logic model for impact evaluation

3 AUTOSUP Use Case 1 (UC1) "Automated maintenance and management of intermodal rail wagons"

3.1 Use Case description

Scope

The first Use Case 1 (UC1) aims to implement predictive maintenance to support rail wagon maintenance needs, bringing the maintenance areas closer to the end users of the wagons by carrying out the widest possible range of activities on-site and avoiding more than one hour of delay for the wagons' technical inspections during the trip. Such would lead to the timely identification of faulty or non-compliant wagons during the train preparation and inspection phase.

Automated maintenance and management of intermodal rail wagons

The UC1 doesn't shift freight transport modes, but rather improves operational efficiency and reduces unnecessary trips, downtime, and emissions caused by faulty wagons. The following Key Assumptions:

- Number of rail wagons managed: 1 000/year
- Unnecessary empty trips per year: 80 wagons
- Average distance per avoided trip: 100 km
- Average wagon load (if in service): 18 tonnes
- Emission factor (rail diesel): 15 gCO_2 per tonne-km (Glec framework, 2023)
- CO_2 cost per tonne: EUR 50

Predictive maintenance will have an internal impact on the Trieste port rail operator.

This transition from reactive management to predictive maintenance supports AUTOSUP's broader goal of enabling automation-driven multimodal integration within Living Hubs. These parameters were used to calculate environmental benefits and fuel/operation reductions from avoided empty movements.

3.2 Innovation components to be implemented (physical infrastructure, software, hardware, etc.)

Based on the selected automation technologies (D1.3) and further analysis, as well as Living Hub's consultation activities, the list of technologies addressed and considered for the CBA is presented in Table 3-1.

Table 3-1: List of technologies for UC1

Technology	Purchase price (EUR)	Life span of technology	Expected technology implementation period (in years)
IoT Sensor Kits for Wagons	300 000 (for 1 000 wagons)	10 years	1 year
Edge Processing Units (Gateways)	150 000	8 years	1 year
Predictive Maintenance Software & Platform License	200 000 (initial setup)	5 years (license cycle)	1 year
Data Analytics & Monitoring	100 000	7 years	1 year
Total/Average	**750 000**	**7,5 years**	**1 year**

Source: investigations of AUTOPSUP (data provided by ARS).

Total Investment costs amount to EUR 750,000 (CAPEX) over 7 full years of the technology's lifespan. These components cover wagon-mounted sensors, track-side units, backend analytics, and diagnostics and maintenance planning software. The system is designed for 1 000 wagons, and implementation is assumed to occur within a 12-month pilot phase.

3.3 Costs and benefits estimates (related to investment, operational)

The total costs of UC1 (including one-time costs of solutions setup are part of the investment phase and yearly costs**)** amount to EUR 795,000 **(at 2025 market prices).** Amounts come from ARS market quotations and historical maintenance/IT support costs.

Table 3-2: Costs for UC1

Costs	Not discounted values (EUR)	Discounted values of 2025 (EUR) for 2026
Sensor Maintenance & Calibration (operational costs, yearly)	10 000	9 615,38
Software License & Support (operational costs, yearly)	20 000	19 230,77
Data Hosting & IT Maintenance (operational costs, yearly)	15 000	14 423,08
Total OPEX (for 2025)	**45 000**	**43 269,23**
Total CAPEX	**750 000**	**721 153,85**
Total Investment (CAPEX + 1y OPEX)	**795 000**	**764 423,08**

Source: Net discounted values are provided using a discount rate of 4 %.

The discount rate is assumed to be 4%, which means Opex will be between EUR 45 000 and EUR 43 269, and the 5-year discount Opex will be EUR 196 442. So, the total discounted cost (investment + 1year Opex, in 2025 values) amounts to EUR 721 153 + EUR 43 269 = EUR 764 423.

Table 3-3: Total benefits for UC1

Impact/benefit	Constant (real) values in 2025 (EUR)
Reduction of operational costs	**324,5 kEUR/year**
Fewer emergency repairs	110 kEUR/year
Fuel/inspection cost reductions	132 kEUR/year
Sensor-driven inspection planning	82,5 kEUR/year
Productivity & Efficiency Gains	**88 kEUR**
Time savings in inspection prep	55 kEUR
Increased wagon uptime/productivity	33 kEUR
Main activity costs reduction	**412,5 kEUR**

Source: ARS data

The total Constant (Real) Value of Benefits (in 2025) is EUR 412 500 per year. At the same time, the share of Operational Cost Reduction in Total Benefit is EUR 324 500/EUR 412 500 ≈ 78,6%. Finally, the primary benefit of the Use Case 1 (UC1) is operational cost reduction, which accounts for over 78% of the total impact value.

The following assumptions drive the estimate of 412 500 EUR/year in operational savings:

- Reduction of emergency repairs: Based on ARS data, emergency interventions cost about 1.375 EURper wagon * predictive maintenance avoids approx. 80 interventions equal to 110 000 EUR/year saved
- Fuel and inspection savings: No train repositioning for faulty wagons, based on 100 km avoided trips equal to 132 000 EUR/year
- Sensor-driven planning efficiency: Reduced manual inspection hours, it has been assumed 2 hours saved/day * 330 days * 125 EUR/operational hour equal to 82 500 EUR/year
- Increased wagon uptime: Minor, but quantified at 33 000 EUR based on 1–2% improved availability
- Inspection preparation time savings: Shorter prep time for daily departures about 55 000 EUR/year.

3.4 Revenue estimates (services, demand, pricing) for wider impact

The success of UC1 could lead to increased revenues from services, which depend on factors determining both the supply side and demand side. **The demand analysis of UC1 aims to estimate the number of future users of the Hub-provided service.** Table 3-4 presents the forecasts of additional sales per year resulting from the implementation of automated transshipment management at full capacity, i.e., from 2028 onwards.

Table 3-4: The changes in demand for UC1

Increase in demand	Realistic scenario (EUR)	Net revenue (EUR)
Additional revenue from new customers (improved reliability/ availability)	120 kEUR	93 kEUR
Higher fees for premium predictive-maintenance-enabled services	80 kEUR	62 kEUR
Extra sales	**200** kEUR	**155 kEUR**

Source: ARS data. Yearly values are expressed in nominal values.

Starting with the revenues, the cost-of-service provision has been accounted for to assess the profitability. COGS include technology investment, maintenance and operational, staff and automation labor, energy, and IT infrastructure. Net Revenue is Gross Revenue - COGS, as such EUR 200 000 - Operational COGS EUR 45 000. Net Revenue is EUR 155 000 and Net Margin ≈ 77,5%. So, the net Annual Benefit from 2028 onward (37,6 kEUR of Savings + 155 kEUR of Revenues - 45 kEUR of Operational Costs) is 147,6 kEUR. Finally, the modest environmental savings improve European legislative compliance and corporate brand image.

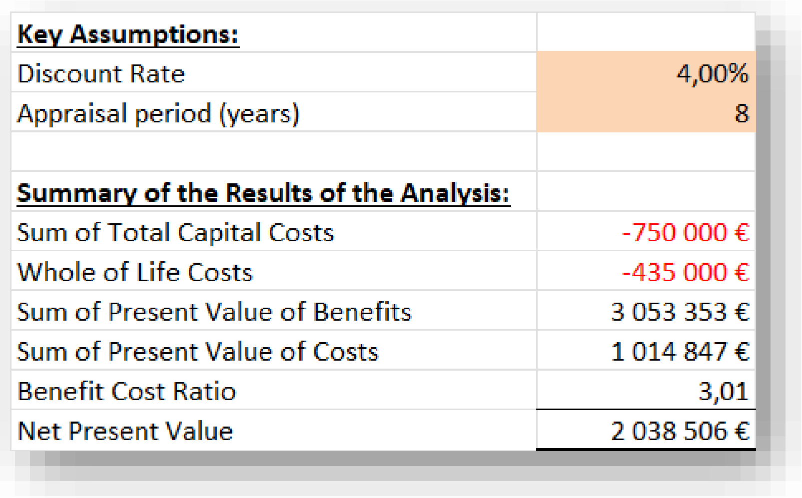
3.5 Financial analysis

Use Case 1 (UC1):

- Technologies – EUR 750 000 (with a life span – 5 years & implementation – 1 year)
- OPEX – EUR 45 000/year.
- Benefits – EUR 412 500/year.
- Increase in Net revenue from year 2028 – EUR 155 000/year.

Results

In the CBA calculator, one year is planned for technology implementation, and 7 years are planned for technology usage.



Key Assumptions:	
Discount Rate	4,00%
Appraisal period (years)	8
Summary of the Results of the Analysis:	
Sum of Total Capital Costs	-750 000 €
Whole of Life Costs	-435 000 €
Sum of Present Value of Benefits	3 053 353 €
Sum of Present Value of Costs	1 014 847 €
Benefit Cost Ratio	3,01
Net Present Value	2 038 506 €

Figure 3-1: Summary of financial analysis data

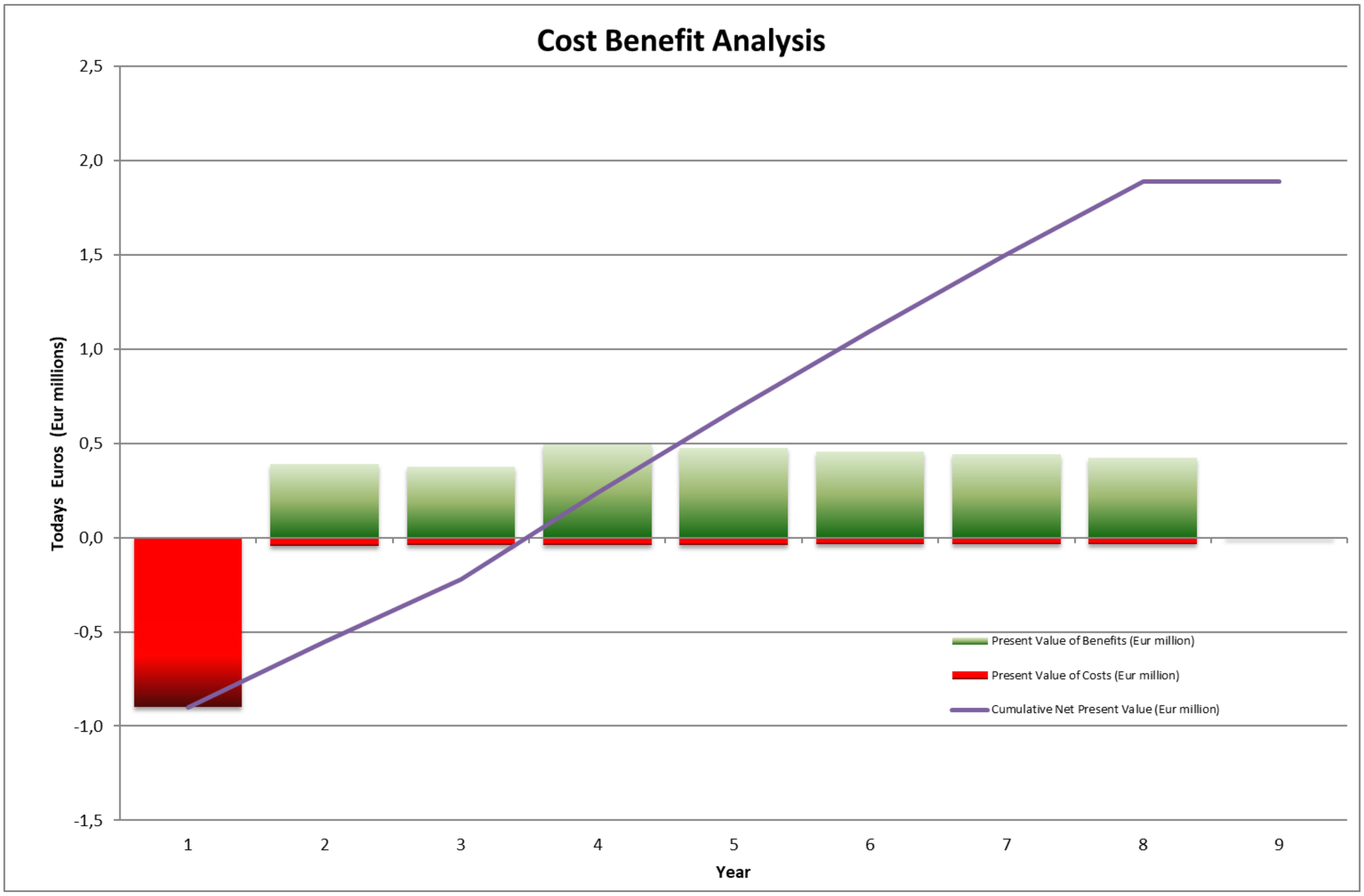


Figure 3-2: Changes of Present Values over time

The cumulative net present value indicates that investments in technology are not recouped during the years of technology usage.

Profitability on investment analysis

ROI metric used to evaluate the forecasted profitability of different investments.

$$\text{ROI}_{\%} = \frac{\text{Annual Net benefits}}{\text{Initial value of investments}} \times 100$$

Where:
Initial value of investments – EUR750 000
Annual costs – EUR45 000
Annual benefits – EUR412 500
Annual Net benefits – EUR367 500

ROI = (367 500 / 750 000) x 100.

ROI = 49 %

Using this equation, the return on investment comes out to 49%.

3.6 Environmental considerations

Further on, the environmental benefits are presented. Environmental benefits are calculated based on the description provided in Annex A I.

Predictive maintenance avoids unnecessary wagon movements and reduces inefficient wagon handling (e.g., empty runs or faulty equipment recirculation). Below is a sample calculation per diagnostic vehicle or intervention unit (used for inspections and predictive diagnostics).

Table 3-5: Data for the calculation of Environmental benefits for UC1

	Rail Movement Avoidance (via Predictive Diagnostics)
Avoided unnecessary empty or faulty wagon trips/year	880 wagons
Average km per wagon-trip avoided	100 km
Weight per wagon	18 t
Total km avoided	880 × 100 km = 88 000 km
Total t-km avoided	88 000 km × 18 t = 1 584 000 t-km
CO_2 per t-km by freight rail	15 gCO_2/t-km (for electric rail, average)
Total CO_2 avoided per year	1 584 000 t-km × 15 g/t-km = 23 760 000 g = 23,76 t

Source: ARS data for operational inputs, Glec framework (2023), Annex 4, Table 4 for 15 gCO_2/t-km (electric rail average) input.

Effect on transport user

Summary of Environmental Impacts of the Use Case 1 (UC1) per year: the avoided rail Wagon Movements mean a saving of 23,16 t (EUR1 188 monetized benefit). Values are conservative and based on a single mobile unit and current EU carbon cost benchmarks (EUR50/t), as provided by Adriafer Rail Services (ARS).

Environmental Impact Justification: The predictive maintenance reduces emergency interventions, unnecessary wagon movements, and idle train time, which leads to:

- Reduced empty runs,
- Increased energy efficiency per tonne-km moved.

Calculation Basis:

- Estimated annual CO_2 savings: 23,76 t CO_2
- Carbon cost (social cost, conservative average): EUR50/t CO_2 (ARS data)
- Resulting impact: 23,76 t × EUR50 = EUR1 188/year

The methodology follows the EU standard external cost methodology (e.g., Handbook on the External Costs of Transport, EC DG MOVE).

Externalities

Externalities are spillover effects from the project towards third parties (neither consumers nor producers), for which no monetary compensation is provided. Examples are environmental effects (air pollution).

The air pollution multiplier (2021) was 2,78 EUR/km for Electric rail (Greece case) (DG REGIO, 2021).

Monetized savings for air pollution are achieved after the implementation of selected automatisation technologies (88 000 km are saved):

88 000 km x 2,78 EUR/km = 244 640 kEUR saved

The effect on externalities is positive and equal to EUR244 640 per year.

Externality (air pollution) reductions use EU DG REGIO multiplier for electric rail: 2.78 EUR/km, giving: 88,000 km × 2.78 EUR/km ≈ 244,640 EUR/year.

Environmental externalities lead to reduced emissions or energy savings, these environmental benefits (valued at societal prices, such as the EU carbon price for CO_2 reduction) would be quantified on the benefit side. These environmental gains through shadow pricing of externalities ensure that the automation delivers net positive welfare for society at large.

Summary

Input	Input's value	Multiplicator	Multiplicator's value	Comment and source
Saved t-km (avoided empty runs)	1 584 000 t-km	For scope 1	15 g CO2/t-km	Electric rail, average value (Glec framework, Annex4, Table 4)
Tonnes of CO2 avoided	23,76 t CO2	Shadow cost for carbon in Euro	50 Eur/ t CO2	Provided by ARS
Externalities for air pollution per year	88 000 km avoided	For air pollution rail type	2,78 Eur/km	Calculation sheet of DG REGIO (2021) (Greece case) for electric rail

3.7 Sensitivity analysis

Analysis of how changes in inputs affect changes in output (NPV)

The sensitivity of the base case NPV has been analyzed following changes (which were specified in chapter 2.2) of several key variables, as follows:

1. an increase in technology purchase costs of 20 %
2. a decrease in benefits by 20 %
3. an increase in costs by 20 %
4. a delay in the implementation period, causing a delay in benefits generation by one year.

Proposed changes in key variables should be well-explained. The sensitivity analysis is based on the most likely changes. The effects of the above changes are summarized in the table below.

Table 3-6: Results of sensitivity analysis for UC1

Item	**Change**	**NPV1** (EUR)	**SI(NPV1)**
Base Case		2 038 506	
Purchase costs of technology	20 % Xb – 750 000, X1 – 900 000	1 888 506	-0,368
Benefits	-20 % Xb – 412 500, X1 – 330 000	1 552 952	1,191
Annual costs	20 % Xb – 45 000, X1 – 54 000	1 985 536	-0,130
Implementation delay	One year Xb – 412 500, X1 – 0	1 649 573	0,191
SI – sensitivity indicator, NPV – net present value			

The higher the absolute value of the SI, the more sensitive the NPV is to the change in the variable concerned. NPV1 simultaneously declined in all cases. The worst-case scenario among the four key variables of the sensitivity analysis is observed in the second variable change case.

Regarding the 20 % increase in technology purchase costs, the sensitivity indicator (SI) is -0,368. This means that a 20% change in the variable (purchase costs) results in a 7 % change (reduction) in the NPV.

The highest sensitivity indicator is in the reduction of benefits by 20 % case. Regarding the 20 % reduction in benefits, the sensitivity indicator (SI) is 1,191. This means that the change of 20 % in the variable (benefits) results in a change (reduction) of 24 % in the NPV1.

In the event of a 20 % increase in annual costs, the sensitivity indicator (SI) is -0,130. This means that the change of 20 % in annual costs results in a change (reduction) of 3 % in the NPV1.

A one-year implementation delay means that benefits will be available one year later. The sensitivity indicator (SI) is 0,191, and NPV1 will decrease by 19 %.

4 AUTOSUP Use Case 2 (UC2) “Automated management of multimodal slots and last-mile routes”

4.1 Use Case description

Scope

Use Case 2 (UC2) aims to automate the management of multimodal slots and last-mile routes along the Trieste-Ambarli corridor. This Use Case 2 (UC2) will address inefficiencies in current logistics processes that heavily depend on manual coordination. The objective of deploying automation and decision support systems is to improve freight handling accuracy, reliability, and speed.

The implementation will also aim to enable scalable automation for first- and last-mile transport and transshipment, including seamless data integration and predictive rerouting in the event of disruptions. The Use Case 2 (UC2) will optimize capacity planning, reduce delays, and enable dynamic, cross-border freight operations through process automation and real-time system communication.

Automated management of multimodal slots and last-mile routes

In the AS IS situation, the multimodal freight transport process managed by Gruber Logistics along the Trieste-Ambarli corridor relies heavily on manual coordination and fragmented planning activities. Shipments originating from industrial areas in Northern Italy are prepared at the shipper’s facilities and transported by road to the Port of Trieste for maritime shipment to Ambarli, near Istanbul.

At both ports, coordination between road and maritime modes is handled through human-mediated exchanges, including phone calls, emails, and spreadsheets, among operators, carriers, and terminal managers. The AS IS results in limited visibility, inefficient slot allocation, and non-optimized routing decisions. The lack of digital integration between Gruber Logistics’ Transportation Management System (TMS) and other stakeholders’ systems (such as Port Community Systems and carriers’ platforms) leads to data fragmentation, duplicated tasks, and inconsistent planning across the logistics chain.

In the envisioned TO BE scenario, Gruber Logistics will implement a Decision Support System (DSS) integrated with its TMS to support strategic and tactical planning of multimodal slots and last-mile operations along the Trieste-Ambarli corridor. Rather than operating in real time, the system focuses on periodic, data-driven planning cycles that enhance coordination, predictability, and resource utilization across modes.

The aimed DSS should enable the strategic allocation of transport resources, such as trucks, vessels, and storage capacity, by integrating data from infrastructure managers, carriers, and port operators. It supports what-if simulations, medium-term scheduling, and demand forecasting to improve multimodal capacity planning. The system helps operators identify optimal transport combinations, estimate lead times, and align logistics plans with port slot availability and carrier timetables.

Through digital integration and advanced analytics, the implemented DSS will reduce the dependency on manual coordination and improve cross-actor synchronization during the planning and operational phases. The automation covers processes such as carrier pre-selection, booking validation, and digital documentation exchange, enabling more consistent and transparent workflows. In contrast to fully real-time dynamic re-routing, the system emphasizes strategic optimization, i.e., improving service reliability, throughput, and overall resource allocation efficiency over extended planning horizons.

By adopting automation technologies and structured decision-support capabilities, Gruber Logistics and its partners will benefit from:

- Improved planning accuracy through better forecasting of transport demand and port capacity utilization.
- Reduced administrative workload, thanks to the automation of slot booking and document exchange.
- Higher operational efficiency, as multimodal operations are better aligned across stakeholders and infrastructure nodes.
- Enhanced service reliability, driven by predictable schedules and proactive coordination mechanisms.

The UC2 solution demonstrates how digital decision-support tools can optimize multimodal freight flows and coordination efficiency without requiring full real-time autonomy, paving the way for scalable and sustainable automation in European logistics corridors.

4.2 Innovation components to be implemented (physical infrastructure, software, hardware, etc.)

Based on the selected automation technologies (D1.3) and further analysis and L-Hub's consultation activities, the list of technologies addressed and considered for the CBA is indicated in Table 4-1:

Table 4-1: List of technologies for UC2

Technology	Purchase price (EUR)	Life span of technology	Expected technology implementation period (in years)
Decision Support System (DSS) software	110 000	7 years	2 years
Integration middleware (API TMS + PCS)	20 000	5 years	1 year
Server infrastructure (cloud setup & maintenance)	25 000	5 years	1 year
Carrier onboarding and user interface tools	15 000	5 years	1 year
Training and support tools	10 000	3 years	1 year
Total/Average	**180 000**	**5,4 years**	**1,2 years**

Source: Gruber Logistics data.

As defined in D1.3, the Decision Support System comprises the Truck Appointment System (TAS) and the Digital Platform for Freight/Autonomous e-Procurement, integrated with TMS and PCS. These components are covered under the investment items for DSS software and API/middleware integration.

The main investments are planned for 180 kEUR with 5 full years of technology lifespan and 1 year dedicated to technology setup. Apart from main investments, yearly maintenance and update costs, presented in Table 4-2, will be relevant during the technology's lifespan period.

4.3 Costs and benefits estimates (related to investment, operational)

Implementing Use Case 2 (UC2) is estimated to require total investment and operational costs of EUR240 000 at 2025 market prices. These include one-time investments in technology, project management, training, and initial operational costs linked to onboarding and testing.

Table 4-2: Costs for UC2

Costs OPEX	Not discounted values (EUR)	Discounted values of 2025 (EUR) for 2026
DSS development and deployment	110 000	105 769
API & middleware integration	20 000	19 230
Server infrastructure (cloud)	25 000	24 038
Training & onboarding	10 000	9 615
Project management (setup phase)	30 000	28 846
Maintenance & update costs (operational costs, yearly)	15 000	14 423
Testing & validation (pilot ops)	30 000	28 846
Total OPEX	**240 000**	**230 769**

Source: Net discounted values are provided using a discount rate of 4 %.

Against its investment-related and operational costs, Use Case 2 (UC2) produces several benefits (positive impact) worth **EUR 125 000 in real value**.

Table 4-3: Total benefits for UC2

Impact/benefit	Constant (real) values in 2025 (EUR)
Reduction of operational costs	75 000
Main activity costs reduction	50 000
Total	**125 000**

Source: Gruber Logistics data, see Annex II.

Automating multimodal coordination and carrier selection is expected to yield a 20-25 % reduction in manual coordination costs, resulting in annual savings of EUR75 000. Additionally, improved activity efficiency is estimated to generate EUR50 000 in service productivity gains, including better routing and carrier utilization following the implementation of the Truck Appointment System.

4.4 Revenue estimates (services, demand, pricing) for wider impact

Implementing the DSS is also expected to contribute to new service streams, including faster service execution and premium rerouting capabilities. This may lead to increased demand from both current and new clients. From 2028 onwards, at full implementation, revenues from improved and new services are expected to grow incrementally.

Table 4-4: The changes in demand for UC2

Increase in demand	Realistic scenario (EUR)
Increase in net revenues from improved services	14 000/year
Increase in net revenues from launching new services	10 500/year
Extra net sales	7 000/year
Total net estimated increase	**31 500/year**

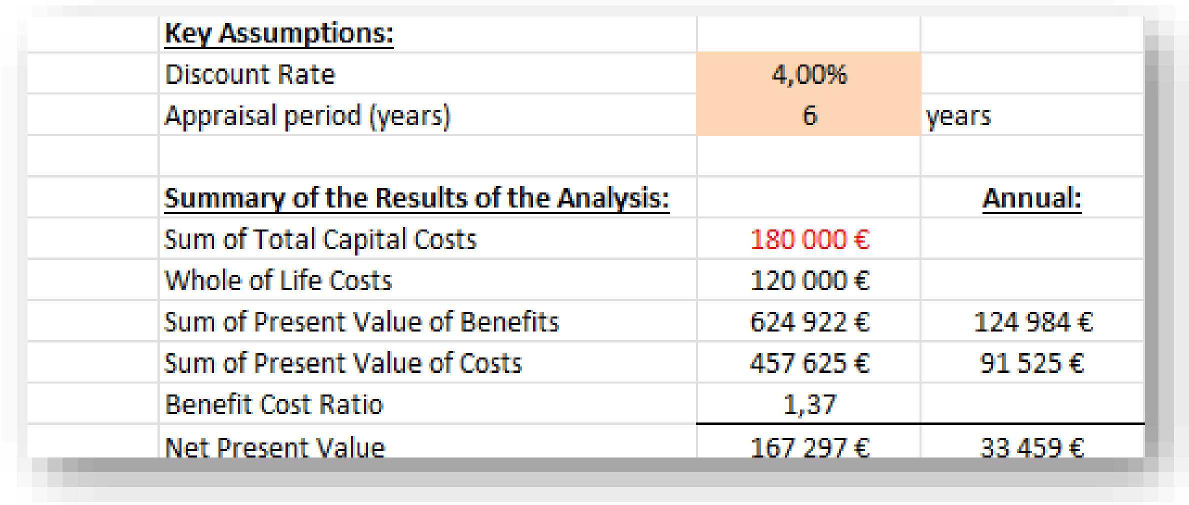
Source: Gruber Logistics data. Yearly values are expressed in nominal values.

4.5 Financial analysis

Use Case 2 (UC2):

- Technologies – EUR180 000 (with life span – 5 years & implementation – 1 year)
- Implementation costs (one-time) – EUR225 000.
- Maintenance costs – EUR15 000/year.
- Benefits – EUR125 000/year.
- Increase in Net revenue from year 2028 – EUR31 500/year.

Results



Key Assumptions:		
Discount Rate	4,00%	
Appraisal period (years)	6	years
Summary of the Results of the Analysis:		**Annual:**
Sum of Total Capital Costs	180 000 €	
Whole of Life Costs	120 000 €	
Sum of Present Value of Benefits	624 922 €	124 984 €
Sum of Present Value of Costs	457 625 €	91 525 €
Benefit Cost Ratio	1,37	
Net Present Value	167 297 €	33 459 €

Figure 4-1: Summary of financial analysis data

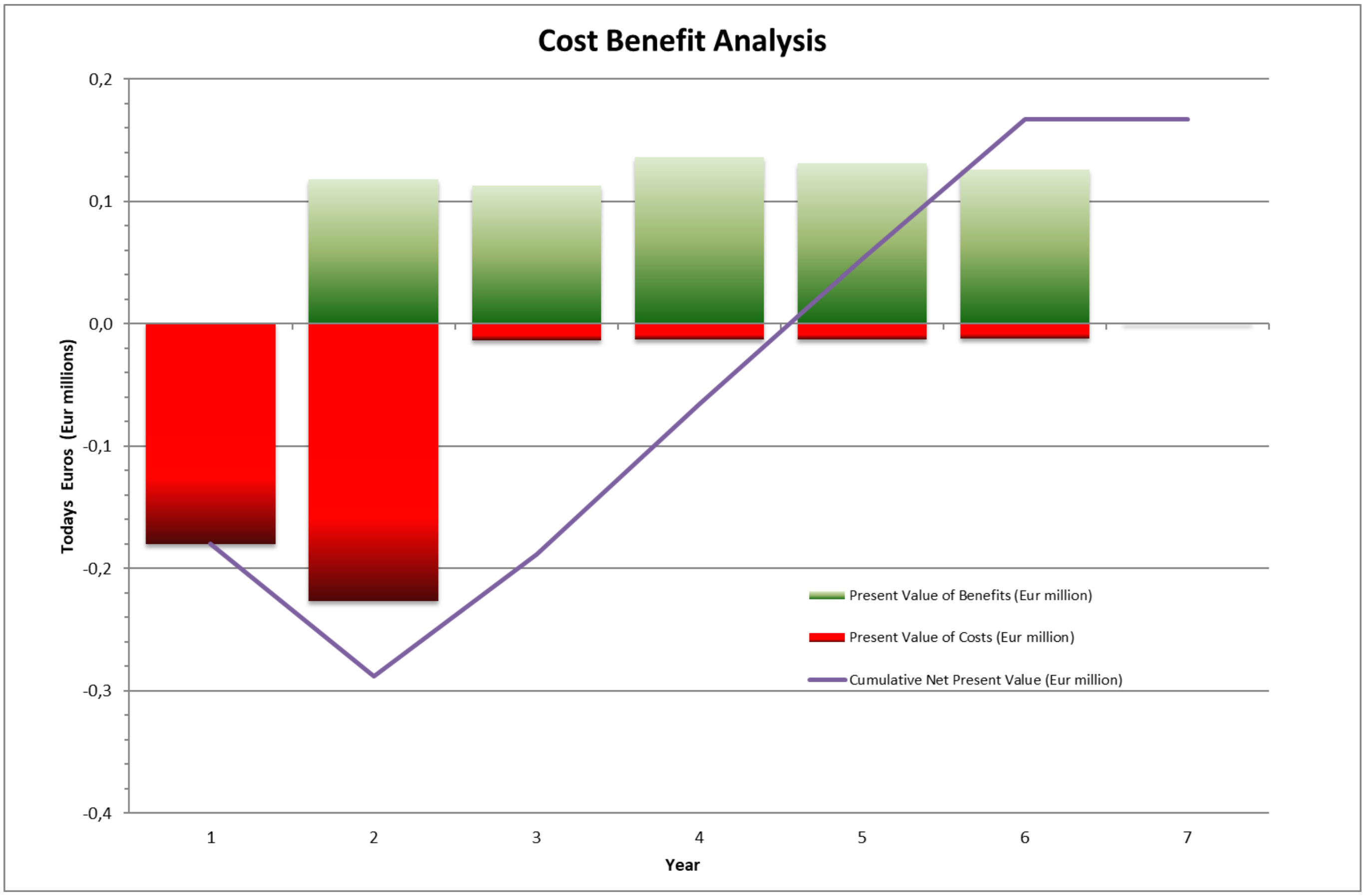


Figure 4-2: Changes of Present Values over time

Cumulative Net Present Value shows that the investments into the set of technologies are paid back during their lifespan period (during the fifth year after the investment start year).

Profitability on investment analysis

ROI metric used to evaluate the forecasted profitability of different investments.

$$\text{ROI}\ \% = \frac{\text{Annual Net benefits}}{\text{Initial value of investments}} \times 100$$

Where:
Initial value of investments – EUR180 000
Annual average costs in present value – EUR91 525
Annual average benefits in present value – EUR124 984
Annual Net benefits (average benefits – average costs) in present value – EUR33 459

ROI = (33 459 / 180 000) x 100.

ROI = 18,59 %

Using this equation, the return on investment comes out to almost 18,6 %.

4.6 Environmental considerations

The shift from manual coordination to automated slot and route management is expected to reduce empty runs and enhance the efficiency of first- and last-mile transport. This optimization contributes to measurable environmental benefits. In the case of AS IS, diesel trucks are used for the first and last-mile legs, resulting in significant fuel consumption per trip. In the TO BE scenario, improved routing and reduced idle time will result in fewer kilometers driven per shipment.

Further on, the environmental benefits are presented. Environmental benefits are calculated based on the description presented in Annex A I. Both pieces of equipment are used for cargo deliveries.

Table 4-5: Data for the calculation of Environmental benefits for UC2

Fuel-based transport equipment	**Equipment1**
Yearly distance with allocated consignment (t-km)	700 000
Yearly distance without allocated consignment (km)	140 000
Average weight of consignment (tonnes/year)	1 800
Type of transport equipment	Rigid truck
Fuel type	Diesel
Avg, CO2 (gCO2/t-km)	90 gCO2/t-km
Cost of CO2 (EUR/tonne)	100 EUR/t
Electrically powered transport equipment	**Equipment2**
Yearly distance (kWh/equipment-km) with allocated consignment	70 000
Yearly distance (kWh/equipment-km) without consignment	10 000

Avg, consignment weight (tonnes/year)	1 800
Electricity consumption per working hour	3,2 kWh
Avg, working hours/month	160
Electricity source, proportion of Hydro and wind 70 %/30 %	Hydro/wind mix
CO2 cost (EUR/tonne)	20 EUR/t

Source: Gruber Logistics data.

Environmental considerations are present through:

a) saved CO2 emissions,
b) benefits for transport user,
c) externalities.

The description is presented below.

Saved CO2 emissions

Rigid trucks and electrically powered deliveries contributed to a reduction in CO2 emissions.

Rigid truck (26-32 t) using diesel generates 90 g CO2e/t-km (source: Glec framework (2023), Table 8, p. 92, TTW case). When annual CO2 emissions are 63 t CO2e:

700 000 t-km x 90 g CO2e/t-km = 63 t CO2e generated

Annual CO_2 emissions for electricity generation for an electricity-powered vehicle:

70 000 kWh x 20,1 g/kWh (when hydro 70 % - 24 g/kWh and wind 30 % – 11 g/kWh) = 1,407 t CO2e generated

10 000 kWh x 20,1 g/kWh (when hydro 70 % - 24 g/kWh and wind 30 % – 11 g/kWh) = 0,201 t CO2e generated

When annual CO2 emissions for electricity generation for an electricity-powered vehicle are 1,608 t CO2e.

The annual savings in CO2 emissions after TMS implementation are reduced by 5 %.

When annual savings for CO2 emissions are:

63 t CO2e x 0,05 = 3,15 t CO2e.

1,608 t CO2e x 0,05 = 0,0804 t CO2e.

Benefits for transport users

The multiplier provided by Gruber Logistics is EUR100/t CO2e.

Monetized savings of transport users:

3,15 t CO2e x 100 EUR/t CO2e = EUR315

0,0804 t CO2e x 20 EUR/t CO2e = EUR1,608

The transport user saves EUR316,60 per year.

Externalities

Externalities are spillover effects from the project towards third parties (neither consumers nor producers), for which no monetary compensation is provided. Examples are environmental effects (air pollution).

The multiplier for air pollution in 2021 for t-km (Greece case) was 0,41 EUR/t-km and 5,81 EUR/km for Heavy goods vehicles using diesel (DG REGIO, 2021).

Monetized savings for air pollution when 5 % savings are achieved after TMS implementation (35 000 t-km and 7 000 km are saved):

700 000 t-km x 0,05 x 0,41 EUR = 14,35 kEUR

140 000 km x 0,05 x 5,81 EUR = 40,67 kEUR

Following DEFRA (2023) report, the latest non-traded carbon price from the Green Book supplementary guidance is 248 GBP / tonne CO2e for 2020, which was applied in this analysis to calculate damage costs (BEIS, 2021).

When 1,000 GBP = EUR1,189, the price is EUR294,96/t CO2e
1,608 t CO2e x 0,05 x EUR294,96/t CO2e = 0,0237 kEUR

Monetized savings for air pollution are 55,02 kEUR/year.

Environmental externalities lead to reduced emissions or energy savings, these environmental benefits (valued at societal prices, such as the EU carbon price for CO_2 reduction) would be quantified on the benefit side. These environmental gains through shadow pricing of externalities ensure that the automation delivers net positive welfare for society at large.

Summary

Input	Input's value	Multiplicator	Multiplicator's value	Comment and source
Saved km for rigit truck	5%	For scope 1	90 g CO2/t-km	Rigid truck (20-26 t) using diesel
Saved km for electric vehicle	5%	For scope 1	20,1 g CO2/kWh	Electricity powered vehicle. Calculated using Quora (2024) values, when for electricity generation 70% hydro & 30% wind sources are used in UC2 case.
Tonnes of CO2 avoided	3,15 t CO2 1,608 t CO2	Shadow cost for carbon in Euro	100 Eur/ t CO2 20 Eur/ t CO2	Provided by Gruber Logistics for diesel rigit truck and electricity-equiped vehicle.
Saved km for road case	35 000 t-km 7 000 km 0,08 t CO2	For air pollution & vehicle type	0,41 Eur/t-km 5,81 Eur/km 294,96 Eur/t CO2	Calculation sheet of DG REGIO (2021) (Greece case) for Heavy goods vehicle and BEIS (2021) for electricity generation.

4.7 Sensitivity analysis

Analysis of how changes in inputs affect changes in output (NPV)

The sensitivity of the base case NPV has been analyzed following changes (which were specified in chapter 2.2) in several key variables, as follows:

1. an increase in technology purchase costs of 20 %
2. a decrease in benefits by 20 %

3. an increase in maintenance costs by 20 %
4. a delay in the implementation period, causing a delay in benefits generation by one year.

Proposed changes in key variables should be well-explained. The sensitivity analysis is based on the most likely changes. The effects of the above changes are summarized in the table below.

Table 4-6: Results of sensitivity analysis for UC2

Item	**Change**	**NPV1** (EUR)	**SI(NPV1)**
Base Case		167 297	
Purchase costs of technologies	20 % Xb – 180 000, X1 – 216 000	131 297	-1,076
Benefits	-20 % Xb – 125 000, X1 – 100 000	58 163	3,262
Maintenance costs	20 % Xb – 15 000, X1 – 18 000	154 201	-0,391
Implementation delay	One year Xb – 125 000, X1 – 0	49 439	0,704
SI – sensitivity indicator, NPV – net present value			

The higher the SI, the more sensitive the NPV is to the change in the variable concerned. NPV1 simultaneously declined in all cases.

The worst-case scenario among the four key variables considered in the sensitivity analysis is observed in the second variable change case.

Regarding the 20 % increase in technology purchase costs, the sensitivity indicator (SI) is -1,076. This means that a 20 % change in the variable (purchase costs of technologies) results in a 22 % change (reduction) in NPV1.

The highest sensitivity indicator is a 20 % reduction in benefits, as seen in the case. Regarding the 20 % reduction in benefits, the sensitivity indicator (SI) is 3,262. This means that the change of 20 % in the variable (benefits) results in a change (reduction) of 65 % in the NPV1.

In the case of an annual cost increase of 20 %, the sensitivity indicator (SI) is -0.391. This means that a 20 % change in annual costs results in an 8 % change (reduction) in the NPV1.

A one-year implementation delay means that benefits will be available one year later. The sensitivity indicator (SI) is 0,704, and NPV1 will decrease by 70 %.

5 AUTOSUP Use Case 3 (UC3) “Automated cross-border roll-on/roll-off (Ro-Ro) transhipment”

5.1 Use Case description

Scope

The Use Case 3 (UC3) aims to transition to rail transport instead of road, supporting sustainability and efficiency goals. Automated solutions can handle loading and unloading much more quickly; entire trains can be processed in about 20 minutes, reducing overall transit times for origin-destination (O-D) connections. By shifting traffic from road to rail and optimizing operations, overall emissions across O-D pairs are lowered, contributing to environmental goals.

Automated cross-border roll-on/roll-off (Ro-Ro) transhipment

In the AS-IS scenario, Gorizia primarily conducts road-to-road transport operations, focusing on traffic flows to/from Eastern Europe and the Balkans. Very few multimodal road-rail activities are currently in place. As a result, opportunities to shift road traffic towards rail on selected connections (O-D pairs) are currently lost.

The AS IS business processes can be described as follows:

- Trailers are attached to trucks’ tractors at the origin.
- Trailers are transported by road (trucks).
- Trailers are unloaded at the destination for local distribution logistics (possibly, using some transit points).

In the TO BE scenario, the Gorizia hub will adopt innovative automation technologies, such as horizontal transhipment, to optimize road-to-rail freight loading. This will enable the shift of road traffic from the port of Trieste to rail on selected connections within the Gorizia hub and on the Domodossola-Kaldenkirchen route. DACs and rail wagons equipped to handle semi-trailers will be used. Provided that a critical mass of flows already exists from the port to the final destination, the hub will employ automation technologies that enable the horizontal movement of trailers from trucks to rail wagons, thereby reducing the carbon footprint of trailers on the road and avoiding large investments in the terminal, such as gantry cranes.

The solution utilizes a minimal amount of terminal area and does not require significant investments in infrastructure. Trailers can be either traditional or non-crane (to note that most trailers on the market are not craneable). Road-rail operations will be faster, simpler, and more flexible than those performed by gantry cranes/transtainers. Using these technologies, when arriving at the hub, the trailer is detached from its tractor, temporarily parked, and then moved to the railcar.

This Use Case 3 (UC3) will focus on experimentation with potential improvements: (a) enhancing integration of the rail networks to extend capacity planning and operation, enabling capacity optimization and automatic management of cross-border traffic; (b) delivering scalable automation in train operations with fully unattended train operations including loading and unloading of semitrailers; (c) increasing capacity for all types of rail freight transport (e.g., with Digital Automatic Coupler), improving cross-border multimodal services. In this Use Case, the Trieste port infrastructure will provide certain benefits, which will be realised as output through process automation.

Assumptions & Basis for Monetary Value Estimation related to the Modal Shift Parameters:
- Road-to-rail modal shift: approx. 42 million t-km/year moved from road to rail
- Emission factors used: Road (diesel truck): 90 gCO_2/t-km; Electric rail: 15 gCO_2/t-km; Net savings: 75 gCO_2/t-km
- Cost of CO_2: 50 EUR/t

These values drive the CO_2 and air pollution savings.

5.2 Innovation components to be implemented (physical infrastructure, software, hardware, etc.)

Based on the selected automation technologies (D1.3) and further analysis, as well as Living Hub's consultation activities, the list of planned technologies addressed and considered for the CBA is indicated in Table 5-1. The exact number of investments is specified in Table 5-2, under the total CAPEX line.

Table 5-1: List of planned technologies for UC3

Technology	Purchase price (EUR)	Life span of technology	Expected technology implementation period (in years)
The Horizontal Transshipment System (HTS) enables the horizontal movement of semi-trailers from trucks to rail wagons, eliminating the need for large gantry cranes and allowing for faster and more efficient transshipment.	4 MEUR	20 years	2 years
The Digital Automatic Coupler (DAC) automates the coupling and uncoupling of rail wagons, improving efficiency in train operations and cross-border multimodal services. 50 railcars are planned to be implemented.	20 kEUR/railcar+ 100 kEUR for installation & setup, i.e., 1,1 MEUR	30 years	2 years
The Automated Terminal Operating System (TOS) is a software-driven automation system designed to manage freight movements, optimize capacity utilization, and enhance real-time logistics coordination.	1,2 MEUR	10 years (with updates)	2 years
Driverless Automated Guided Vehicles (AGVs) for Trailer Handling	350 kEUR/AGV+ 300 kEUR for	10 years	2 years

will transport semi-trailers within the terminal for optimized loading and unloading processes. 4 AGVs are planned to be implemented.	installation of charging stations and control systems, i.e., 1,7 MEUR		
Total/Average	**8 MEUR**	**17,5 years**	**2 years**

Source: ARS data.

The main investments are planned for EUR 8 million, covering 17 full years of the technology's lifespan and 2 years dedicated to technology setup. Table 5-2 will provide a more detailed explanation of main and other investments (construction & site preparation; training & change management; miscellaneous & contingency, etc.).

5.3 Costs and benefits estimates (related to investment, operational)

The total costs of the UC3 (including one-time costs of solutions setup are part of the investment phase and yearly costs**)** amount to 12.26 MEUR (at 2025 market prices).

Table 5-2: Costs for UC3

Costs	Not discounted values (EUR)	Discounted values of 2025 (EUR) for 2026
HTS Acquisition - Procurement of 1 system for trailer horizontal transfer – 20-year lifespan	3,5 MEUR	3 365 384,6
HTS Installation & Setup - Site preparation, infrastructure modification, and system commissioning – 20-year lifespan	500 kEUR	48 076,9
DAC for Railcars - Deployment of DAC across 50 railcars – 30-year lifespan	20 kEUR × 50 railcars = 1 MEUR	961 538,4
DAC Installation & Setup - System calibration and training for maintenance staff – 30-year lifespan	100 kEUR	9 615,3
Automated TOS Procurement - Acquisition of software for freight handling automation – 10-year lifespan	900 kEUR	865 384,6
TOS Implementation & Integration - Customization, software deployment, training, and IT integration – 10-year lifespan	300 kEUR	288 461,5
AGVs for Trailer Handling - Purchase of 4 AGVs for internal transport of semi-trailers – 10-year lifespan	350 kEUR × 4 = 1,4 MEUR	1 346 153,8

AGV Charging & Control Infrastructure - Installation of AGV charging stations and control systems – 10-year lifespan	300 kEUR	288 461,5
Construction & Site Preparation -Minor infrastructure adaptation, security upgrades, and automation compatibility – 15-year lifespan	2,0 MEUR	19 230 76,9
Training & Change Management - Operator and maintenance training, digital adoption strategies – 15-year lifespan	200 kEUR	192 307,7
Miscellaneous & Contingency (x % buffer) - Unforeseen costs in procurement, installation, or integration – 15-year lifespan	1,0 MEUR	961 538,4
Miscellaneous & Contingency (operational costs, yearly)	0,2 MEUR	192 307,7
HTS Maintenance & Spare Parts - Annual servicing, spare parts replacement, and software updates (operational costs, yearly)	150 kEUR	144 230,7
DAC System Maintenance - Railcar coupling system inspections and repairs (operational costs, yearly)	50 kEUR	48 076,9
TOS Software Licensing & Updates - Software subscription, updates, and cybersecurity enhancements (operational costs, yearly)	200 kEUR	192 307,7
AGV Maintenance & Energy Costs - Battery replacements, power consumption, and servicing	50 kEUR × 4 = 200 kEUR	192 307,7
Staff Costs (Operators, Technicians, IT Support) FTEs for operational and technical personnel (operational costs, yearly)	500 kEUR	480 769,2
Terminal Utilities & Energy Consumption - Electricity, internet, and other utilities – overheads (operational costs, yearly)	300 kEUR	288 461,5
Total Capex	**10,66 MEUR**	**10 250 000**
Total Opex (1st year of operation)	**1,6 MEUR**	**1 538 461,5**
Total (Capex + 1st year Opex)	**12,26 MEUR**	**11 788 461,5**

Source: Net discounted values are provided using a discount rate of 4 %.

Against its investment-related and operational costs, Use Case 3 (UC3) produces several benefits (positive impacts) worth **2,62 MEUR in real value**. A 2,62 MEUR/year benefit is obtained from:

- a. Operational cost reductions
1 - Manual labor savings from automation: 300 000 EUR/year
2 - Fuel savings (road-to-rail shift): 800 000 EUR/year
3- Truck maintenance reduction (fewer km): 200 000 EUR/year
4 - Congestion delay reduction: 100 000 EUR/year
b. Productivity & efficiency
1 - 20-minute automated transshipment, it means faster turnaround equal to 400 000 EUR/year
2 - Fewer handling errors from automation: 250 000 EUR/year
3 - Improved asset utilization (space & wagons): 300 000 EUR/year

Table 5-3: Total benefits for UC3

Impact/benefit	Constant (real) values in 2025 (EUR)
Reduction of operational costs	**1,4 MEUR**
Reduction in manual labor costs - Automation reduces the workforce needed for loading/unloading and rail coupling	300 kEUR
Lower fuel costs due to modal shift (road-to-rail). Shifting freight from road to rail reduces fuel consumption	800 kEUR
Lower truck maintenance costs. Fewer road miles for trucks = lower wear & tear	200 kEUR
Reduction in congestion-related delays. Faster transshipment processes improve logistics flow	100 kEUR
Environmental impacts	**272 kEUR**
CO_2 emission reduction (less road transport). Estimated savings based on reduced CO_2 emissions (EUR50/t)	122 kEUR
Reduced noise pollution & air quality. Rail transport generates less noise and air pollution	150 kEUR
Productivity & Efficiency Gains	**950 kEUR**
Faster transshipment time (20 minutes using train compared to the traditional method). Increased throughput, reducing waiting times, and improving capacity.	400 kEUR
Improved reliability & reduced errors in freight handling. Automation reduces handling errors, improving service quality.	250 kEUR
Higher asset utilization (wagons & terminal space). Optimized capacity usage due to automation	300 kEUR
Main activity costs reduction	**2 622 000 EUR**

Source: ARS data.

As assessed for Use Case, to justify the environmental impact of the Automated Ro-Ro Transshipment, it has been considered that the automation leads to a modal shift from road to rail, particularly for non-craneable trailers. Road transport (e.g., diesel trucks) has a higher CO_2 intensity than rail; the CO_2 savings calculation was based on annual tonne-kilometers shifted from road to rail. The emission factor difference considered is

- Truck: ~90 gCO_2/t-km
- Electric rail: ~15 gCO_2/t-km

Net savings × total t-km shifted is multiplied by the social carbon cost (EUR50/tonne), as the total monetized benefit is approximately EUR154 395 per year. The methodology is aligned, based on a shift from diesel-powered trucks to electric rail, to standard gCO_2/t-km rates, and EU carbon pricing norms.

Noise pollution reduction explanation
Clarification of the EUR150k Figure – Reduced Noise & Air Pollution EUR150k were derived:
Based on the EU average for shifting from truck to rail (~EUR0,002 – EUR0,004 per t-km saved) = ~42 million t-km × EUR0,0025 = EUR105 000
Air quality improvement (PM, NOx, etc.)
Based on EC Handbook (diesel trucks vs. rail per km external cost differential ≈ EUR0,001 – EUR0.002 per t-km) = ~42 million t-km × EUR0,0011 = EUR46 000
Rounded: EUR105k + EUR46k ≈ EUR150k/year
This figure is derived from externality cost differentials between diesel road transport and electric rail, based on EU standard values from the European Commission (2019) and (2021). Rail has far lower noise, particulate, and NOx emissions.
Assumptions: 42 million t-km/year shifted from road to rail; CO_2 reduction = 42M t-km × 75 g/t-km = 3 150 t CO_2/year; Monetized at 50 EUR/t equal to 157 500 EUR; Noise & air pollution externalities: by using EU guidelines (EUR0,0025/tkm for noise, EUR 0,0011/tkm for air quality) equals to approx. 150 000 EUR/year, rounded.

5.4 Revenue estimates (services, demand, pricing) for wider impact

The success of Use Case 3 (UC3) could lead to an increase in revenues from services, which depend on factors that determine both the supply side and the demand side.
The demand analysis of Use Case 3 (UC3) aims to estimate the number of future users of the Hub-provided service.
Table 5-4 presents the forecasts of additional sales per year resulting from the implementation of automated transshipment management at full capacity, i.e., from 2028 onwards.

Table 5-4: The changes in demand for UC3

Increase in demand	Realistic scenario (EUR)	Net revenue (EUR)
Additional revenue from new customers (modal shift from road to rail). Increased capacity attracts new logistics flows	1 200 000	576 706
Higher fees for premium automated services. Faster, more reliable transshipment justifies higher pricing	500 000	240 294
Extra sales	**1 700 000**	**817 000**

Source: ARS data. Yearly values are expressed in nominal values.

It has been defined as COGS, the full cost of deploying and operating the technologies required to deliver the automated Ro-Ro transshipment service. This includes investment, construction/setup, and operational costs over the analysis period (5 years). Breakdown of COGS 2025 at Market Prices, Non-Discounted has been calculated as follows:

- Total Investment Costs EUR5 450 000;
- Operational Costs (5 years, total) EUR3 380 000, including electricity, maintenance, software, etc.
- Total COGS (Use Case) EUR8 830 000 at 2025 market value, non-discounted.

Based on that, gross revenues at full regime, from 2028 onward, are an annual revenue value (1,7 MEUR), spread COGS over a 10-year lifespan of the infrastructure, amortising yearly EUR883 000. The Net Revenue, so the Gross Revenue – Annualized COGS, is EUR1 700 000 – EUR883 000 = EUR817 000/year

The Net Annual Benefit from 2028 (2,71 MEUR of Savings + 0,817 MEUR of Net Revenues – 1,4 MEUR of Operational Costs) is 2,12 MEUR.

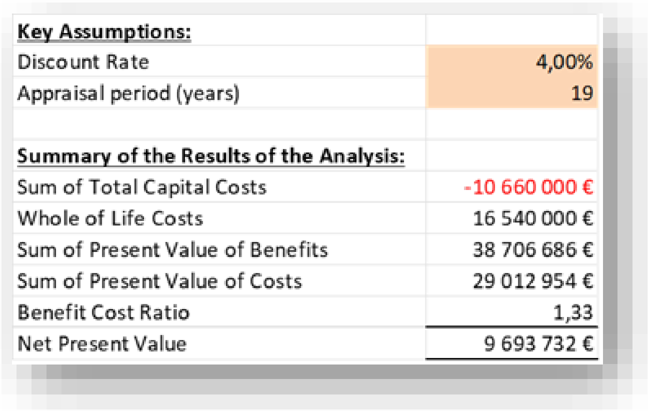
5.5 Financial analysis

Use Case 3 (UC3):

- Technologies – 10,66 MEUR (with life span – 17 years & implementation – 2 years)
- OPEX costs – 1,6 MEUR/year.
- Benefits – 2,6 MEUR/year.
- Increase of Net revenue from year 2028 – 0,8 MEUR/year.

Results

In the CBA calculator, 2 years are planned for technology implementation, and 17 years for technology usage.



Key Assumptions:	
Discount Rate	4,00%
Appraisal period (years)	19
Summary of the Results of the Analysis:	
Sum of Total Capital Costs	-10 660 000 €
Whole of Life Costs	16 540 000 €
Sum of Present Value of Benefits	38 706 686 €
Sum of Present Value of Costs	29 012 954 €
Benefit Cost Ratio	1,33
Net Present Value	9 693 732 €

Figure 5-1: Summary of financial analysis data

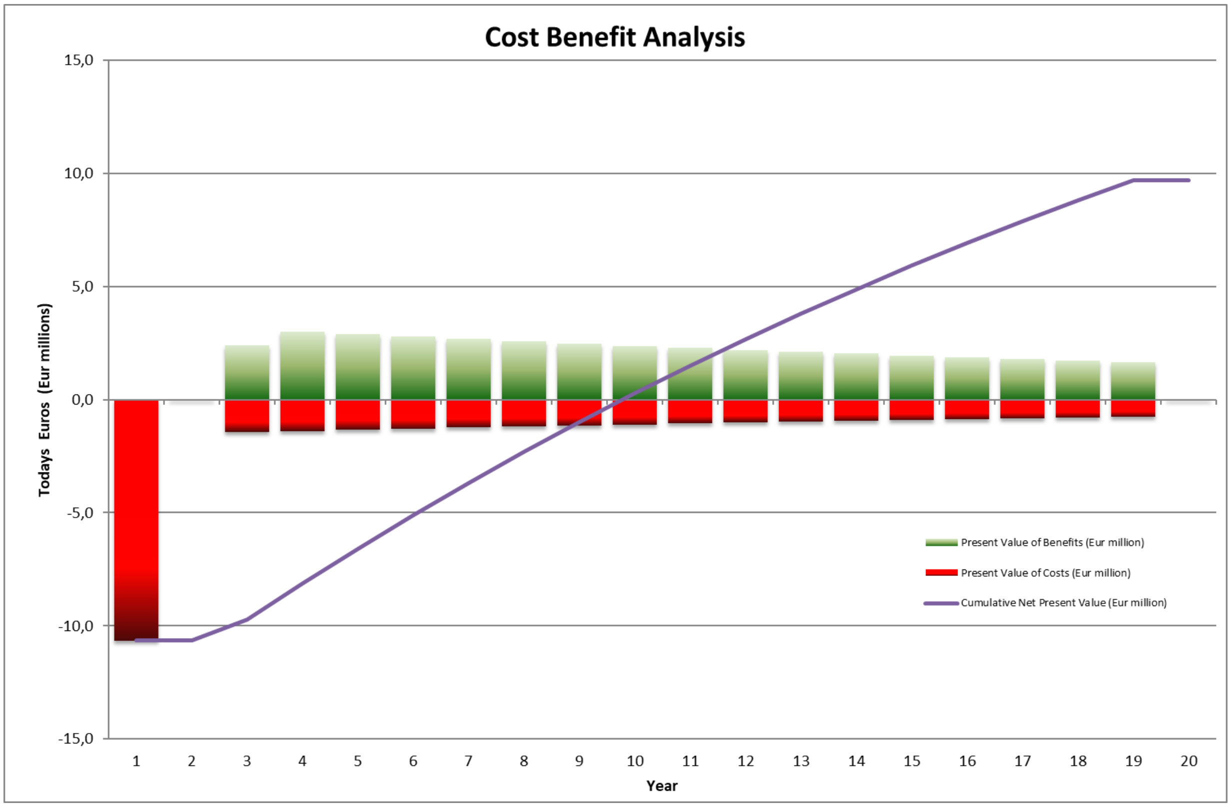


Figure 5-2: Changes of Present Values over time

The Cumulative Net Present Value indicates that the investments in technology are paid back in nine years after the start of the investment year.

Profitability on investment analysis

ROI metric used to evaluate the forecasted profitability of different investments.

$$\text{ROI}\,\% = \frac{\text{Annual Net benefits}}{\text{Initial value of investments}} \times 100$$

Where:
Initial value of investments – EUR10 660 000
Annual costs – EUR1 600 000
Annual benefits – EUR2 622 000
Annual Net benefits – EUR1 022 000

ROI = (1 022 000 / 10 660 000) x 100.

ROI = 9,59 %

Using this equation, the return on investment comes out to 9,59 %.

5.6 Environmental considerations

Further on, the environmental benefits are presented. Environmental benefits are calculated based on the description provided in Annex A I.

Table 5-5: Data for the calculation of Environmental benefits for UC3

	Road Transport Emissions Avoided (Shift to Rail)
Truck trips avoided per year	6 000 trailer trips
Average distance avoided (per trip)	350 km (road leg from Trieste to N. Europe)
Average load per trailer	20 t
Total t-km avoided per year	6 000 × 350 × 20 = 42 000 000 t-km
CO_2 emission from a road (diesel truck)	90 gCO_2/t-km (EU avg for long-haul)
Total CO_2 avoided (road)	3 780 000 000 g = 3 780 t CO_2
Monetized value (EUR50/t CO_2)	EUR189 000/year
	Added Emissions from Rail Freight (Electric)
New freight t-km on rail (electric) per year	6 000 trips x 350 km/trip = 2 100 000 km
New freight t-km on rail (electric)	42 000 000 t-km
CO_2 emissions rail (electric)	15 gCO_2/t-km
CO_2 emitted	630 000 000 g = 630 t CO_2
Monetized value (EUR50/t CO_2)	EUR31 500/year (cost)

	Electric Equipment (AGVs, Sensors, Automation) Added
AGVs' energy consumption (kWh/equipment-km)	4,5 kWh/km
Average annual AGV movement (km)	30 000 km/AGV, 2 AGVs → 60 000 km
Total energy consumption (per year)	270 000 kWh
Electricity source	Italian grid (mixed, ~0,23 kgCO₂/kWh)
Total CO₂ from AGVs	62 100 kg = 62,1 t CO₂
Monetized value (EUR50/t CO₂)	EUR3 105/year (cost)
Total	**EUR154 395/year** **(189 000-31 500-3 105)**

Source: ARS data.

Benefits for transport user

The Use Case 3 (UC3) will avoid road emissions annually by 3 780 t, resulting in EUR 189 000 in benefits. Rail emissions would be added annually to electric power for 630 tons, which would incur costs of EUR31 500. It would add a generalized advertisement for AGV electricity emissions, +62,1 t, with EUR3 105 related costs. The overall net CO₂ savings are 3 087,9 t, which yields a net benefit of EUR 154 395 per year in avoided carbon costs, using conservative assumptions (EUR50/tCO₂) provided by Adriafer Rail Services. Emission reduction is mainly driven by replacing road transport with more efficient electric rail. Terminal AGV emissions are minor compared to the benefits gained from the road-to-rail modal shift. Transport user saves EUR154 395/year.

Externalities

Externalities are spillover effects from the project towards third parties (neither consumers nor producers), for which no monetary compensation is provided. Examples are environmental effects (air pollution).

The multiplier for air pollution (year 2021) was EUR0,41/t-km for Heavy goods vehicles (Greece case), EUR2,78/km for Electric rail (Greece case) (DG REGIO, 2021), and EUR294,96 per tonne CO2e for AGVs (BEIS, 2021).

Following DEFRA (2023) report, the latest non-traded carbon price from the Green Book supplementary guidance is 248 GBP / tonne CO2e for 2020, which was applied in this analysis to calculate damage costs (BEIS, 2021). When 1,000 GBP = EUR1,189, the price is EUR294,96/t CO2e

Monetized savings for air pollution are achieved after selected automation technologies implementation (42 000 000 t-km, 2 100 000 km, and 62,1 t CO₂ are saved):

42 000 000 t-km x 0,41 EUR/t-km = 17 220 kEUR

2 100 000 km x 2,78 EUR/km = 5 838 kEUR

62,1 t CO₂ x EUR294,96/t CO2e = 18,31 kEUR

In total, the externalities amount to 23 076,31 kEUR per year.

Environmental externalities lead to reduced emissions or energy savings, these environmental benefits (valued at societal prices, such as the EU carbon price for CO_2 reduction) would be quantified on the benefit side. These environmental gains through shadow pricing of externalities ensure that the automation delivers net positive welfare for society at large.

Summary

Input	Input's value	Multiplicator	Multiplicator's value	Comment and source
Saved km for rigit truck	42 mln t-km	For scope 1	90 g CO2/t-km	Rigid truck (20-26 t) using diesel
Added km for electric rail	42 mln t-km	For scope 1	15 g CO2/t-km	Rail using electricity
Added km for 2 AGVs	60 000 km	For scope 1	0,23 $kgCO_2/kWh$	Italian grid, mixed source of electricity
Tonnes of CO2 avoided	3 780 t	Shadow cost for carbon in Euro	50 Eur/ t CO2	Provided by ARS
Tonnes of CO2 added	692,1 t	Shadow cost for carbon in Euro	50 Eur/ t CO2	Provided by ARS
Externalities for air pollution per year	42 000 000 t-km 21 000 000 km 62,1 t CO2	For air pollution rail & vehicle type	0,41 Eur/t-km 2,78 Eur/km 294,96 Eur/t CO2	Calculation sheet of DG REGIO (2021) (Greece case) for Heavy goods vehicle, electric rail, BEIS (2021) for AGVs.

The table shows that 21 000 km avoided per year will reduce traffic congestion.

5.7 Sensitivity analysis

Analysis of how changes in inputs affect changes in output (NPV)

The sensitivity of the base case NPV has been analyzed following changes (which were specified in chapter 2.2) in several key variables, as follows:

1. an increase in technology purchase costs of 20 %
2. a decrease in benefits by 20 %
3. an increase in costs by 20 %
4. a delay in the implementation period, causing a delay in benefits generation by one year.

Proposed changes in key variables should be well-explained. The sensitivity analysis is based on the most likely changes. The effects of the above changes are summarized in the table below.

Table 5-6: Results of sensitivity analysis for UC3

Item	Change	NPV1 (EUR)	SI(NPV1)
Base Case		9 693 732	
Purchase costs of technologies	20 % Xb – 10 660 000, X1 – 12 792 000	7 561 732	-1,1

Benefits	-20 % Xb – 2 622 000, X1 – 2 097 600	3 678 552	3,103
Annual costs	20 % Xb – 1 600 000, X1 – 1 920 000	6 023 141	-1,89
Implementation delay	One year Xb – 2 622 000, X1 – 0	7 316 622	0,245
SI – sensitivity indicator, NPV – net present value			

The higher the SI, the more sensitive the NPV is to the change in the variable concerned. NPV1 simultaneously declined in all cases.

The worst-case scenario among the four key variables considered in the sensitivity analysis is observed in the second variable change case.

Regarding the 20 % increase in technology purchase costs, the sensitivity indicator (SI) is -1,1. This means that a 20 % change in the variable (purchase costs of technologies) results in a 22 % change (reduction) in the NPV1.

The highest sensitivity indicator is a 20 % reduction in benefits, as seen in the case. In the case of reducing benefits by 20 %, the sensitivity indicator (SI) is 3,103. This means that the change of 20 % in the variable (benefits) results in a change (reduction) of 62 % in the NPV1.

In the event of a 20 % increase in annual costs, the sensitivity indicator (SI) is -1,89. This means that the change of 20 % in annual costs results in a change (reduction) of 38 % in the NPV1.

A one-year implementation delay means that benefits will be available one year later. The sensitivity indicator (SI) is -0,245, and NPV1 will be worse by 25 %.

6 AUTOSUP Use Case 1 (UC4) "Port automations coordination and environmental performance"

6.1 Use Case description

Scope

The strategic objective of UC1 (UC4) is to enhance the port's container flow, optimise capacity, and ensure an efficient transport link between the hinterland and the port by maximising the utilisation of available infrastructure (road, water, rail). Strategically located storage areas (Cargo Hubs) will be used as a buffer between the hinterland and the port, implementing smart technologies to drive modal shift, and promoting night transport by AGVs.

Port automations, coordination, and environmental performance monitoring

In its current state, the Port of Antwerp-Bruges terminals are experiencing a decline in turnaround efficiency due to severe road congestion in the surrounding transportation network. This congestion creates a bottleneck effect that significantly impacts the port's operational capacity and the fluidity of its supply chain. The congestion is particularly strong around the Antwerp ring road (R1), where multiple segments consistently experience heavy traffic volumes exceeding 125 000 vehicles per working day.

The impact is compounded by the region's high proportion of freight traffic, with over 20 % of the total traffic volume comprising heavy goods vehicles on highways to and from Antwerp. These conditions create a challenging environment for container transportation between the various port terminals and inland destinations. The resulting delays and unpredictable transit times reduce terminal productivity and create scheduling difficulties for shipping lines, trucking companies, and cargo owners. The current situation threatens the port's competitiveness and limits its ability to handle growing cargo volumes efficiently. This logistical challenge has a significant impact on the working conditions of truck drivers, making the job less attractive and contributing to a shortage of qualified drivers, particularly during peak hours. The combination of road congestion and driver shortages creates a critical need for innovative solutions to maintain the port's operational efficiency while addressing these interconnected challenges.

In the proposed scenario, the Port of Antwerp-Bruges aims to establish a network of strategic cargo hubs within the port area, thereby fundamentally transforming container movement patterns and significantly improving terminal turnaround efficiency. These cargo hubs will function as intermediate consolidation and transfer points, effectively decoupling the hinterland transportation from terminal operations. The innovative approach focuses on a time-shifted logistics model, where containers arriving from the hinterland (via truck or barge) during daytime hours are received at these cargo hubs. During nighttime hours, when road congestion drops substantially, autonomous trucks would execute the final delivery of containers between the cargo hubs and the various terminals.

By adopting automation technologies, benefits are expected in terms of:

- Increase logistics efficiency (less time in traffic jams and less waiting times for the truck drivers);
- More predictable transit times and higher throughput of containers between hubs and terminals, and increased cargo handling capacity at the terminals.

- Address the critical shortage of qualified drivers while enabling frequent shuttle movements during non-traditional working hours.
- Reducing CO2 emissions.
-

6.2 Components to be implemented (physical infrastructure, software, hardware, etc.)

Based on the selected automation technologies (D1.3) and further analysis, as well as Living Hub's consultation activities, the list of technologies addressed and considered for the CBA is indicated in Table 6-1. The assumption is that 3 autonomous trucks will be used per cargo hub, making it 12 trucks in total. These trucks will drive during the night (8 hours).

Table 6-1: List of technologies for Use Case UC1 (UC4)

Technology	Purchase price (EUR)	Life span of technology	Expected technology implementation period (in years)
12 Autonomous Trucks	6MEUR	13 years	1 year
Central Coordination platform for Autonomous assets (trucks, vessels, wagons, drones, etc.)	300kEUR	10 years	3 years
Total/Average	**6,3**MEUR	**12 years**	**2 years**

The main investments are planned for 6,3 MEUR, covering 12 full years of the technology's lifespan and 2 years dedicated to technology setup.

6.3 Costs and benefits estimates (related to investment, operational)

The total costs of Use Case 1 (UC4) (including one-time costs of solutions setup are part of the investment phase and yearly costs**)** amount to 386 kEUR (at 2025 market prices).

Table 6-2: Costs for UC1 (UC4)

Costs per Cargo Hub	Not discounted values (EUR)	Discounted values of 2025 (EUR) for 2026
Autonomous Trucks: hardware maintenance for 12 trucks (operational costs, yearly)	96kEUR/year	92 308
Autonomous Trucks: insurance for 12 trucks (operational costs, yearly)	60kEUR/year	57 692
Autonomous Trucks: electricity	0,25EUR/km	
Autonomous Driving Software Platform (operational costs, yearly)	50kEUR/year	48 077
Central coordination platform: maintenance (operational costs, yearly)	30kEUR/year	28 846
Training	150kEUR	144 231
Total	**386kEUR**	**371 154**

Source: Net discounted values are provided using a discount rate of 4 %.

Against its investment-related and operational costs, Use Case 1 (UC4) produces several benefits (positive impacts) worth 1 080 kEUR in real value. The main results are presented and commented on in this section.

Table 6-3: Total benefits for UC1 (UC4)

Impact/benefit	Constant (real) values in 2025 (EUR)
Reduction of labour costs – truck drivers	117 000 30 % cost reduction per year
Reduction of energy costs – autonomous trucks	27 955 25 % energy cost reduction per year
Reduction of labour costs – terminal automation	70 % cost reduction over 10 years
Efficiency gains – waiting times reduction	936 000 Average waiting time reduction by 2 hours per trip
Efficiency gains – terminal automation	Throughput increased from 15/25 to 25/40 containers per hour
Main activity costs reduction	**1 080 955**

Source: PoAB data. Assumptions: driver costs per hour – 37,5 EUR*, 12 480 trips per year for 3 trucks, 4 trips per hour; diesel price per liter – 1,6* EUR*, fuel consumption diesel truck – 20 l/100 km; electricity consumption autonomous truck per km – 1,2 kWh, price per kWh – 0,08* EUR.

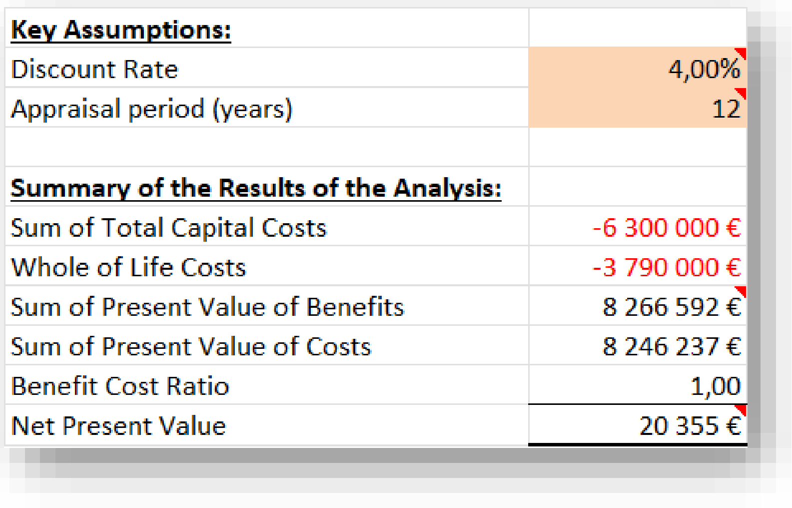
The main benefit of reducing operational costs is 39 % (936 kEUR) of the total value of Use Case 1 (UC4) impact. Being designed for the Use Case, the Hub is expected to have more efficient operations, which may also translate into additional quality of services (fewer errors, faster operations).

6.4 Financial analysis

Use Case 1 (UC4):

- Technologies – 6,3 MEUR (with life span – 12 years & implementation – 2 years)
- Implementation costs (one-time) – EUR150 000.
- OPEX– 0,236 MEUR/year.
- Benefits – 1,08 MEUR/year.

Results



Key Assumptions:	
Discount Rate	4,00%
Appraisal period (years)	12
Summary of the Results of the Analysis:	
Sum of Total Capital Costs	-6 300 000 €
Whole of Life Costs	-3 790 000 €
Sum of Present Value of Benefits	8 266 592 €
Sum of Present Value of Costs	8 246 237 €
Benefit Cost Ratio	1,00
Net Present Value	20 355 €

Figure 6-1: Summary of financial analysis data

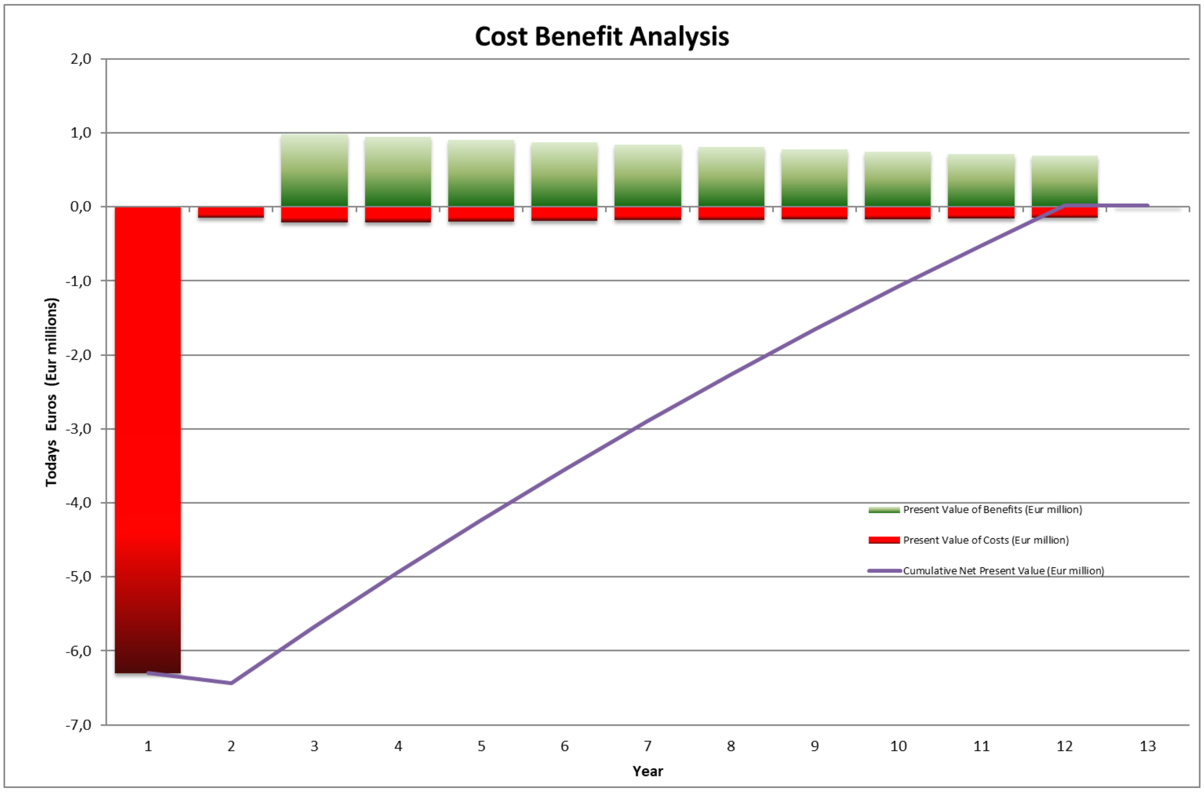


Figure 6-2: Changes of Present Values over time

Cumulative net present value shows that investments in technology are paid back during their lifetime (in the last year of technology application).

Profitability on investment analysis

ROI metric used to evaluate the forecasted profitability of different investments

$$\text{ROI \%} = \frac{\text{Annual Net benefits}}{\text{Initial value of investments}} \times 100$$

Where:
Initial value of investments – EUR6 300 000
Annual costs – EUR236 000
Annual benefits – EUR1 080 955
Annual Net benefits – EUR844 955

ROI = (844 955 / 6 300 000) x 100.

ROI = 13,41 %

Using this equation, the return on investment comes out to 13,41 %.

6.5 Environmental considerations

The shift from manual coordination to automated slot and route management is expected to reduce empty runs and enhance the efficiency of first- and last-mile transport. This optimisation contributes to measurable environmental benefits. In the case of AS IS, diesel trucks are used for the first and last-mile legs, resulting in significant fuel consumption per trip. In the TO BE scenario, improved routing and reduced idle time will result in fewer kilometers driven per shipment.

Further on, the environmental benefits are presented. Environmental benefits are calculated based on the description presented in Annex A I. Both equipment are used for cargo deliveries.

Table 6-4: Data for the calculation of Environmental benefits for UC1 (UC4)

Fuel-based transport equipment	**Equipment1**
Yearly distance with allocated consignment (t-km), 20 tonnes	12 480 000
Type of transport equipment	Rigid truck
Fuel type	Diesel
Average, CO2 (gCO2/t-km)	90 gCO2/t-km
Cost of CO2 (EUR/tonne)	EUR148/t CO2e
Electrically powered transport equipment	**Equipment2**
Yearly distance with allocated consignment	124 800
Electricity consumption per kilometer	1,2 kWh/km
Avg, working hours/month	160
Electricity source, proportion of Hydro and wind 50 %/50 %	green/non-green mix
Price per kWh	0,08 EUR/kWh

Environmental considerations are present through a) saved CO2 emissions, b) benefits for transport user, and c) externalities. The description is presented below.

Saved CO2 emissions

Rigid trucks and electrically powered deliveries contributed to a reduction in CO2 emissions.

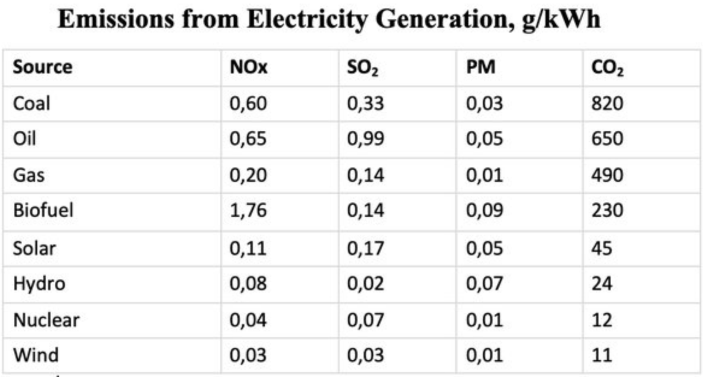
Rigid truck (26-32 t) using diesel generates 90 g CO2e/t-km (source: Glec framework (2023), Table 8, p. 92, TTW case). When annual CO2 emissions are 11 232 t CO2e:

12 480 000 t-km x 90 g CO2e/t-km = 11 232 t CO2e generated

Annual CO_2 emissions for electricity generation for an electricity-powered vehicle:

124 800 kWh x 1,2 kWh/km = 149 760 kWh in total

Following the article "How much carbon dioxide is produced when you charge an electric car?" available on the Quora (2024) website, **such CO2 emissions from electricity generation were reported.**



Emissions from Electricity Generation, g/kWh

Source	NOx	SO_2	PM	CO_2
Coal	0,60	0,33	0,03	820
Oil	0,65	0,99	0,05	650
Gas	0,20	0,14	0,01	490
Biofuel	1,76	0,14	0,09	230
Solar	0,11	0,17	0,05	45
Hydro	0,08	0,02	0,07	24
Nuclear	0,04	0,07	0,01	12
Wind	0,03	0,03	0,01	11

Figure 6-3: Emissions from electricity generation
Source: Quora, 2024

CO2 emissions depend on the energy mix (50 % hydro and 50 % wind) **that is used for electricity generation.** So, fully charging a 100-kW battery with 100 % wind share in the energy mix will produce approximately 1,1 kg of CO2.

149 760 kWh x 257 g/kWh (when hydro 50 % - 24 g/kWh and gas 50 % – 490 g/kWh) = 38,48 t CO2e generated.

Benefits for transport users

The multiplier provided by the European Commission (2021) for 2024 is EUR148/t CO2e.

Monetised savings of transport users:

11 232 t CO2e x EUR148/t CO2e = EUR1 662,3

38,48 t CO2e x EUR148/t CO2e = EUR5 695.

The transport user saves EUR4 032,7 per year.

Externalities

Externalities are spillover effects from the project towards third parties (neither consumers nor producers), for which no monetary compensation is provided. Examples are environmental effects (air pollution).

The multiplier for air pollution in 2021 for t-km (Belgium case) was EUR1,28/t-km for Heavy goods vehicles using diesel (DG REGIO, 2021).

Monetised savings for air pollution:

12 480 000 t-km x 1,28 EUR/t-km = 15 974,4 kEUR

Following DEFRA (2023) report, the latest non-traded carbon price from the Green Book supplementary guidance is 248 GBP / tonne CO2e for 2020, which was applied in this analysis to calculate damage costs (BEIS, 2021).

When 1,000 GBP = EUR1,189, the price is EUR294,96/t CO2e

38,48 t CO2e x EUR294,96/t CO2e = 11,35 kEUR

Monetized savings for air pollution after the shift from AS IS to TO BE are 15 963,05 kEUR/year.

Environmental externalities lead to reduced emissions or energy savings, these environmental benefits (valued at societal prices, such as the EU carbon price for CO_2 reduction) would be quantified on the benefit side. These environmental gains through shadow pricing of externalities ensure that the automation delivers net positive welfare for society at large.

Summary

Input	Input's value	Multiplicator	Multiplicator's value	Comment and source
T-km for rigit truck	12 480 000 t-km	For scope 1	90 g CO2/t-km	Rigid truck (20-26 t) using diesel Glec framework (2023)
Tonnes of CO2 avoided	11,2 t CO2 39,48 t CO2	Shadow cost for carbon in Euro	148 Eur/ t CO2	Economic Appraisal Vademecum (EAV) (2021)
Inputs for air pollution calculaton	12 480 000 t-km 39,48 t CO2	For air pollution & vehicle type	1,28 Eur/t-km 294,96 Eur/t CO2	Calculation sheet of DG REGIO (2021) (BE case) for Heavy goods vehicle and BEIS (2021) for electricity generation.

6.6 Sensitivity analysis

Analysis of how changes in inputs affect changes in output (NPV)

The sensitivity of the base case NPV has been analysed following changes (which were specified in chapter 2.2) in several key variables, as follows:

1. an increase in technology purchase costs of 20 %
2. a decrease in benefits by 20 %
3. an increase in annual costs by 20 %
4. a delay in the implementation period, causing a delay in benefits generation by one year.

Proposed changes in key variables should be well-explained. The sensitivity analysis is based on the most likely changes. The effects of the above changes are summarised in the table below.

Table 6-5: Results of sensitivity analysis for UC1 (UC4)

Item	Change	NPV1 (EUR)	SI(NPV1)
Base Case		20 355	
Purchase costs of technologies	20 % Xb – 6 300 000, X1 – 7 560 000	-1 239 645	-309
Benefits	-20 % Xb –1 080 955, X1 – 864 764	-1 632 963	406
Annual costs	20 %	-340 606	-88

	Xb – 236 000, X1 – 283 200		
Implementation delay	One year Xb – 1 080 955, X1 – 0	-959 641	48
SI – sensitivity indicator, NPV – net present value			

The higher the SI, the more sensitive the NPV is to the change in the variable concerned. NPV1 simultaneously declined in all cases.

The worst-case scenario among the four considered key variables in the sensitivity analysis is observed in the second variable change case.

Regarding the increase in technology purchase costs of 20 %, the sensitivity indicator (SI) is -309. This means that the change of 20 % in the variable (purchase costs of technologies) results in a change (reduction) of 6190 % in the NPV1.

The highest sensitivity indicator is a 20 % reduction in benefits, as seen in the case. Regarding the 20 % reduction in benefits, the sensitivity indicator (SI) is 406. This means that a 20 % change in the variable (benefits) results in an 8 122 % change (reduction) in the NPV1.

In the event of a 20 % increase in annual costs, the sensitivity indicator (SI) is -88. This means that 20 % change in annual costs results in a change (reduction) of 1 773 % in the NPV1.

A one-year implementation delay means that benefits will be available one year later. The sensitivity indicator (SI) is 48, and NPV1 will be worse by 4 815 %.

7 AUTOSUP Use Case 2 (UC5) "Port-Shipper collaboration towards increased modal shift"

7.1 Use Case description

Scope

The objective is to gain a comprehensive, consolidated view of freight flows originating from the Port of Antwerp/Zeebrugge to the UK, Iberia, and Italy. This will enable us to model ideal multimodal freight flows, estimate new routings, analyse potential environmental and financial opportunities, and evaluate the availability and quality of Geo-Visibility data for intermodal loads. Additionally, Use Case 2 (UC5) aims to build a roadmap for operationalising geo-visibility data in the region, further advancing our intermodal transport strategy.

Port-Shipper collaboration towards increased modal shift

The AS IS scenario is characterised by a lack of accurate estimated times of arrival (ETAs) and insufficient visibility across the end-to-end (E2E) multimodal freight transport corridors, specifically between the Port of Antwerp/Zeebrugge and regions such as the UK, Iberia, and Italy. The absence of reliable data makes it challenging to plan resource needs effectively, resulting in significant losses, particularly in the form of unproductive waiting times for service providers. Furthermore, the inability to provide accurate ETAs often leads to denying intermodal service loads, even when road transport does not significantly improve service time.

The envisioned 'TO BE' scenario focuses on enhancing visibility and resource planning across the identified end-to-end multimodal freight corridors. Optimising resource allocation can be achieved by leveraging artificial intelligence (AI), machine learning (ML) technologies, and improved goods visibility data. This advancement aims to eliminate inefficiencies and losses throughout the entire supply chain, facilitating seamless coordination among stakeholders and ensuring timely and efficient freight transport between the Port of Antwerp/Zeebrugge and the UK, Iberia, and Italy regions. The selection of relevant multimodal freight transport lanes for the AUTOSUP project is being defined in WP2.

By adopting automation technologies, benefits are expected in terms of:

- The project aims to minimize waiting times for the loads at loading and unloading points. This reduction is crucial for enhancing operational efficiency and ensuring that shipments are processed more efficiently.
- As a direct result of reduced waiting times, we anticipate a positive impact on transportation costs for the specific lanes where waiting times are minimized. This cost efficiency will contribute to overall savings in logistics operations.
- With decreased waiting times, we expect a positive effect on driver availability for the specific lanes. By reducing the time drivers wait during a trip, more efficient use of driver resources can be achieved, resulting in improved service and productivity.
- By addressing the current inefficiencies in intermodal transport, the project facilitates better coordination between manufacturers, logistics service providers, and ports. This enhances the overall effectiveness of intermodal services, making them a more attractive option than road transport.

- By integrating improved visibility data for selected freight lanes, stakeholders will gain real-time insights into shipment statuses, including accurate ETAs and actual arrival times. This transparency helps in better decision-making and coordination among all parties involved. Enhanced visibility within the supply chain at every moment allows for better planning and execution. As a result, we expect less unnecessary transport to be ordered, as more accurate and timely information will support critical business needs.
- The project leverages AI and machine learning to analyse historical data, enabling optimal resource planning and allocation. This optimisation will further minimize unproductive waiting times and improve the overall efficiency of logistics infrastructure.
- The project will generate valuable data and insights that can be used to continuously refine and improve supply chain processes. This includes understanding the required accuracy of ETAs and assessing the flexibility needed at ports and destinations.

Currently, customers, shippers, and ports operate in relative silos, resulting in limited end-to-end (E2E) information flow. This fragmentation leads to structural inefficiencies and missed opportunities. By integrating customer data, shipper data, and port data, we can better identify potential shipment needs and provide real-time updates on prioritisation and estimated times of arrival (ETAs).

7.2 Innovation components to be implemented (physical infrastructure, software, hardware, etc.)

Based on the selected automation technologies (D1.3) and further analysis, as well as Living Hub's consultation activities, the list of technologies addressed and considered for the CBA is indicated in Table 7-1.

Table 7-1: List of technologies for UC2 (UC5)

Technology	Purchase price (EUR)	Life span of technology	Expected technology implementation period (in years)
Transportation Telematics (GPR/Track and Trace) Data Pipeline from Data Provider to P&G Systems, plus integration with port data	~200 000	5-7 years	1-2 years
Software and AI/ML-based algorithms to predict ETA and minimize port waiting time	~700 000	5-7 years	1-2 years
Total/Average	**~900 000**	**6 years**	**1 year**

The main investments are planned for 0,9 MEUR with 6 full years of the technology's life span and 1 year is dedicated to the technology setup.

7.3 Costs and benefits estimates (related to investment, operational)

The total costs of Use Case 2 (UC5) (including one-time costs of solutions setup are part of the investment phase and yearly costs**) amount to 380 000 EUR (at 2025 market prices).**

Table 7-2: Costs for UC2 (UC5)

Costs	Not discounted values (EUR)	Discounted values of 2025 (EUR) for 2026
Project Management **(operational costs, yearly)**	80 000 / year	75 429
POC with Telematics Data Provider **(one time)**	50 000	47 143
Project Launch with Telematics Data Provider to establish Telematics Data Flow **(one time)**	80 000	75 429
Telematics Data running cost **(operational costs, yearly)**	100 000 / year	94 286
Software/Model running cost (infrastructure, etc.) **(operational costs, yearly)**	50 000 / year	47 143
Training and communication **(one time)**	20 000	18 857
Total	**150 000 one time** **+ 230 000 annual**	**141 429 one time** **+ 216 859 annual**

Source: Net discounted values are provided using a discount rate of 4 %.

Against its investment-related and operational costs, Use Case 2 (UC5) produces several benefits (positive impacts) worth EUR**500 000 in real values** from 2026 and increasing to EUR**1 000 000 in real values** from 2028.

Table 7-3: Total benefits for UC2 (UC5)

Impact/benefit	Constant (real) values in 2025 (EUR)	Assumptions towards estimation
Reduction of yearly operational costs from 2026	500 000	Transit time reduction by ~3-5 days for the lanes going via Port: Transport Services Rates reduction behind

		higher transport utilisation and turnover Supply Chain inventory reduction is behind transit time reduction Adoption level 50%
Reduction of yearly operational costs from 2028	1 000 000	Transit time reduction by ~3-5 days for the lanes going via Port: Transport Services Rates reduction behind higher transport utilisation and turnover Supply Chain inventory reduction behind transit time reduction Adoption level 100%
Main activity yearly costs reduction	**500 000 - 1 000 000**	

Source: Procter and Gamble data.

7.4 Financial analysis

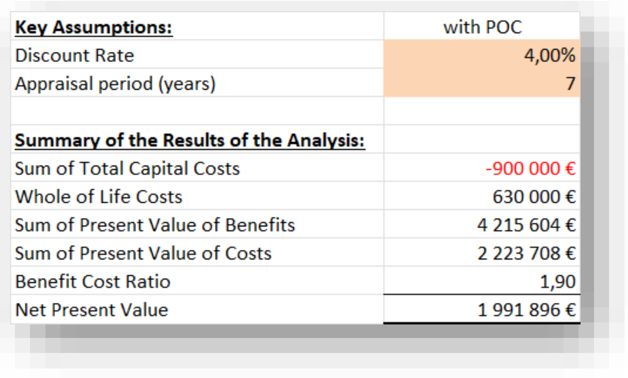
Use Case 2 (UC5):

- Technologies – EUR900 000 (with life span – 6 years & implementation – 1 year)
- Implementation costs (one-time) – EUR150 000.
- OPEX– EUR230 000/year.
- Benefits – EUR500 000-1 000 000/year.

Separate CBA calculations are performed for the POC (Proof-of-concept) case.

Results

Total number of years used for CBA: 1 year is planned for technology implementation, plus the life span of technologies and the years planned for technology usage. The life span of technologies dedicated after their implementation will be 6 years.



Key Assumptions:	with POC
Discount Rate	4,00%
Appraisal period (years)	7
Summary of the Results of the Analysis:	
Sum of Total Capital Costs	-900 000 €
Whole of Life Costs	630 000 €
Sum of Present Value of Benefits	4 215 604 €
Sum of Present Value of Costs	2 223 708 €
Benefit Cost Ratio	1,90
Net Present Value	1 991 896 €

Figure 7-1: Summary of financial analysis data

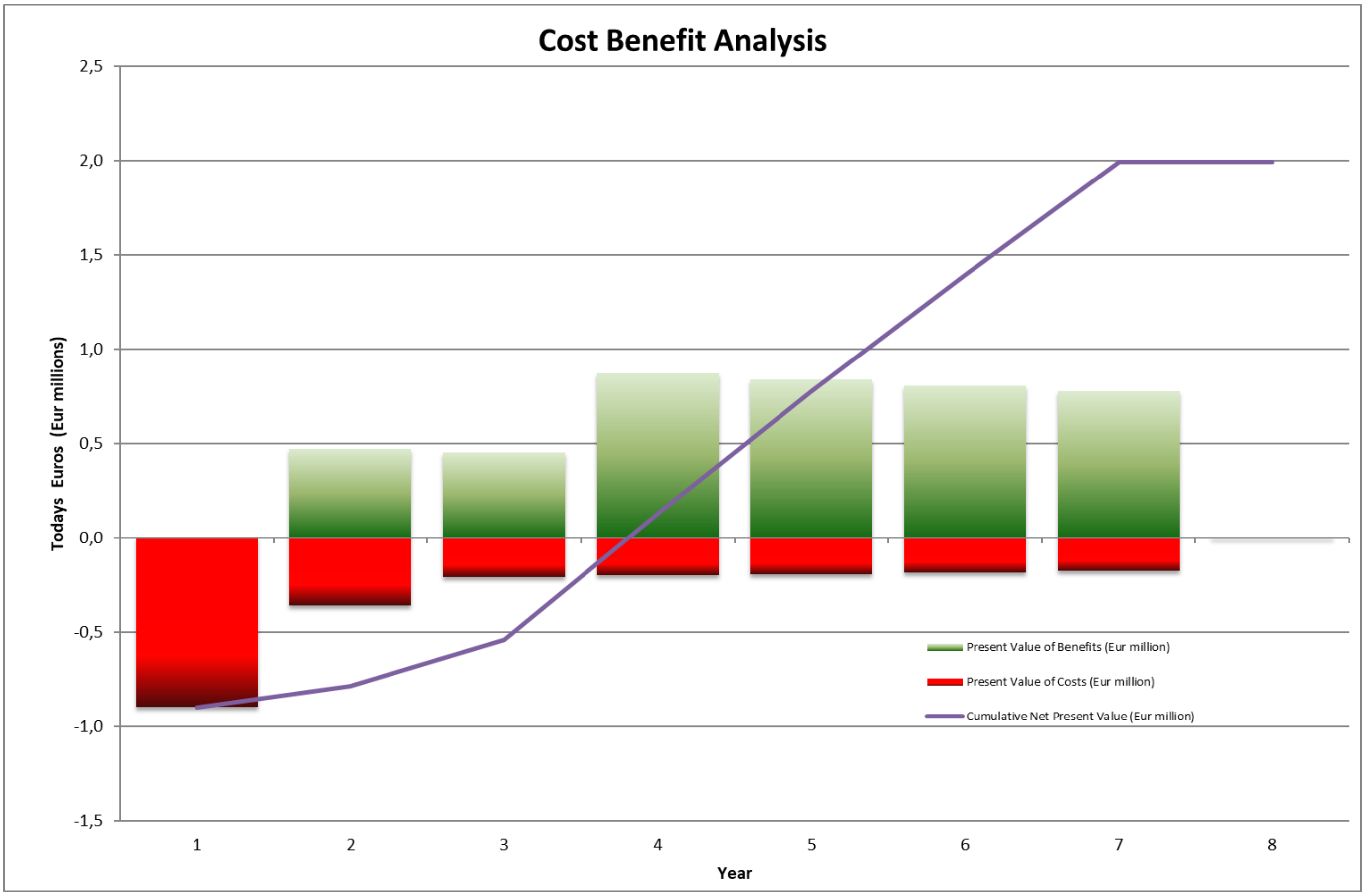


Figure 7-2: Changes of Present Values over time

The cumulative net present value indicates that investments in technology are recouped during the 4th year of technology usage.

Profitability on investment analysis

ROI metric used to evaluate the forecasted profitability of different investments

$$\text{ROI \%} = \frac{\text{Annual Net benefits}}{\text{Initial value of investments}} \times 100$$

Where in with POC case:
Initial value of investments – EUR900 000
Annual Net benefits – EUR500 000

ROI with POC = (900 000 / 500 000) x 100.

ROI with POC = 55,6 %

Using this equation, the return on investment reaches 55,6 % in the POC case.

7.5 Sensitivity analysis

Analysis how changes in inputs affect changes in output (NPV)

The sensitivity of the base case NPV has been analysed following changes (which were specified in chapter 2.2) in several key variables, as follows:

1. an increase of the purchase costs of technologies by 20 %
2. a decrease in benefits by 20 %
3. an increase in costs by 20 %
4. a delay in the implementation period, causing a delay in benefits generation by one year.

Proposed changes in key variables should be well-explained. The sensitivity analysis is based on the most likely changes. The effects of the above changes are summarised in the table below.

Table 7-4: Results of sensitivity analysis for UC2 (UC5) with POC

Item	**Change**	**NPV** (EUR)	**SI(NPV)**
Base Case		1 991 896	
Purchase costs of technologies	20 % Xb – 900 000, X1 – 1 080 000	1 811 896	-0,45
Benefits	-20 % Xb – 500 000, X1 – 400 000	1 148 776	2,11
Annual costs	20 % Xb – 230 000, X1 – 276 000	1 755 441	-0,59
Implementation delay	One year Xb – 500 000, X1 – 0	1 520 463	0,23
SI – sensitivity indicator, NPV – net present value			

The higher the SI, the more sensitive the NPV is to the change in the variable concerned. NPV1 simultaneously declined in all cases. The worst-case scenario among the four key variables considered in the sensitivity analysis is observed in the second variable change case.

Regarding the increase in purchase costs of technologies by 20 % case, the sensitivity indicator (SI) is -0,45. This means that a 20 % change in the variable (purchase costs of technologies) results in a 9 % change (reduction) in the NPV1.

The highest sensitivity indicator is a reduction in benefits by 20 % case. Regarding the reduction of benefits by 20 %, the sensitivity indicator (SI) is 2,11. This means that the change of 20 % in the variable (benefits) results in a change (reduction) of 42 % in the NPV1.

In case of increased annual costs by 20 %, the sensitivity indicator (SI) is -0,59. This means that the change of 20 % in annual costs results in a change (reduction) of 11 % in the NPV1.

Implementation delay for one year means that benefits will be available one year later, the sensitivity indicator (SI) is 0,23, and NPV1 will be worse by 23,6 %.

8 AUTOSUP Use Case 3 (UC6) "Port – Transport Mode Automation-systems integration"

8.1 Use Case description

Scope

The strategic objective of this Use Case 3 (UC6) is to improve terminal and port operations by using transport mode automation systems. This involves integrating advanced automated systems to streamline the movement of goods and containers within the port, thereby enhancing overall efficiency. Additionally, these solutions accelerate the adoption of emission-free and low-noise technologies, thereby contributing to a more sustainable and environmentally friendly port operation. By reducing reliance on manual labor for repetitive tasks, these automated systems enable qualified personnel to focus on higher-value activities, thereby increasing productivity and job satisfaction.

By addressing these strategic objectives, Use Case 3 (UC6) aims to position the port as a leader in innovation and sustainability, ultimately enhancing its competitiveness and operational excellence.

Port-Shipper collaboration towards increased modal shift

In the AS IS scenario, efficient terminal and port operations are essential for the seamless execution of multimodal freight transport. However, intra-port and intra-terminal movements still often rely on manual labour and polluting assets, creating operational inefficiencies and environmental concerns. Two illustrative use cases at the Port of Antwerp reveal these bottlenecks and emphasise the need for automated and sustainable solutions. Today, the current **truck operations** at the Port of Antwerp-Bruges rely heavily on manual labor and diesel-powered vehicles. Containers that need to be moved within terminal areas are transported using manually driven trucks, creating a significant dependency on human operators.

Additionally, these operations are restricted to daytime hours due to driver availability and labor regulations, limiting the port's operational capacity during nighttime hours when infrastructure utilisation could be optimised. Rail operations present an even more complex challenge in their current state. First and last-mile rail deliveries are extremely fragmented and lack the flexibility for efficient operations. The primary issue stems from power line limitations, where electric power lines often terminate at bunding areas or before reaching terminal gates. This infrastructure constraint necessitates a complex process involving multiple locomotive changes, which significantly impact operational efficiency.

The typical rail process begins when long-haul trains with electric locomotives arrive at the bundling Pelicaan yard in Zeebrugge. The electric locomotive must disconnect and depart at this point, leaving the railcars without propulsion. A diesel shunting locomotive then attaches to the rear of the train formation and couples with the wagons. The diesel locomotive pushes the entire train length toward the terminal tracks until the first wagon reaches the loading ramp. Due to operational constraints and safety considerations, approximately 350 meters of the train's length must be uncoupled.

The diesel locomotive then drives back with the remaining wagons until it clears the track switch. The switch is then changed to redirect traffic to parallel rail tracks, and the remaining wagons are pushed back onto the adjacent track. Finally, the diesel locomotive uncouples and departs, leaving both sections of the divided train ready for loading or unloading operations.

In the envisioned **TO BE scenario**, the future state of **truck operations** envisions a complete transformation through the implementation of Autonomous Electric Vehicles (AEVs), which will replace the current manual diesel truck fleet. These autonomous vehicles will operate continuously 24 hours a day, seven days a week, limited only by charging requirements rather than human factors such as driver rest periods and shift changes. This represents a fundamental shift from diesel-powered vehicles to electric alternatives, delivering significant environmental benefits through zero emissions and substantially reduced noise pollution within the port environment. The autonomous trucks will enhance operational efficiency through consistent performance, eliminating human limitations and variability. Enhanced safety will be achieved by reducing human error and implementing advanced sensor systems and artificial intelligence to respond to operational conditions more quickly and accurately than human operators. The system will also incorporate AI-driven route optimisation capabilities to maximise efficiency by continuously analysing traffic patterns, loading schedules, and infrastructure availability to determine the most effective transportation routes.

By adopting automation technologies, benefits are expected in terms of:

- **Increased efficiency**: AEV's are designed to streamline operations with self-driving technology and minimise human error. The routing can be optimised, which leads to fewer stops and better load planning.
- **Reduced Emissions**: AEV's replace diesel trucks, and when their batteries are charged using green energy, they can significantly reduce greenhouse gas emissions. They also contribute to reducing environmental impact through more efficient driving. Autonomous systems are designed to minimise unnecessary acceleration, braking, and idling, positively impacting battery consumption.

Obtain operational results of AEV that is being developed in the Pioneers project. The Pioneers consortium, Akkodis, and VDL, developed an automated shuttle solution for port operations. To create the necessary cost/benefit analysis, the routing will be simulated in the AUTOSUP project.

The transformation of **rail operations** will be equally comprehensive, involving the replacement of diesel shunting locomotives with autonomous locomotive systems and implementing revolutionary **MagRail technology**. This advanced system incorporates frictionless magnetic rail systems that integrate linear motors directly into existing track infrastructure. Railcars will be equipped with magnetic propulsion systems that allow them to operate autonomously, controlled by electromagnetic forces that enhance precision and operational efficiency. The MagRail system will enable more flexible operations by allowing railcars to be organised into small groups, rather than requiring full trainsets. This is particularly beneficial for last-mile applications in cargo terminals and industrial facilities, where high degrees of flexibility and movement automation are essential. This approach will dramatically simplify the complex process by eliminating the need for multiple locomotive switching procedures and reducing the dependency on infrastructure limitations that constrain operations.

The magnetic rail solution can give the following benefits:

- **Increased Efficiency:** Magnetic rail systems can provide smoother and faster transitions between different sections of the rail network, improving overall delivery times.
- **Reduced Emissions:** No more reliance on diesel locomotives, and greenhouse gas emissions will be lowered.

Magnetic rail wagons can operate continuously; waiting for other equipment or time lost to charge batteries is unnecessary. A magnetic rail system can offer better control and braking capabilities, as wagons are pulled instead of pushed. They are also quieter than traditional rail systems, reducing noise pollution.

8.2 Innovation components to be implemented (physical infrastructure, management of technology, etc.)

Based on the selected automation technologies (D1.3) and further analysis, as well as Living Hub's consultation activities, the list of technologies addressed and considered for the CBA is indicated in Table 7-1.

Table 8-1: List of technologies for UC3 (UC6)

Technology	Total purchase price (for all units) (EUR)	Life span of technology	Expected technology implementation period (in years)
Road			
Autonomous Electric Shunter	1 500 000	15 years	1 year
Supporting Infrastructure (charging station)	100 000	15 years	1 year
Autonomous Driving & Fleet Management Software	50 000	5 years	1 year
Connectivity (5G, Other)	Is available		
Road Total/Average	**1 650 000**	**11 years**	**1 year**
Rail			
Magnetic propulsion shunter	300 000	30 years	1,5-2 years
Track modification	3 900 000	30 years	1,5-2 years
Control system & software	Part of the System		
Rail Total/Average	**4 200 000**	**30 years**	**2 years**

Source: AUTOSUP elaborations.

These numbers are preliminary and indicative. Numbers and results will be adapted based on the use-case evaluation. The decision will be made to purchase or operational lease the solutions.

8.3 Costs and benefits estimates (related to investment, operational)

The total costs of Use Case 3 (UC6) (including one-time costs of solutions setup are part of the investment phase and yearly costs**) amount to 39 kEUR (at 2025 market prices).**

Table 8-2: Costs for UC3 (UC6)

Costs	Not discounted values (EUR)	Discounted values of 2025 (EUR) for 2026
Road		
Personal training	5 000	4 533
Maintenance Shuttle **(operational costs, yearly)**	4 000/year	3 626

Data hosting & IT management **(operational costs, yearly)**	15 000/year	13 599
Road total	**24 000**	**21 758**

Costs	Not discounted values (EUR)	Discounted values of 2025 (EUR) for 2026 (EUR)
Rail		
Maintenance **(operational costs, yearly)**	10 000/year	9 066
Personal training	5 000	4 533
Rail total	**15 000**	**13 599**

Source: Net discounted values are provided using a discount rate of 4 %.

These numbers are preliminary and indicative. Numbers and results will be adapted based on the use-case evaluation. Against its investment-related and operational costs, Use Case 3 (UC6) produces several benefits (positive impacts) worth 2,45 MEUR in real values. The main results are presented and commented on in this section, while the technical details are presented below Table 8-3.

Table 8-3: Total benefits for UC3 (UC6)

Impact/benefit	Constant (real) values in 2025 (EUR)
Road	
Reduction of Manual Truck Drivers	375 000
Fuel cost saving cost	150 000
Maintenance cost reduction	10 000
Insurance & safety cost reduction	10 000
CO2 reduction	85-100 %
Main activity costs reduction	**545 000**

Impact/benefit	Constant (real) values in 2025 (EUR)
Rail	
Reduction of Train crew	1 500 000
CO2 reduction	80-100 %
Port competitiveness	Higher capacity and throughput
Main activity costs reduction	**1 500 000**

Source: PoAB data.

The salary of a locomotive driver is around EUR40 000 per month. If they work 3 shifts per year, it will be around 1,5 MEUR. The positive impact of operational efficiency and infrastructural utilization will be related to eliminating waiting time, achieving high precision, and enabling self-service at the terminal. The system is weather-independent, as traction is achieved via magnetic force rather than through the wheels, ensuring a consistent quality of service.

The maintenance cost reduction is due to the absence of moving parts, resulting in less wear.

Reducing labour costs by introducing autonomous transport represents a significant cost saving for the ROAD shuttle. Especially if we focus on special shifts during the night or on weekends, where a 50 % surplus is paid. The transition from diesel to electric power will provide substantial operational cost savings, especially when the green power is generated on-site. Electric vehicles have lower maintenance requirements than diesel trucks due to their fewer moving parts and reduced wear on brake systems, which is achieved through regenerative braking. We expect productivity and efficiency gains as autonomous vehicles can operate more consistently and efficiently, with no need for idle times or changing drivers during shifts. Autonomous trucks might impact insurance costs due to improved safety records (still need to be determined).

We expect benefits for the Magrail Autonomous rail system by eliminating the current locomotive and safety crew. The magnetic propulsion railcars will replace the diesel locomotives, which consume a significant amount of fuel during idle and shunting operations. The current complex process of locomotive switching, train splitting, and repositioning creates delays and inefficiencies. The autonomous system can reduce this, making the process more flexible and helping to achieve better schedule reliability, increased terminal capacity, and higher throughput. Autonomous rail systems enable more flexible use of track infrastructure and capacity through precise control by the autonomous shunting unit. It also has fewer components and less wear compared to diesel locomotives, which positively impacts maintenance costs.

Both systems replace diesel-powered vehicles, contributing to significant reductions in CO2 emissions and thus a positive environmental impact through zero emissions and substantially reduced noise pollution. The improved efficiency and reduced operational costs enhance the port's competitive position, improve customer satisfaction, and retention rates.

8.4 Financial analysis

Separate CBA calculations are performed for road and rail automation cases.

Road case:

- Technologies – 1,65 MEUR (with life span – 11 years & implementation – 1 year)
- Implementation costs (one-time) – EUR5 000.
- OPEX – EUR19 000/year.
- Benefits – EUR500 000/year.

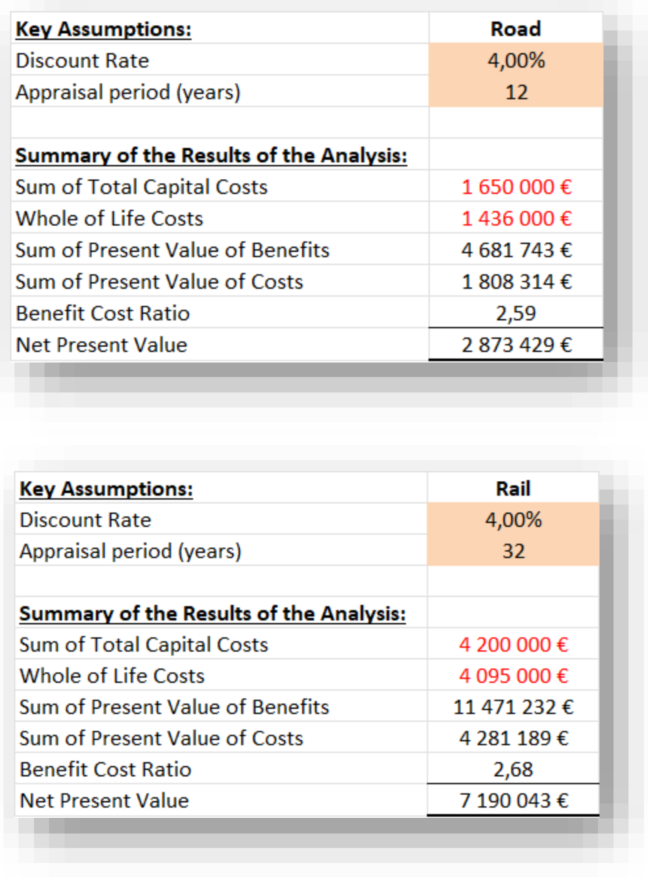
Rail case:

- Technologies – 4,2 MEUR (with a life span – 30 years & implementation – 2 years)
- Implementation costs (one-time) – EUR5 000.
- OPEX – EUR10 000/year.

- Benefits – 1,5 MEUR/year.

Results

Total number of years used for CBA: 1-2 years are planned for technology implementation (road – 1 year, rail – 2 years) plus the life span of technology years planned for technology usage. The life span of technologies dedicated to road and rail cases after implementation will be 11 and 30 years, respectively.



Key Assumptions:	**Road**
Discount Rate	4,00%
Appraisal period (years)	12
Summary of the Results of the Analysis:	
Sum of Total Capital Costs	1 650 000 €
Whole of Life Costs	1 436 000 €
Sum of Present Value of Benefits	4 681 743 €
Sum of Present Value of Costs	1 808 314 €
Benefit Cost Ratio	2,59
Net Present Value	2 873 429 €

Key Assumptions:	**Rail**
Discount Rate	4,00%
Appraisal period (years)	32
Summary of the Results of the Analysis:	
Sum of Total Capital Costs	4 200 000 €
Whole of Life Costs	4 095 000 €
Sum of Present Value of Benefits	11 471 232 €
Sum of Present Value of Costs	4 281 189 €
Benefit Cost Ratio	2,68
Net Present Value	7 190 043 €

Figure 8-1: Summary of financial analysis data

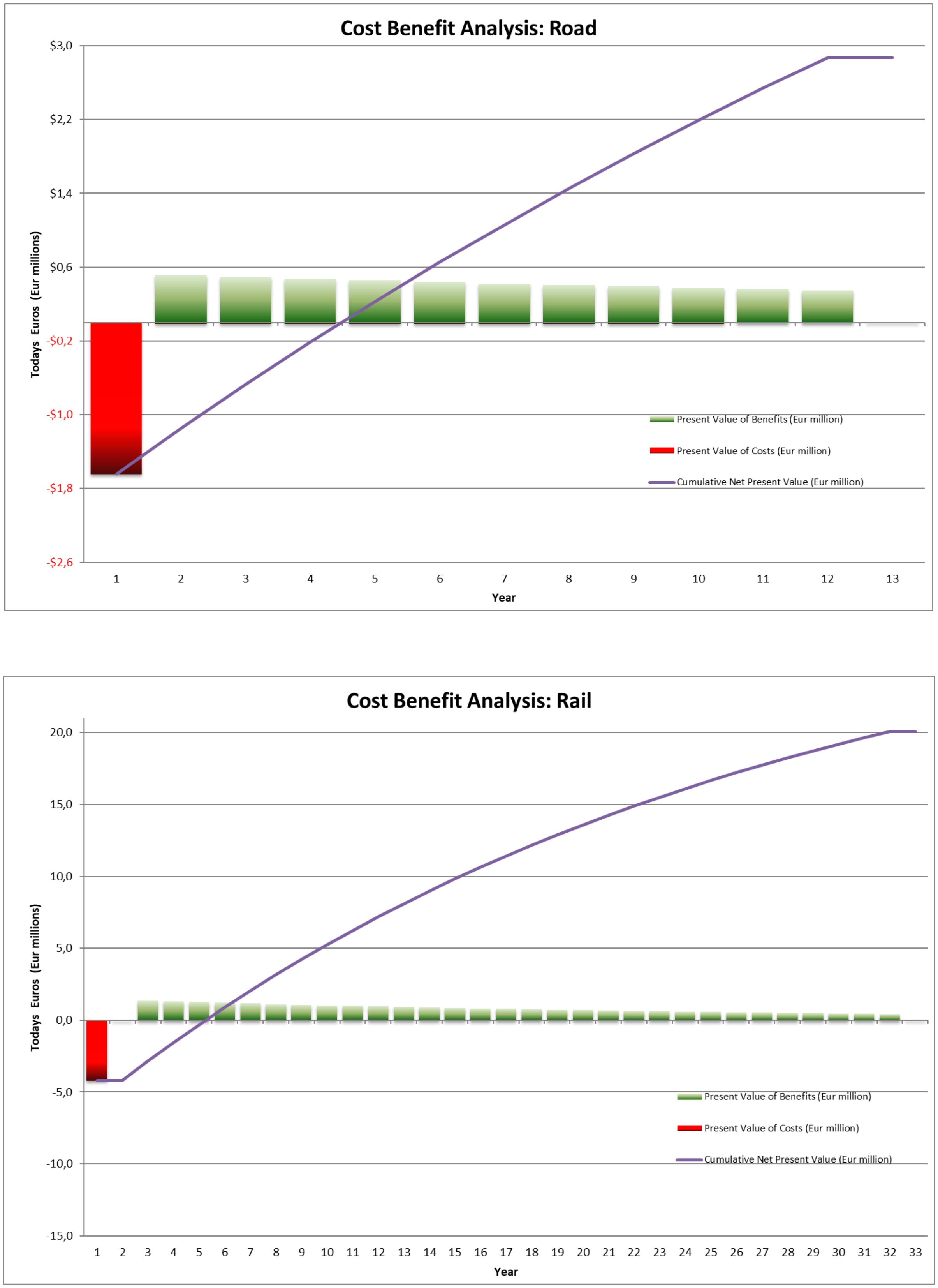


Figure 8-2: Changes of Present Values over time

The Cumulative Net Present Value shows that the investments in technology are paid back after the fourth year in road case and during the fifth year in rail case after the investments initiation.

Profitability on investment analysis

ROI metric used to evaluate the forecasted profitability of different investments

$$\text{ROI}_{\%} = \frac{\text{Annual Net benefits}}{\text{Initial value of investments}} \times 100$$

Where in the road case:
Initial value of investments – EUR1 650 000
Annual costs – EUR19 000
Annual benefits – EUR545 000
Annual Net benefits – EUR526 000

ROI road = (526 000 / 1 650 000) x 100.

ROI road = 31,9 %

Using this equation, the return on investment comes to 31,9 % in the road case.

Where in the rail case:
Initial value of investments – EUR4 200 000
Annual costs – EUR10 000
Annual benefits – EUR1 500 000
Annual Net benefits – EUR1 490 000

ROI rail = (1 490 000 / 4 200 000) x 100.

ROI rail = 35,5 %

Using this equation, the return on investment comes to 35,5 % in the rail case.

8.5 Environmental considerations

Further on, the environmental benefits are presented. Environmental benefits are calculated based on the description provided in Annex A I.

Table 8-4: Data for the calculation of Environmental benefits for UC3 (UC6)

Fuel-based transport equipment - Diesel truck	ROAD case
Yearly distance of equipment with allocated consignment (t-km)	9 120
Yearly distance of equipment without allocated consignment (km)	4 320
Average weight of consignment (in tonnes per year)	150 t/load

Type of transport equipment (Light Bus, Rigid truck, etc., if known)	Truck
Fuel type (diesel, petrol, gas, hybrid, etc.)	Diesel
Average generated CO2 values (gCO2/t-km) by a truck pulling 3 buiscar trailers with empty containers max 16 TEU per voyage. The maximum weight of the load is 150 tonnes	70 gCO2/t-km
Annual CO2 emissions (t CO2)	638,4 t CO2e
Multiplication of the total amount of CO_2 emitted (EUR/tonne) for the specified fuel type, diesel	EUR148/t CO2e

Electrically powered transport equipment - Autonomous shuttle	RAIL case
Yearly distance with allocated consignment (t-km)	9 120
Yearly distance without allocated consignment (empty runs) (km)	4 320
Average weight of consignment (in tonnes per year)	150 t/load
Utilised electricity (in kWh) per working hour	6 kWh/h
Total average working hours per month (in hours)	720 h/month
Specified electricity generation source (100 % wind)	100 % renewable
Multiplication of the total amount of CO_2 emitted (EUR/tonne).	EUR294,96/t CO2e

Environmental considerations are present through a) saved CO2 emissions, b) benefits for transport user, and c) externalities. The description is presented below.

Saved CO2 emissions

Per year 9 120 t-km from Diesel trucks (standard truck pulling 3 buiscar trailers with empty containers max 16 TEU per voyage). During the deliveries that caused the CO2 emission, the maximum load weight was 150 tonnes according to this use case.

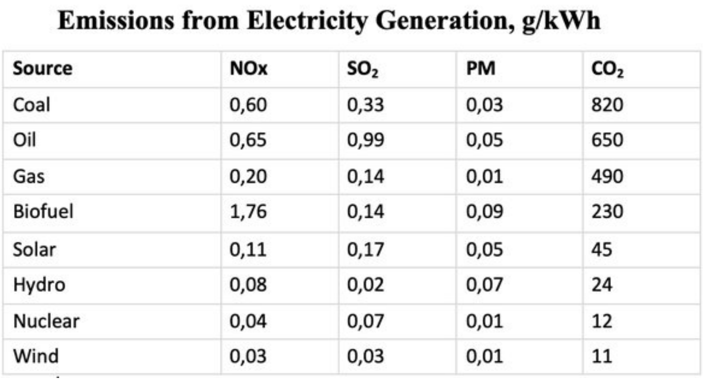
A diesel truck (max 16 TEU per voyage) using diesel generates 70 g CO2e/t-km (source: inputs from PoAB provided in Table 8-4).

When annual CO2 emissions are for the diesel truck usage case:

9 120 t-km x 70 g CO2e/t-km = 638,4 t CO2e

The annual CO2 emissions are 638,4 tonnes for the road case.

Following the article "How much carbon dioxide is produced when you charge an electric car?" available on the Quora (2024) website, **such CO2 emissions from electricity generation were reported.**



Emissions from Electricity Generation, g/kWh

Source	NOx	SO_2	PM	CO_2
Coal	0,60	0,33	0,03	820
Oil	0,65	0,99	0,05	650
Gas	0,20	0,14	0,01	490
Biofuel	1,76	0,14	0,09	230
Solar	0,11	0,17	0,05	45
Hydro	0,08	0,02	0,07	24
Nuclear	0,04	0,07	0,01	12
Wind	0,03	0,03	0,01	11

Figure 8-3: Emissions from electricity generation
Source: Quora, 2024

CO2 emissions for 100% wind is used for electricity generation. So, fully charging a 100 kW battery with a 100 % wind share in the energy mix will produce approximately 1,1 kg of CO2.

Let's assume that during charging in a wind-oriented country, when CO2e generated is calculated this way:

6 kWh/h x 720 x 12 = 51 840 kWh.

51 840 kWh x 11 g/kWh = 570,24 t CO2e per year.

The annual savings of CO2 emissions are 570,24 tonnes for the rail case.

Carbon dioxide equivalents (CO2e) measure the effect of different greenhouse gases (GHGs) on the climate.

Price for transport user

According to the European Commission (2021), Table 4, the multiplier for 2024 is EUR148/t CO2e. Avoided GHG emissions in tonnes of carbon dioxide equivalent (CO2e) are valued in monetary terms with a shadow cost of carbon (in Euro per tonne of CO2e).

Monetised spending of transport users in the diesel truck usage case:

638,4 t CO2e x EUR148/t CO2e = EUR94 483,2.

The transport user spends 94,4 kEUR per year.

Monetised spending of transport users in the electrically powered transport equipment usage case:

570,24 t CO2e x EUR148/t CO2e = EUR84 395,52.

The transport user spends 84,4 kEUR per year.

In total, transport user saves 178,87 kEUR per year.

Externalities

Externalities are spillover effects from the project towards third parties (neither consumers nor producers), for which no monetary compensation is provided.

The multiplier in 2021 for t-km (Belgium case) was EUR0,78 for Heavy goods vehicle (DG REGIO, 2021).
The multiplier in 2021 for t-km (Belgium case) was EUR0,1558 for Heavy goods vehicle (DG REGIO, 2021).

Monetised spending for air pollution using a diesel truck:

9 120 t-km x EUR0,78 = 7,1 kEUR

4 320 km x EUR0,1558 = 0,67 kEUR

Monetised spending for air pollution from diesel truck is 7,77 kEUR.

Following DEFRA (2023) report, the latest non-traded carbon price from the Green Book supplementary guidance is 248 GBP / tonne CO2e for 2020, which was applied in this analysis to calculate damage costs (BEIS, 2021).

When 1,000 GBP = EUR1,189, the price is EUR294,96/t CO2e.

Monetised spending for air pollution using electrically powered transport equipment:

Monetised savings for air pollution when an alternative electricity generation method is used:

570,24 t CO2e x EUR294,96/t CO2e = 168,19 kEUR

Monetised savings for air pollution from both (diesel truck and electrically powered transport equipment) cases are 175,77 kEUR.

Environmental externalities lead to reduced emissions or energy savings, these environmental benefits (valued at societal prices, such as the EU carbon price for CO_2 reduction) would be quantified on the benefit side. These environmental gains through shadow pricing of externalities ensure that the automation delivers net positive welfare for society at large.

Summary

Road case

Input	Input's value	Multiplicator	Multiplicator's value	Comment and source
Saved km for diesiel truck	9 k t-km	For scope 1	70 g CO2/t-km	Standard diesel truck pulling 3 buiscar trailers with empty containers max 16 TEU per voyage.
Tonnes of CO2 avoided/year	638,4 t	Shadow cost for carbon in Euro	148 Eur/ t CO2	Economic Appraisal Vademecum (EAV) (2021)
Externalities for air pollution per year	9 120 t-km 4 320 km	For air pollution based on vehicle type	0,78 Eur/t-km 0,1558 Eur/km	Calculation sheet of DG REGIO (2021) (BE case) for Heavy goods vehicle.

Rail case

Input	Input's value	Multiplicator	Multiplicator's value	Comment and source
Utilised electricity per year	51 840 kWh	For scope 1	11 g/kWh	100% wind
Tonnes of CO2 avoided	570,24 t	Shadow cost for carbon in Euro	148 Eur/ t CO2	Economic Appraisal Vademecum (EAV) (2021)
Externalities for air pollution per year	570,24 t CO2	For air pollution based on rail type	294,96 Eur/t CO2	BEIS (2021) for electric shuttle

8.6 Sensitivity analysis

Analysis of how changes in inputs affect changes in output (NPV)

The sensitivity of the base case NPV has been analysed following changes (which were specified in chapter 2.2) in several key variables, as follows:

1. an increase in the purchase costs of technologies by 20 %
2. a decrease in benefits by 20 %
3. an increase in costs by 20 %
4. a delay in the period of implementation, causing a delay in benefits generation by one year.

Proposed changes in key variables should be well-explained. The sensitivity analysis is based on the most likely changes. The effects of the above changes for road and rail cases are summarized in the tables below.

Table 8-5: Results of sensitivity analysis for UC3 (UC6) Road

Item	**Change**	**NPV** (EUR)	**SI(NPV)**
Base Case		2 873 429	
Purchase costs of technologies	20 % Xb – 1 650 000, X1 – 1 980 000	2 543 429	-0,574
Benefits	-20 % Xb – 545 000, X1 – 436 000	1 937 081	1,629
Costs	20 % Xb – 19 000, X1 – 22 800	2 840 786	-0,055
Implementation delay	One year Xb – 545 000, X1 – 0	2 359 567	0,179
SI – sensitivity indicator, NPV – net present value			

The higher the SI, the more sensitive the NPV is to the change in the variable concerned. NPV1 simultaneously declined in all cases. The worst-case scenario among the four key variables considered in the sensitivity analysis is observed in the second variable change case.

Regarding the 20 % increase in technology purchase costs, the sensitivity indicator (SI) is -0,574. This means that a 20 % change in the variable (purchase costs of technologies) results in an 11 % change (reduction) in the NPV1.

The highest sensitivity indicator is a 20 % reduction in benefits, as seen in the case. In the case of reducing benefits by 20 %, the sensitivity indicator (SI) is 1,629. This means that the change of 20 % in the variable (benefits) results in a change (reduction) of 33 % in the NPV1.

In the event of a 20 % increase in annual costs, the sensitivity indicator (SI) is -0,055. This means that a 20 % change in annual costs results in a 1,1 % change (reduction) in the NPV1.

A one-year implementation delay means that benefits will be available one year later. The sensitivity indicator (SI) is 0,179, and NPV1 will be worse by 18 %.

Table 8-6: Results of sensitivity analysis for UC3 (UC6) Rail

Item	**Change**	**NPV** (EUR)	**SI(NPV)**
Base Case		20 088 351	
Purchase costs of technologies	20 % Xb – 4 200 000, X1 – 5 040 000	19 248 351	-0,209
Benefits	-20 % Xb – 1 500 000, X1 – 1 200 000	15 197 130	1,217
Annual costs	20 % Xb – 10 000, X1 – 12 000	20 055 743	-0,008
Implementation delay	One year Xb – 1 500 000, X1 – 0	18 728 448	0,068
SI – sensitivity indicator, NPV – net present value			

The higher the SI, the more sensitive the NPV is to the change in the variable concerned. NPV1 simultaneously declined in all cases. The highest sensitivity indicator is a 20 % reduction in benefits in a case.

Regarding the 20 % increase in technology purchase costs, the sensitivity indicator (SI) is -0,209. This means that a 20 % change in the variable (purchase costs of technologies) results in a change (reduction) of 4 % in the NPV1.

In the case of reducing benefits by 20 %, the sensitivity indicator (SI) is 1,217. This means that the change of 20 % in the variable (benefits) results in a change (reduction) of 24 % in the NPV1.

In the event of a 20 % increase in annual costs, the sensitivity indicator (SI) is -0,008. This means that a 20 % change in annual costs results in a 0,2 % change (reduction) in the NPV1.

A one-year implementation delay means that benefits will be available one year later. The sensitivity indicator (SI) is 0,068, and NPV1 will be worse by 7 %.

9 Summary per Use Cases

UC	USE CASE NAME	CAPEX, EUR	ROI	SI
UC1	Automated maintenance and management of intermodal rail wagons	EUR750 000/7 years	49 %	1,19 - reduction of benefits by 20 %
UC2	Automated management of multimodal slots and last-mile routes	EUR180 000/5 years	18,4 %	3,7 - reduction of benefits by 20 %
UC3	Automated cross-border roll-on/roll-off (Ro-Ro) transhipment	8 MEUR/17 years	9,59 %	3,1 - reduction of benefits by 20 %
UC1 (UC4)	Port automations coordination and environmental performance	6,3 MEUR/12 years	13,41 %	406 - reduction of benefits by 20 %
UC2 (UC5)	Port-Shipper collaboration towards increased modal shift	0,9 MEUR/ 6 years	55,6 %	2,11- reduction of benefits by 20 %,
UC3 (UC6)	Port – Transport Mode Automation-systems integration	1,65 MEUR/11 years 4,2 MEUR/30 years	31,9 %; 35,5 %	1,63; 1,21 - reduction of benefits by 20 %

10 CBA generalisation and integration in the DSS

Deliverable D3.2 establishes the analytical framework used to evaluate the economic, operational, and environmental impacts of automation technologies applied in multimodal freight hubs within the AUTOSUP project. It defines how costs, benefits, and externalities are systematically identified, quantified, and compared across six automation Use Cases in the Living Hubs of Trieste and Antwerp-Bruges.

After conducting Cost-Benefit Analyses for six Use Cases, the methodology can be generalised into a reusable, configurable model that can be applied across different automation scenarios. This generalised CBA model is structured in a modular way, encapsulating separate components for costs, benefits, environmental impacts, and sensitivity analysis. By abstracting the common elements of each use case, the model ensures that the core logic is reusable and only the input parameters need to be adjusted for new cases, variables, or hubs. All use cases were evaluated under a consistent set of technical assumptions – for example, analyses share a 25-year time horizon (2025-2050) with future cash flows discounted at 4% annually, in line with EU appraisal guidelines. This consistency ensures that results are comparable and the framework remains configurable, allowing stakeholders to input their scenario data (e.g., capital costs, operating costs, demand forecasts) and obtain standardized outputs (NPV, ROI, payback period, emissions saved) without altering the underlying logic.

The CBA model is designed to be embedded within the AUTOSUP DSS, allowing replication of CBA logic across hubs and supporting “what-if” analyses. It provides decision-makers with a transparent, data-driven framework for evaluating automation investments and comparing scenarios for scaling and transferability.

Modular Components of the Generalised CBA Model. The CBA has been broken down into distinct modules, each of which can be customized or extended for new use cases while maintaining a common structure across the Decision Support System (DSS):

The Cost Module captures all investment (CAPEX) and operational (OPEX) costs throughout the project lifecycle. It allows the definition of cost elements (e.g., equipment purchase, maintenance, labor) along with their timing and asset life. Common financial assumptions (e.g., asset lifetimes and residual values) are applied uniformly across Use Cases, ensuring that cost calculations are modular yet comparable.

The Benefit Module accounts for financial and operational benefits generated by the automation. This includes direct savings (e.g., lower labor costs, fuel savings, and maintenance avoidance) and revenue gains or productivity improvements (e.g., higher throughput and reduced transit times) identified in each Use Case. The model standardises benefit categories, ensuring that, for instance, time savings, labor substitution, and error reduction are all quantified and monetised in a consistent manner across different scenarios. Operational benefits are quantified with high fidelity by a traffic micro-simulation that performs a direct comparison of a baseline to a new technology scenario. Non-monetary strategic benefits (such as safety or service quality) can be noted qualitatively or included through proxy metrics, maintaining flexibility in the model. In AUTOSUP’s digital platform, this process is automated by capturing supply-demand trade-offs utilising the EU network flow model. This model is a macro-simulation that considers Europe’s TEN’T network as a system of nodes and corridors to model aggregate cargo movements. The model establishes a network with predefined source and sink nodes, along with their associated multi-commodity supply and demand capacities, respectively. Sources are linked optimally to sink nodes, considering the capacitated links available between various nodes in the network. Network performance is evaluated based on link and node costs that arise from a generalised cost function and travel times. The model produces an estimate of how demand varies for a selected Living-Hub node upon the deployment of a technology that yields operational efficiency improvements, such as higher throughput, reduced travel time, or lower costs.

The Environmental Module integrates environmental benefits by calculating emissions reductions and other external impacts. For each Use Case, the tool estimates changes in CO_2 emissions and energy usage between the baseline (as-is) and automated (to-be) scenarios. The estimations are based on the operational performance improvement measured from the traffic micro-simulation compared to the baseline scenario. These impacts are monetised using standardised factors (e.g., EU reference values for CO_2 pollution) or reported as physical units if preferred. This modular approach ensures that sustainability benefits (such as emission savings from road-to-rail modal shift) are captured and can be compared or summed across scenarios. For example, one use case's automation yielded an external air pollution benefit equivalent, which can be further incorporated either into the benefit-cost calculations or presented alongside financial results to provide a fuller picture of the impact.

The Sensitivity & Risk Module accounts for uncertainty; the CBA logic includes a uniform sensitivity analysis framework applied to all cases. A standard set of sensitivity tests has been defined for all use cases. For instance, a 20 % increase in technology investment costs, a 20 % shortfall in realised benefits, a 20 % rise in operating costs, and a one-year implementation delay are each evaluated. The model computes a sensitivity indicator comparing the percentage change in NPV to the change in each variable. This modular sensitivity approach, embedded in the CBA, highlights which variables each project is most sensitive to (e.g., capital cost overruns versus benefit reduction) and ensures a consistent risk assessment methodology across use cases. By applying the same relative changes and measuring the impact on NPV, the DSS can flag high-risk scenarios; for example, a capital expenditure (Capex) increase might reduce a given use case's NPV, indicating high sensitivity to investment cost. Such findings help stakeholders understand risk factors in any new scenario evaluated with the tool.

All these components are implemented so that inputs and outputs are handled in a standardised format. The DSS CBA interface accepts input datasets (either manually entered by users or retrieved from simulations and databases) corresponding to the above modules, such as cost tables, benefit assumptions, throughput data, and emission factors, and then executes the analysis using this logic. The output is delivered as a set of key performance indicators and charts, including net present value, ROI, benefit/cost ratios, payback period, and aggregated environmental impacts. These results are presented in the DSS in an accessible manner for decision-makers, allowing stakeholders to run "what-if" analyses within the same platform.

In practice, this means the AUTOSUP DSS simulates an automated logistics scenario against a baseline scenario and directly calls the generalised CBA model to evaluate the scenario's financial feasibility and sustainability impact in real-time. This integration aligns with the project's goal of a data-driven DSS that supports strategic decision-making by evaluating new automation solutions across sustainability, financial, and other dimensions.

Through generalisation, the CBA model cannot be static, but rather a dynamic tool within the DSS. Stakeholders (such as port authorities, logistics operators, or policymakers) can adjust parameters or input new use case data and obtain immediate feedback on expected costs, benefits, and risks. The modular design could guarantee that as new information becomes. Moreover, applying a uniform set of technical assumptions and a common sensitivity framework across all analyses ensures fairness and comparability. Decision makers are based on like-for-like evaluations grounded in the same economic principles and assumptions. In summary, the generalised CBA serves as a configurable evaluation engine within the DSS, transforming the rich data from the Living Hub simulations into actionable insights on economic viability and sustainability for any proposed automation initiative.

11 Conclusions / Future work

This deliverable has presented a comprehensive cost-benefit evaluation of six Use Cases, yielding several empirical and methodological insights for autonomous multimodal freight hubs. Across all six Use Cases, clear patterns emerged in terms of financial viability, operational value drivers, and environmental benefits. The analysis also highlighted key risk factors that could impact outcomes, informing both stakeholders and the project team about where to focus their efforts. In this concluding section, we summarise these cross-cutting findings and outline future work to refine the CBA approach and support ongoing decision-making through the DSS.

These patterns suggest that, beyond financial metrics, automation delivers multifaceted value, i.e., speeding up logistics, cutting costs, increasing capacity, and improving sustainability. The Use Cases generating strong ROI generally excelled in harnessing several of these drivers simultaneously (for example, combined labour savings with time savings and capacity expansion), whereas the weaker cases often produced benefits that, while real (e.g., environmental improvements), did not directly accrue as financial gains.

Despite the differences in financial metrics, the six Use Cases revealed common value drivers that underpin the benefits of automation. Across Trieste and Antwerp-Bruges Living Hubs, automation interventions consistently delivered improvements.

The increase in operational costs (e.g., higher maintenance costs than planned) also negatively affected NPVs, albeit to a slightly lesser extent, while implementation delays (e.g., benefits starting a year later) had a noticeable but smaller impact on economic outcomes.

These tests underscore the importance of robust project management and conservative planning, ensuring realistic benefit projections (avoiding overly optimistic uptake assumptions) and containing implementation costs will be key to delivering the promised returns. They also highlight the value of the DSS and digital twin approach in the project - by continuously updating scenarios with real data, stakeholders can detect early if benefits are tracking below expectations and can take corrective action (or re-evaluate the business case). Such insights are invaluable for decision-makers to gauge which projects require risk mitigation strategies, such as contingency budgets or phased deployment, to test benefits before full rollout.

Building on the findings of D3.2, future work will focus on applying the CBA methodology and leveraging it within the project's DSS for ongoing decision support in the validation and feasibility analysis implementation of the multimodal operational models in the two AUTOSUP Living Hubs. The analysis so far has been based on extensive assumptions and pilot data; as the project progresses, more empirical data is collected from demonstrations and stakeholder inputs. In practical terms, cost estimates, benefit calculations, and demand forecasts based on real observed values could increase the decision maker's confidence.

12 References

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Annex I - Environmental benefits

Two transport modes fuel-based and electricity-based are compared in terms of CO_2 emissions and electricity consumption.

Emissions for Hyperloop, which are electrically powered, are assessed concerning the upstream process of production of the required increase in electric energy. These emissions do not happen at the point of use of the Hyperloop but at the point of energy production, depending on the national energy mix.

In summary, although a small increase in CO2 emissions is expected due to the increase in electricity consumption for Hyperloop's operations (emissions related to energy production), the project will lead to an overall (incremental) reduction of CO2 emissions.

The calculation of the impact of CO2 emissions for the current fuel-based transport unit was made based on the following steps:

- yearly distance, in vehicle-km, by transport unit with allocated consignment;
- yearly distance, in vehicle-km, by transport unit without allocated consignment;
- average weight of consignment (in tonnes per year);
- type of transport equipment (Light Bus, Rigid truck, etc.);
- Fuel type (diesel, petrol, gas, hybrid, etc.);
- average consumption values (gCO2/v-km) to calculate the incremental emission of CO2;
- multiplication of the total amount of CO2 emitted by a unit cost (EUR/tonne).

The calculation of the impact of CO2 emissions for Hyperloop was made based on the following steps:

- yearly distance (KWh/hyperloop-km) for Hyperloop with allocated consignment;
- yearly distance (KWh/hyperloop-km) for Hyperloop without allocated consignment;
- average weight of consignment (in tonnes per year);
- average consumption values (in KWh) by a national average emission factor (gCO2/KWh) to calculate the incremental emission of CO2;
- Utilised electricity (in kWh) per working hour;
- Total average working hours per month (in hours);
- Specified electricity generation source (hydro, coal, wind, etc., if known);
- multiplication of the total amount of CO2 emitted by a unit cost (EUR/tonne).

Table AI-1: Data for the calculation of Environmental benefits

Fuel-based transport equipments	Equipment1
Yearly distance of equipment with allocated consignment (t-km)	
Yearly distance of equipment without allocated consignment (km)	
Average weight of consignment (in tonnes per year)	
Type of transport equipment (Light Bus, Rigid truck, etc., if known)	
Fuel type (diesel, petrol, gas, hybrid, etc.)	
Average generated CO2 values (gCO2/t-km)	▨

Multiplication of the total amount of CO_2 emitted (EUR/tonne) for specified fuel type……………………….	
Electrically powered transport equipment	**AGV or Hyperloop**
Yearly distance (kWh/equipment-km) with allocated consignment	
Yearly distance (kWh/equipment-km) without allocated consignment (empty runs)	
Average weight of consignment (in tonnes per year)	
Utilised electricity (in kWh) per working hour	
Total average working hours per month (in hours)	
Specified electricity generation source (hydro, coal, wind, etc., if known)	
Multiplication of the total amount of CO_2 emitted (EUR/tonne).	

Based on the data provided, environmental benefits are calculated (Equations AIII.1-AIII.3):

Calculate CO2 Emissions:
The CO2 Emissions for both scenarios (Base scenario and New scenario) can be calculated as follows, where the weight is important for figuring out Average Consumption values:

$$CO2\ Emissions\ =\ Distance\ \times\ Average\ Consumption\ value$$
(AIII.1)

Calculate the Difference in CO2 Emissions:
Compare the emissions for the Base scenario with the emissions for the New scenario to find the Additional CO2 Emissions (the difference in CO2 Emissions):

$$Additional\ CO2\ Emissions\ =\ CO2\ Emissions\ (Base\ scenario)\ -\ CO2\ Emissions\ (New\ scenario)$$
(AIII.2)

Calculate the Impact:
Multiply the Additional CO2 Emissions by the Cost per tonne of CO2 emitted (EUR/tonne):

$$Impact\ =\ Additional\ CO2\ Emissions\ \times\ Cost\ per\ tonne\ of\ CO2\ emitted$$
(AIII.3)

The accurate data for distance, average consumption, and cost per tonne of CO2 emitted have to be entered.

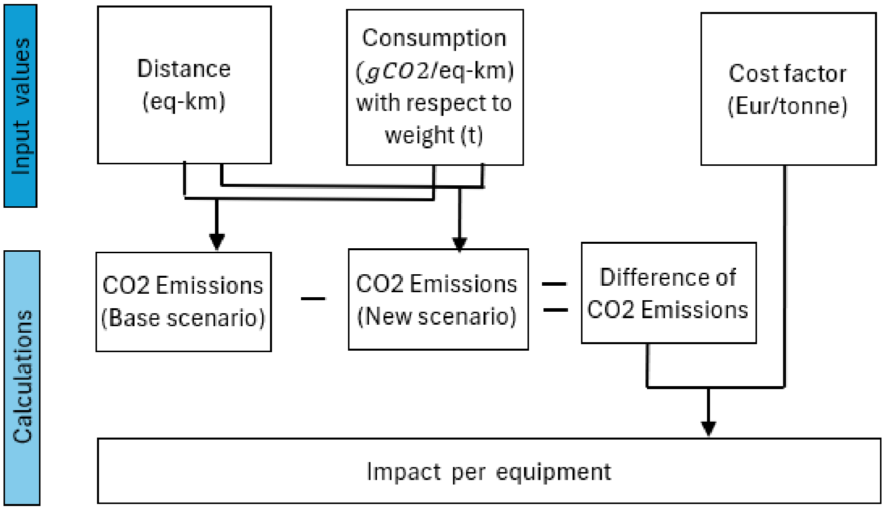

Figure AI-1: Methodology for impact evaluation

In other more complex cases, for impact evaluation specific methodology could be applied following European Commision (2019) handbook.

Annex II – Data sources for UC2 Trieste

Below are reported the assumptions and the calculation logic used to estimate the monetary values in Table 4-3 for UC2.

Summary of assumptions used

1. Annual shipments on Trieste–Turkey corridor taken as an order of magnitude to avoid sensitive disclosure: ~3 500 shipments/year (used for internal modelling; we can provide ranges if needed).
2. Manual coordination time (AS-IS) per shipment: 1.0 hour (calls, emails, admin). Automation reduces this by 70 % (TO-BE).
3. Staff cost (fully loaded) for coordination tasks: EUR30 / hour.
4. Average waiting/idle time at terminal per shipment (AS-IS): 1.2 hours; expected waiting after DSS/TAS: 0,3 hours → 0,9 h saved per shipment.
5. Truck operating cost (driver + fuel + overhead while waiting/idle): EUR16 / hour (conservative composite value used to monetise waiting-time savings and avoided inefficiencies).
6. Additional productivity/efficiency gains (better routing, reduced empty-km, fewer re-schedules/errors) are aggregated into the "main activity costs reduction" line rather than itemised, to avoid exposing sensitive operational metrics.

Calculations (how we reach the Table 4-3 numbers)

A) Reduction of operational costs — target EUR75 000
This refers mainly to saved labour for manual coordination.

Saved hours from reduced manual coordination = shipments × manual time per shipment × reduction = 3 500 × 1,0 h × 0,70 = 2 450 h saved

Monetary saving = saved hours × staff cost = 2 450 h × EUR30/h = EUR73 500 → rounded to EUR75 000 (conservative rounding and allowance for small additional admin savings during onboarding).

B) Main activity costs reduction — target EUR50 000 This covers waiting/idle time reductions and routing/empty-km efficiencies.

Saved truck hours (waiting/idle) = shipments × waiting time saved = 3 500 × 0,9 h = 3 150 h saved

Monetary saving (waiting + productivity) = saved truck hours × truck operating cost = 3 150 h × EUR16/h = EUR50 400 → reported as EUR50 000 (rounded and aggregated with modest routing/empty-km gains).

Total benefits = EUR75 000 + EUR50 000 = EUR125 000 (reported in Table 4-3).

Notes

- Numbers are conservative, rounded and expressed at an aggregated level to avoid disclosing commercially sensitive detail. If reviewers need a sensitivity/range table we can provide a ± scenario (low/medium/high) showing the effect of shipment volumes, % time reduction, and unit costs on benefits.
- Key drivers: number of shipments per year, assumed coordination time saved (70 % is our conservative estimate for TAS+DSS automation), and the cost rates used. Small changes in any of these parameters materially affect results (this is already visible in our sensitivity analysis).
- If you prefer, we can replace the fixed 3 500 shipments with an interval (e.g., 3 000 – 4 500) and show benefit ranges rather than point estimates.

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