Cost and Demand Prognostication Tool for Demand-Responsive Transportation

Written by Spare Labs in contribution to SEI Tallinn's RESPONSE Project

October 2021

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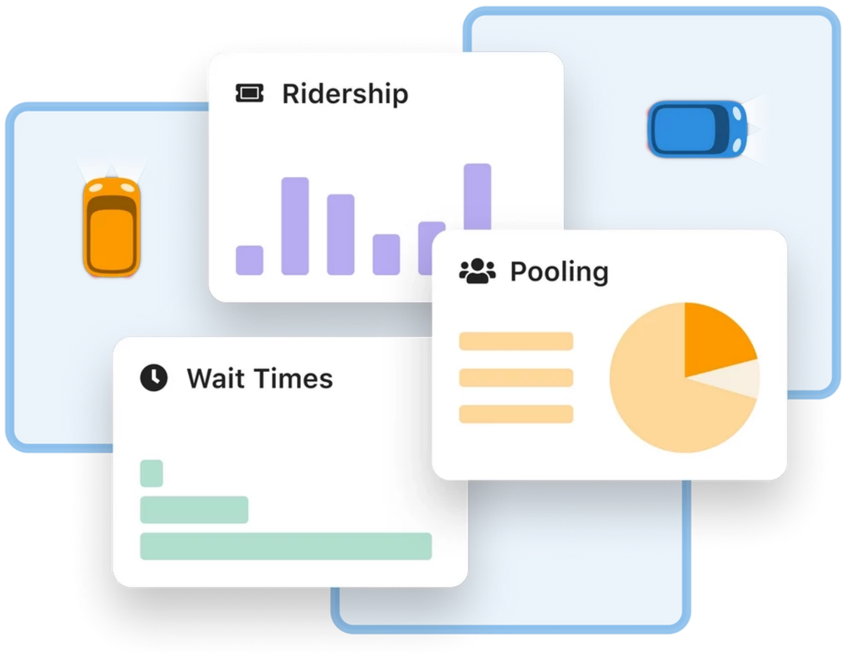

Spare Realize is a fundamentally new way of planning and optimizing transportation networks. At its core, it is a transportation network simulation tool that can be used to run quick and informative transit simulations during the planning and operational stages of a transportation service.

This document, prepared by Spare Labs (henceforth referred to as Spare) for the Stockholm Environment Institute (SEI), documents Spare's development of a demand responsive transport cost and demand prognostication model for public use.

This report and the model form part of the RESPONSE Project, which aims to develop, coordinate, and expand existing publicly funded transport services in the Baltic Sea Region. The project was financed by Interreg.

Response

Interreg Baltic Sea Region

EUROPEAN UNION

EUROPEAN REGIONAL DEVELOPMENT FUND

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Executive summary

Overview

In this report, we outline how Spare Labs developed a bespoke demand prognostication model for demand-responsive transportation (DRT), as part of the RESPONSE project. The report includes details on the methodology for how the model was developed, instruction material for using the model, training of selected participants in a workshop and one-to-one settings, and the testing and refinement of the model.

Project objectives

The main objectives of this project with Spare was to:

1. Introduce a new way of simulating demand-responsive transportation (DRT) services to stakeholders who plan and operate transportation in the Baltic Sea region, and understand their needs regarding a public-facing planning model.
2. Develop a planning model for forecasting the cost and demand of DRT, allowing users to analyze the costs, prices and demand related to transport planning.
3. Help formulate policy in sparsely populated areas of the Baltic Sea region, by outlining how to make current public transport and DRT more cost-effective and determine the most optimal ticket price for the transport services in these areas.

Workshops and training

As a core part of the project, and to address Objective 1, Spare provided free licenses for up to 20 separate municipalities and transit agencies to use Realize over a period of 12 months. Two workshops were provided for potential participants. In exchange for free access and training to Realize, partners agreed to actively provide feedback on the features of the Realize tool.

Based on this feedback, Spare organised followup discussions with a handful of engaged workshop participants to better understand their needs when it came to a publicly accessible, Excel-based model. This was used to develop the DRT model included as part of this report, which can be published in public form by SEI as part of the RESPONSE project.

Model functionality

The core functionality of the Excel-based model is split into three key themes:

1. The model estimates the demand for DRT in the study region, given basic demographic information from the user.
2. The model calculates the key performance indicators (KPIs) of a service designed to address that demand.
3. The model estimates basic financial, social and environmental return on investment (ROI) from the designed service.

Cutting across the key functionalities, the model also compares the forecasted costs and quality of DRT with the currently available public transport service in the study area.

The model is built in such a way that the user inputs some key information in an input tab, and navigates to an output dashboard tab to evaluate the predicted performance of their simulated DRT system. Full instructions are provided in this report and in an 'Introduction' tab in the model file itself.

Two versions of the model were provided to SEI:

1. A complete non-public version of the model with all editable tabs shown, including model formulae and default (non-editable) values and cells.
2. A simplified version of the model for public consumption, where the majority of the 'backend' is hidden from view.

Additionally, an online training video was produced by Spare to help guide users in how to navigate through the model. It is intended for public use and can be found at: https://www.loom.com/share/9e30d703fae541198b97522936cf23e3

Case studies

In order to demonstrate the value of both the Excel-based demand prognostication model and the platform-based Realize model, we explore a variety of case studies at the end of this report. For the Excel-based model, we used Saaremaa (Estonia), Võru (Estonia) and Sunne (Sweden), to demonstrate how the model can be applied to typical rural areas in the Baltic Sea region.

The results from the case studies are summarised in Table 0. Brief recommendations and conclusions are provided for each case study, based on the findings. Spare provided some recommendations and general scenarios for each case study region, but it was not within the scope of this study to comment on the strategic, procurement and legal framework for adopting DRT in each region, because these issues are so context-specific.

		Daily trips	No. of vehicles	Vehicle hours	Efficiency (PPVH)	Median wait time (mins)	Max wait time (mins)	Annual costs (,000 €)	Annual benefits (,000 €)	Cost per trip (€)	Agency ROI	Annual GHG emissions (tonnes CO2e)
Saaremaa	Small scale	213	4	40	5.3	20.8	91	500	180	7.84	0.36	230
	Medium scale	711	18	180	4	33.6	181	2,200	670	11	0.3	770
	Large scale	3557	70	700	5.1	-	-	8,820	3,330	8.33	0.38	3,840
Võru	Small scale	28	1	15	1.7	13.4	41.5	186	17	28.27	0.09	20
	Medium scale	85	2	24	3.6	15.7	56.7	300	59	12.65	0.2	60
	Large scale	427	10	110	3.9	25.4	124.2	1,380	370	11.47	0.27	320
Sunne	Small scale	11	1	10	1.1	13.1	39.3	126	7	46.84	0.06	10
	Medium scale	36	1	15	2.4	13.9	45	186	25	19.65	0.13	30
	Large scale	179	4	40	4.5	19	79.4	504	160	9.73	0.32	140

Table 0. Summary of case study findings.

Overview and context

Spare Labs is a leading software provider that powers demand-responsive transportation all over the world. Spare has developed Realize, a planning tool that allows users to easily and rapidly prototype demand-responsive transportation (DRT) zones in a simulation environment.

As part of the RESPONSE project, Spare was contracted by the Stockholm Environment Institute (SEI) to develop a DRT cost and demand prognostication model for public use. This included preparing instruction material for the model, training of selected participants, and producing this summary report.

It was important for the model to be publicly available and free of charge in the Baltic Sea region, to contribute to the broader development of DRT. Its remit was to be usable independently by public transport authorities, local public transport service providers as well as public sector coordinators in policymaking.

RESPONSE project

The RESPONSE project aims to develop, coordinate, and expand existing publicly funded transport services in the Baltic Sea region. Public authorities currently responsible for organizing public transport often lack the capacity to address the challenges or capitalize on new technological opportunities to further develop public transport infrastructure and usability. The RESPONSE project aims to increase the use and uptake of best practice and new technological improvements within the public transport sector, such as open access to mobility data, the digital revolution and demand-responsive solutions.

The RESPONSE project aims to outline and address the untapped potential of DRT solutions that have been developed in the Baltic Sea region since the 1990s, and improve the accessibility and reliability of transport in sparsely populated areas. Unlike fixed bus lines, it creates opportunities, DRT enables smoother journeys, digital business models and flexible demand-based service design, to allow services and user groups to be coordinated more cost-effectively than specialized transport services (such as medical transport).

Objectives and approach

Project objectives

Together with SEI and RESPONSE, Spare outlined the following objectives for this project:

1. Introduce a new way of simulating demand-responsive transportation (DRT) services to stakeholders who plan and operate transportation in the Baltic Sea region, and understand their needs regarding a public-facing planning model.
2. Develop a planning model for forecasting the cost and demand of DRT, allowing users to analyze the costs, prices and demand related to transport planning.
3. Help formulate policy in sparsely populated areas of the Baltic Sea region, by outlining how to make current public transport and DRT more cost-effective and determine the most optimal ticket price for the transport services in these areas.

Realize workshops

As a core part of the project, and to address Objective 1, Spare provided free licenses for up to 25 separate municipalities and transit agencies to use Realize over a period of 12 months. Two workshops were provided for potential participants:

1. February 25th 2021: Introduction and demonstration of Realize
2. March 3th 2021: A practical training session for prospective users

In exchange for free access, partners agreed to actively provide feedback on the features of the Realize tool (see Figure 1 for the advertised opportunity). As a beta product (i.e. still in development) that was already adding huge value to transportation planning departments, Spare was looking to improve the user experience.

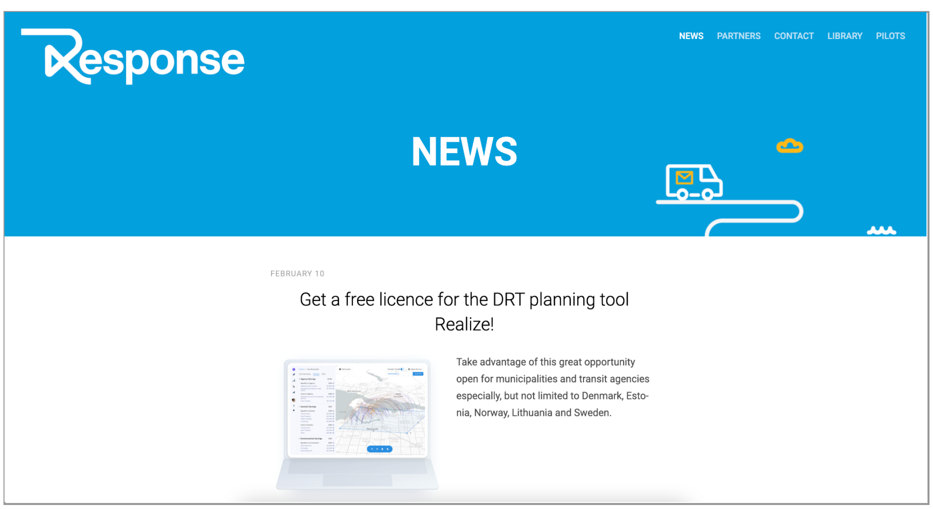

Figure 1. A screenshot of the advertisement for a free Realize licence on the RESPONSE webpage.

Eligible study regions for the Realize workshops extended to any transit agency or municipal planning department especially, but not limited to, Denmark, Estonia, Norway, Lithuania and Sweden. All fourteen organizations that participated in the training workshop were consulted for feedback, after 1 month of being granted access to the Realize platform. Three organizations replied with helpful feedback, which was acted upon by the Spare team. The feedback addressed usability issues of the Demand Model, as well as visual tweaks requested for mapping and dataset visualization.

Feedback and testing

Spare contacted all workshop participants to gather feedback about the Realize tool, to improve its functionality for users during the free trial period, but also to understand their needs for the eventual public-facing model to be handed over to SEI/RESPONSE.

As part of the project agreement, the model was due to be tested in at least three sparsely populated rural areas within at least one RESPONSE project partner countries, where DRT is a relatively new service or will soon be launched. This testing phase was achieved in two ways:

1. The Spare team explored Realize projects with workshop participants, and spoke directly with them to gather feedback and understand what they needed from the model for their particular test sites.
2. Once Spare had built a stable version of the public-facing model, the SEI/RESPONSE team distributed it to participants and asked for testing feedback. Once received, this was forwarded to Spare, and appropriate changes were made to the model before finalising the model.

Case studies

In order to demonstrate the value of both the Excel-based demand prognostication model and the platform-based Realize model, we explore a variety of case studies at the end of this report. For the Excel-based model, we used Saaremaa (Estonia), Võru (Estonia) and Sunne (Sweden), to demonstrate how the model can be applied to typical rural areas in the Baltic Sea region.
By applying the model to the chosen case study regions, we are able to provide some indications on how to improve the DRT service in the regions. We do this by comparing the alternatives, analyses of possible measures to be taken, and recommendations for making DRT more efficient, appealing and user friendly in the regions. In Saaremaa and Võru, where a DRT service is currently already being provided, the model allows us to assess the efficiency of the transport service (both in terms of costs and quality) and, if necessary, to improve the service.

Methodology

Core functionality of model

The core functionality is split into three key themes:

1. The model estimates the demand for DRT in the study region, given basic demographic information from the user.
2. The model calculates the key performance indicators (KPIs) of a service designed to address that demand.
3. The model estimates basic financial, social and environmental return on investment (ROI) from the designed service.

Cutting across the key functionalities, the model also compares the forecasted costs and quality of DRT with the currently available public transport service in the study area.

Input and output data

The model is built in such a way that the user inputs some key information in an input tab, and navigates to an output dashboard tab to evaluate the predicted performance of their simulated DRT system. Table 1 summarizes the sheets, their public/hidden status in the public-facing model, and a description of each sheet.

Table 1. Summary of model sheets.

Sheet name	Status	Description
Introduction	Public	Overview of the model and instructions for how to use it.
Inputs	Public	Main inputs for the model, which affect calculations and the results displayed in the Dashboard.
Dashboard	Public	At-a-glance demand estimations, KPIs and ROI results.
Model_TripData	Hidden	Calculates key trip-based parameters to estimate demand.
Model_CostBenefits	Hidden	Calculates the costs/benefits of the DRT service to the transportation authority and environment.
Model_TripDistanceDistributions	Hidden	Calculates cumulative distributions of trip distances by zone type.
Model_TripTimeDistributions	Hidden	Calculates cumulative distributions of trip times over a typical day.
Model_KPIcoefficients	Hidden	Coefficients for the regression model predicting KPIs, trained on real data acquired by Spare.

Model usage instructions

The principal steps to be taken by the user are as follows:

1. Navigate to the Inputs sheet and input as many parameters as possible based on data relevant to your study area.
    a. The parameters are split into different categories: General, Service Design, Operational Assumptions, Costs for both DRT and Fixed Route Transportation, Auto, Mode Split / Mode Shift for both before and after DRT.
    b. You should enter parameters for each field as accurately as possible in Column B (yellow column).
    c. If you're not sure about a value for your area, you can always use the default value provided in Column D.
    d. Ensure all fields in "Parameter Value" (column B) of the Inputs tab are NOT EMPTY. Use suggested default values if needed.
2. Once the input data is as accurate as possible, navigate to the Dashboard sheet.
3. The results and dashboard graphs are automatically calculated based on your inputs, and shown in the Dashboard sheet.
    a. You can save the data from the tables or the graphs by copying and pasting to a new sheet, or by taking a screenshot.
4. If interested in scenario testing, navigate back to the Inputs sheet and change parameters accordingly.
5. All sheets named 'Model_xxxx' contain model calculations. Do not alter the calculations in these sheets.

The Dashboard is organised into the three key themes of the model's core functionality. The first section displays a summary of the service, including total ridership split by vehicle type, typical trip distances and the distribution of trips throughout a typical day (Figure 2).

DRT service summary (daily)			Detail
Daily DRT trips (dedicated and non-dedicated)		248	Total number of on-demand trips taken on all types of vehicles in the service.
Daily DRT trips (dedicated only)		198	Total number of on-demand trips taken on dedicated vehicles only.
Daily DRT trips (non-dedicated only)		50	Total number of on-demand trips taken on non-dedicated vehicles only (e.g. taxis).
Daily vehicle hours (dedicated vehicles)		20	Total number of vehicle hours supplied to the service by dedicated vehicles.

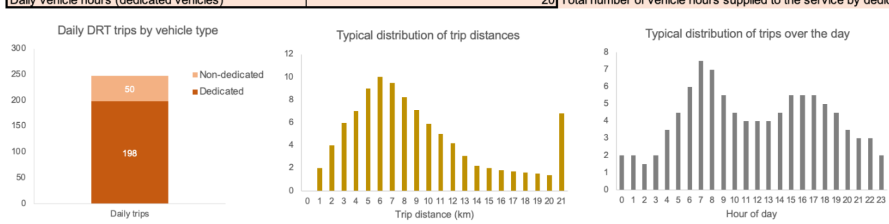

Figure 2. Example of the service summary section in the model dashboard tab.

The second section displays operational Key Performance Indicators (KPIs), including service efficiency, wait times, and pooled trip ratios (Figure 3). These are calculated based on a regression model built across the Model_xxx tabs.

Key Performance Indicators (KPIs) (daily)		Detail
DRT service efficiency (PPVH) (#)	9.9	Average efficiency (or 'productivity') of the service, measured in passengers per dedicated vehicle hour (PPVH).
Median wait time (mins)	21.9	The median time a passenger must wait to be picked up once they have booked a trip.
Max wait time (mins)	97.0	The maximum time a passenger must wait to be picked up once they have booked a trip.
Pooled trips ratio (%)	100.0	Percentage of trips where a passenger shared their trip with another passenger.
Mass transit service efficiency (PPVH) (#)	10.0	Average efficiency (or 'productivity') of mass transit, measured in passengers per dedicated vehicle hour (PPVH).

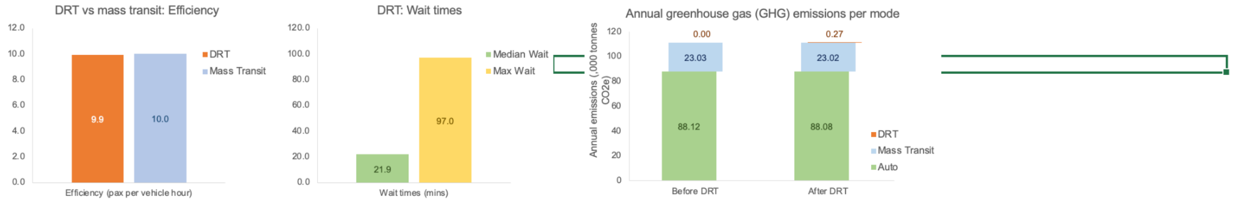

Figure 3. Example of the key performance indicators (KPIs) section in the model dashboard tab.

The third section displays a financial summary of the service, including cost/benefit analysis, return-on-investment analysis and cost-per-trip analysis (Figure 4).

Cost / Benefit Analysis (annual)		Detail
Fare revenue (€)	120,437	Total revenue from increased fares collected in the on-demand service.
Fixed-route transportation cost savings (€)	50,022	Changes in operational costs of fixed-route mass transportation, following the introduction of on-demand service.
Agency benefits (€)	170,459	Total of transit cost savings and revenue from fares. Negative values represent a loss.
Agency costs (€)	-430,524	Annual operational costs and amortized capital costs of running the on-demand service. Negative values represent a loss.
Agency net savings (€)	**-260,065**	Total benefits minus total costs per year. Negative values represent a loss.
Net annual savings for environment (GHGs) (€)	26,254	Total benefits from GHG savings. Negative values represent a loss.

ROI / Costs Per Trip		Detail
Return on Investment for agency (ROI)	0.40	Total benefits to the agency, divided by the cost of investment annually. For every €1 , what is the return?
Return on Investment for environment (EROI)	0.06	Total benefits to the environment, divided by the cost of investment annually. For every €1, what is the return?
Cost per DRT trip (€)	5.03	Total costs, minus fare revenue, divided by total trips.
Cost per mass transit trip (€)	8.50	Total costs, minus fare revenue, divided by total trips.

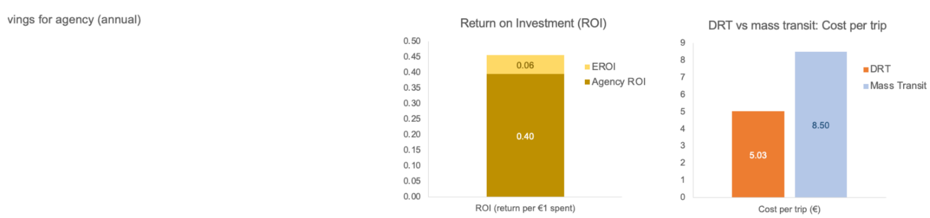

Figure 4. Example of the financial summary section in the model dashboard tab.

Assumption rate for modelling demand

It is worth mentioning a specific model parameter that forms a key part of the demand prognostication section of the model. That is the 'Assumption rate', located in the 'Inputs' sheet of the model.

The Assumption rate describes the proportion of all mobility trips that are taken using DRT, once a service is introduced to a particular region. Adoption rates are notoriously difficult to predict in any region, and are affected by a multitude of interlinked factors including the availability of other transportation options, local attitudes to public transportation, and the marketing of the service.

To simplify the process of choosing an appropriate assumption rate for users who may be less familiar with transportation dynamics in a given region, Spare has developed a range of adoption rates that capture over 90% of predictable demand in its operational services worldwide. We set the 'low' adoption rate to 0.05% of all trips taken by local residents, 'medium' adoption rate to 0.3% of all trips, and 'high' adoption rate to 1% of all trips. Of course, it is quite possible for an exceptionally well-resourced and popular service to exceed even the 'high' adoption rate scenario, but from Spare's experience it is so rare that setting the highest rate to 1% provides the most realistic upper bound for most DRT scenarios.

Model files

Spare delivered the complete model file to SEI/RESPONSE in Microsoft Excel format in August 2021. Model data was correct at the time of publication. Two versions of the model were provided:

3. A complete version of the model with all editable tabs shown, including model formulae and default (non-editable) values and cells. This version is not for public consumption or distribution, but could be used by SEI/RESPONSE to build a native web-based version of the model.
4. A simplified version of the model where the majority of the 'backend' is hidden from view. This is the version of the model that can be distributed publicly outside of SEI/RESPONSE.

How-to video

Spare recorded a short, 5-minute video as a walkthrough of the model for the users. This video can be accessed at the following web address: https://www.loom.com/share/9e30d703fae541198b97522936cf23e3

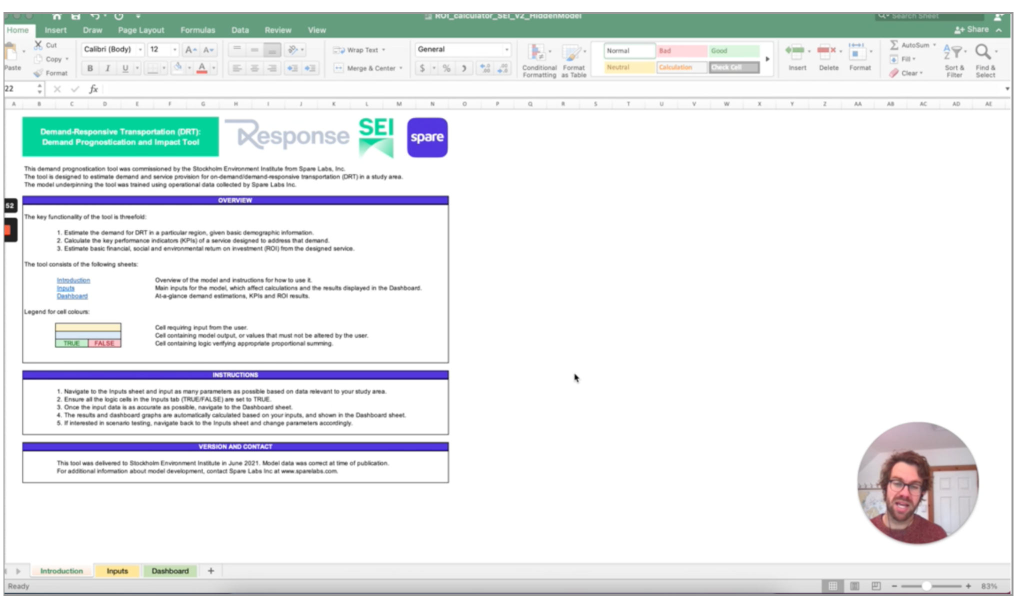

Figure 5. A screenshot of the model how-to video.

Feedback on the Excel-based demand prognostication model

Following the creation of the public-facing Excel-based model, SEI/RESPONSE circulated it to select respondents, who sent feedback about issues and bugs with the model. These were addressed by the Spare team to improve the final deliverable. Two main feedback themes emerged:

1. The inputs tab in the model contains a few dozen input values that must be supplied by a user. When participants did not know or were unsure of the correct values to input, they understandably left these fields blank. As a result, a few users received N/A as output values in the Dashboard. In response to this, the Spare team improved documentation around how to avoid N/A results (i.e. all fields must not be left blank), and supplied additional information about suggested default values.

2. A few users indicated that they may not have the appropriate data to supply the hourly costs needed in the Inputs tab. This issue arises because public transit agencies often grant concessions for certain lines or services to private operators, who in turn charge the agency a cost per kilometer. Changing the entire model to a per-kilometer rather than per-hour basis was not a trivial task, and was deemed to be out of scope for this project. However, we encourage users as much as possible to estimate the hourly cost that DRT has for them by contacting their finance department. Typically, hourly costs for DRT services range from €40 per hour to €100 per hour, so values within this range could be used as a default by agencies. In any case, this information around cost reporting is important feedback for future development of a DRT prognostication tool.

General approach to model testing and case studies

In order to demonstrate the usability and applicability of the model to different real-life regions, we applied to three case studies. In agreement with the SEI team, we outlined three different locations that would satisfy a range of situations (e.g. geographical size, nationality, public transportation context, existence (or not) of DRT, etc.). These were:

- Saaremaa (Estonia) - currently has a form of DRT system
- Võru (Estonia) - currently has a form of DRT system
- Sunne (Sweden) - does not have a DRT system

The SEI team provided local transportation context for Saaremaa and Võru based on past interactions with these towns, and the Spare team provided additional desk research. Information about the Sunne case study was collected based on direct one-to-one discussions with representatives from Värmlandstrafik. These representatives had conducted detailed testing for specific subregions in Sweden using the online Realize platform, so the Spare team walked through these Realize projects with them to understand their needs and the local context. This formed the basis for the Sunne case study.

Key parameter assumptions for case studies

For all case study scenarios, we establish a weekday (5-day-a-week) service from 5am to 8pm. The goal for the DRT service is to create an efficient service with target average wait times of 20–30 minutes, using as few vehicle hours as possible. We assume that 100% of DRT trips will be serviced using dedicated vehicles (see explanation below), which cost €50 per hour to run, and €30,000 to purchase in capital costs. These operational and capital costs are typical for rural and suburban transportation agencies in Europe, and often quite hard to ascertain using public information.

We assume a typical driver shift length of 10 hours, which is based on the average shift length run by Spare's partners across the Nordic countries where we help power services (Norway and Iceland). Average trip fare is presumed to be €3 per trip, in line with average fares reported for within-zone travel by the Estonian Southeastern Public Transport Center, which operates a special DRT service in Võru and Põlva counties in Estonia (see the Võru case study for more details). We assume that, all transportation modes considered, mass transit trips make up 10% of all trips in each area before the introduction of DRT. The mass transit system is assumed to have an average efficiency of 8 passengers per vehicle hour. These assumptions are based on known metrics that were reported prior to the introduction of DRT operations in Spare's Nordic services.

As mentioned above, we assume that all vehicles in the simulations are dedicated vehicles. A dedicated vehicle is one that is owned by the operator/transportation agency themselves, and is usually seen as an hourly cost on an agency's balance sheet. A non-dedicated vehicle is a separate vehicle, such as that operated by a taxi or ride-hailing company, which is used to outsource rides to. It is usually seen as an hourly cost to the transportation agency. We explore the benefits of blending dedicated and non-dedicated vehicle supply in the Considerations for implementing DRT section.

For the Saaremaa and Võru case studies, we relied as much as possible on the desk research provided to us by the SEI team, based on websites and RESPONSE reports. This provided us with detailed information on operational costs and hours supplied to the existing DRT services in these regions, from which we could conduct accurate comparisons with our model outputs. For the Sunne case study, there was relatively little information online from the Värmlandstrafik website. Spare relied on workshop conversations conducted with Värmlandstrafik representatives, and inputted assumptions based on Norwegian DRT operations where there were gaps.

Note that all input parameters for each case study are provided in Appendix 1.

Case studies: Excel-based model

Here we present results from the Excel-based model for the three case study regions. Please note that the model inputs used to achieve these results are presented in Appendix 1.

Case study 1: Saaremaa, Estonia

Context

Saaremaa is a 2,600 square-kilometre island in the Baltic Sea region, linked to the mainland by a bridge and ferry combination. Roughly 31,000 people reside on the island, and the population density is 11.7 people per square kilometre.

The island is currently running a small DRT pilot project in Sõrve Peninsula, which was launched in July 2021.It is open to residents and visitors to the peninsula, is open from 8am to 9pm, 7 days a week. All trips were free to users during the period of the pilot project, with costs covered by the Estonian Transport Administration. The service was supplied with two 7–9 seat vehicles (Toyota Proace City, provided by Toyota Baltic at a capital cost of €21,000), and the drivers were provided by the Saaremaa municipality, which operates transportation on the island.

Modern Mobility produced assessing the success and impact of the pilot service.[1] They found that, after six months of operation, the DRT service carried over 200 passengers, at an average rate of 1.5 passengers per ride. In total, the service cost approximately $5,600, including driver and dispatcher wages, as well as fuel, maintenance, leasing and software costs. This equated to a cost of €28 per passenger and €0.79 per passenger kilometer. Modern Mobility estimated that boosting passenger numbers to 800 over the same study period could have decreased the cost per passenger by three times, to €8.50 per passenger.

In their assessment of the success of the pilot project, Modern Mobility conducted a survey of users and found that great appetite exists among the residents of the Sõrve peninsula to use DRT for their everyday needs. Users found the process of booking DRT convenient, and users expressed a willingness to co-finance the service. These findings bode well for the potential success of a larger-scale DRT service on the island, which could become more financially viable through fare charges.

[1] Modern Mobility, 2021. “Developing and piloting the demand responsive transport service model in Saaremaa as part of the Interreg BSR “RESPONSE” project”

Scenario 1: Small-scale DRT

In this scenario, we assume only a small part of the existing public transport infrastructure will be replaced by DRT. For example, this could include replacing fixed routes that only visit some areas once or twice a day, or fixed routes that receive low passenger numbers.

This low-demand, small-scale DRT system is estimated to generate about 210 trips per day (Figure 6). To achieve a target waiting time of 20 minutes, we assume 4 vehicles will be needed a day, equivalent to 40 vehicle hours.

Results suggest that the DRT system would achieve an efficiency of around 5.3 passengers per vehicle hour, an average wait time of 20.8 minutes and a maximum wait time of ~90 minutes for the most remote of trips. Greenhouse gas emissions from the DRT system would amount to about 230 tonnes of CO2 per year.

In terms of financial performance, this small-scale service would cost about €500,000 per year to run, with direct returns of €180,000 per year. This would equate to costs of €7.84 per trip. The return on investment (ROI) would be 0.36, with a further 0.04 of environmental ROI.

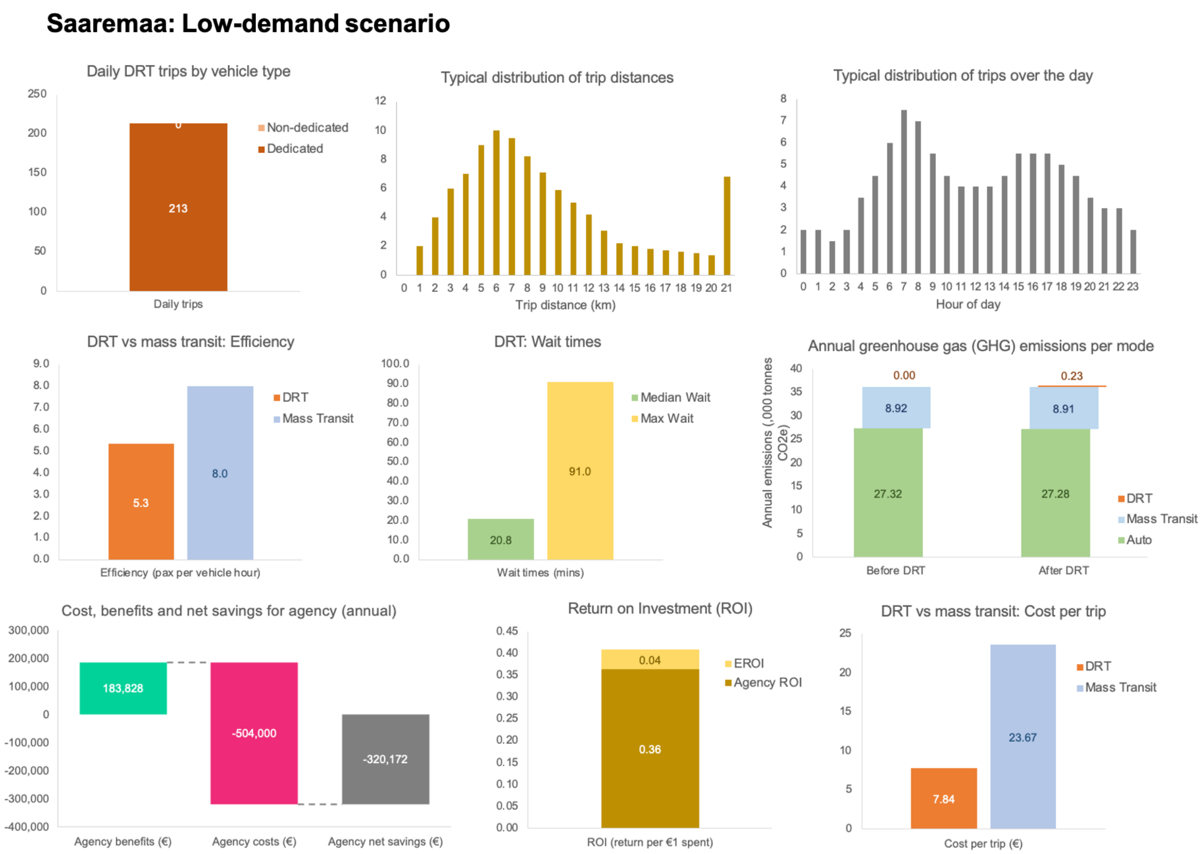

Figure 6. Model results for the low-demand scenario in Saaremaa.

Scenario 2: Medium-scale DRT

In this scenario we assume most of the existing fixed route bus infrastructure will be replaced by DRT. Only high-demand, high-capacity fixed route bus lines would remain alongside DRT.

This medium-scale DRT system is estimated to generate about 710 trips per day (Figure 7). To achieve a target waiting time of 30 minutes, we assume 18 vehicles will be needed a day, equivalent to 180 vehicle hours.

Results suggest that the DRT system would achieve an efficiency of around 4.0 passengers per vehicle hour, an average wait time of 33.6 minutes and a maximum wait time of ~180 minutes for the most remote of trips. Greenhouse gas emissions from the DRT system would amount to about 770 tonnes of CO2 per year.

In terms of financial performance, this small-scale service would cost about €2,200,000 per year to run, with direct returns of €670,000 per year. This would equate to costs of €11.00 per trip. The return on investment (ROI) would be 0.30, with a further 0.03 of environmental ROI.

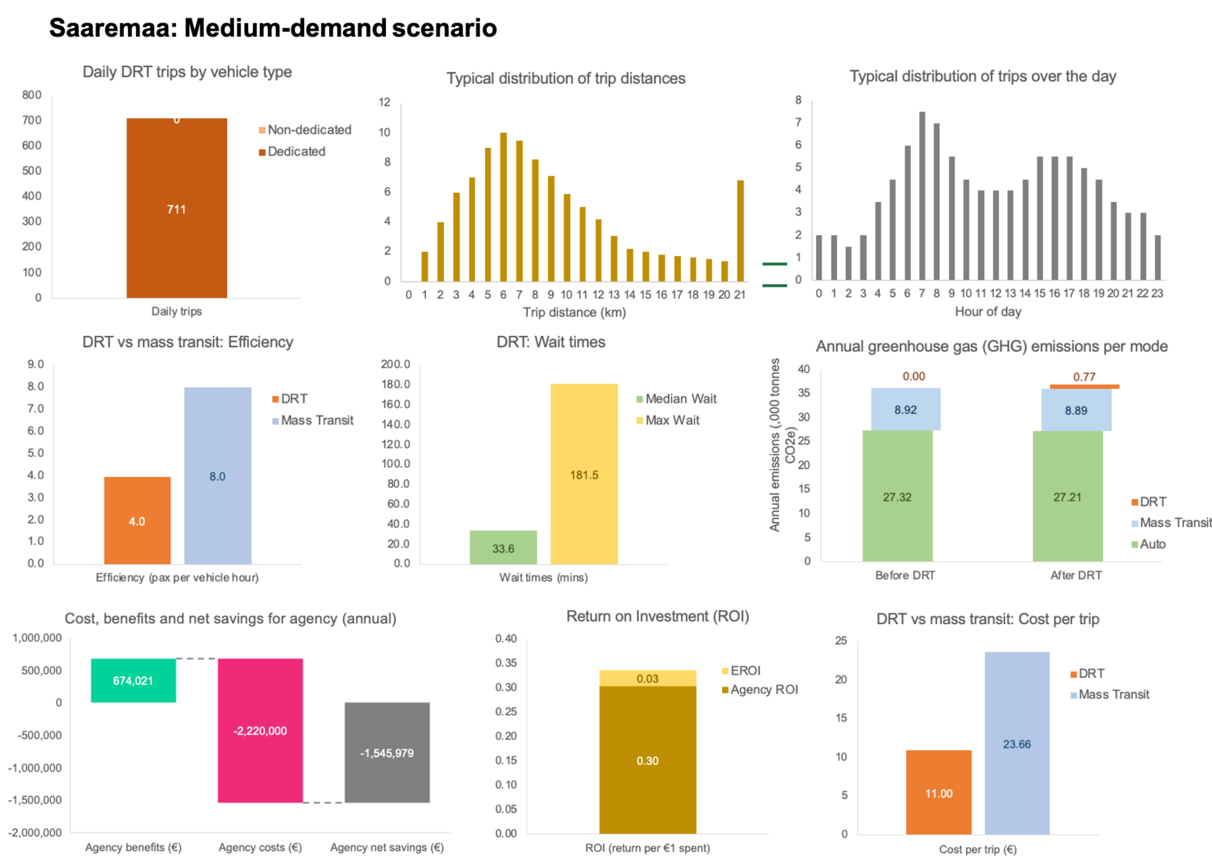

Figure 7. Model results for the medium-demand scenario in Saaremaa.

Scenario 3: Large-scale DRT

In this scenario, we assume all existing public transport on Saaremaa will be replaced by DRT. This is an extreme option that is rarely deployed in many systems around the world. The model underpinning the performance metrics prediction may therefore not be as accurate as for the low- and medium-demand scenarios. The results should therefore be viewed with a degree of uncertainty.

This large-scale DRT system is estimated to generate about 3,500 trips per day (Figure 8). Achieving a target waiting time of 30 minutes in our model is difficult in this scenario, due to the extremely high ridership volume involved. However, based on basic scaling of a vehicle supply rule of thumb, we assume 70 vehicles will be needed a day across Saaremaa, equivalent to 700 vehicle hours.

Results suggest that the DRT system would achieve an efficiency of around 5.1 passengers per vehicle hour, with an uncertainty around wait times. Greenhouse gas emissions from the DRT system would amount to about 3,840 tonnes of CO2 per year.

In terms of financial performance, this small-scale service would cost about €8,800,000 per year to run, with direct returns of €3,30,000 per year. This would equate to costs of €8.33 per trip. The return on investment (ROI) would be 0.38, with a further 0.04 of environmental ROI.

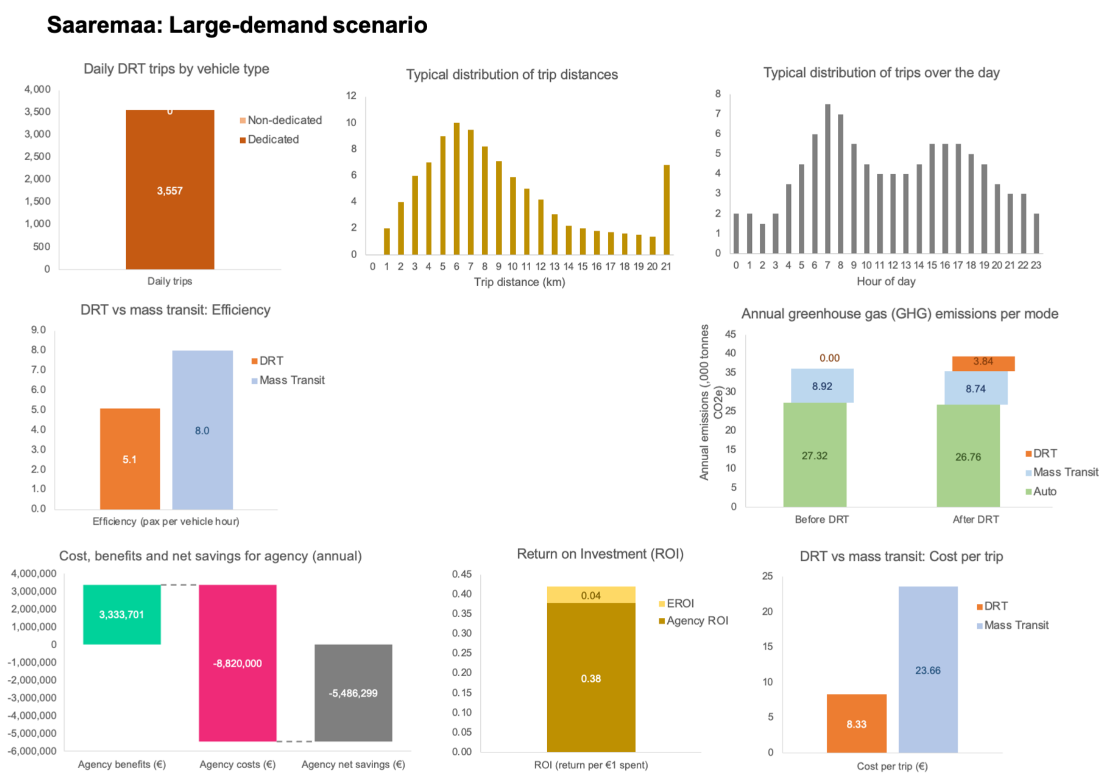

Figure 8. Model results for the large-scale, high-demand scenario in Saaremaa.

Case study 2: Võru, Estonia

Context

Võru is a 13 square-kilometre rural town in southeastern Estonia. Roughly 12,300 people reside in the town, and the population density is 1,100 people per square kilometre.

The counties of Võru and neighbouring Põlva have a specialized social transport service, organized by the Southeastern Public Transport Center (PTC).[2] The service is provided by OÜ Abuss, and financed by the European Social Fund and local government budgets.

The social transport service is available to all residents of Põlva and Võru county who cannot use public transport due to their special needs, and whose need for assistance has been assessed by the local government. An assistant to each rider is permitted. The service is operated using five dedicated vehicles, four of which are available to wheelchair users. The vehicles are also equipped with additional aids such as crutches and stair lifts.

Depending on the customer's needs, the service organizer has the right to interface the journeys with each other or to link them with the service provided by regular public transport, a process known as ‘commingling' in the DRT industry.

Customers must pay a one-time ‘entry fee' of €3 per trip to ride the service, with more expensive fares for travel outside the counties. Accompanying helpers travel for free.

Based on customer feedback reported by Southeaster PTC, the service has grown rapidly and customer satisfaction (and that of cooperation partners such as local governments) is high. While operational data for the service is not publicly available, the costs of OÜ Abuss are reported to be €1.23 per kilometer. The annual distance covered by the provider's vehicles since September 2020 is approximately 400,000 km, meaning that the annual cost of the service is approximate €490,000.

[2] Kagu, 2021. https://kagu.ytk.ee/sotsiaaltransport/

Scenario 1: Small-scale DRT

In this scenario, we assume only a small part of the existing public transport infrastructure will be replaced by DRT. This low-demand, small-scale DRT system is estimated to generate about 26 trips per day (Figure 9). To achieve a target waiting time of 20 minutes or less, we assume 1 vehicle will be needed, equivalent to 15 vehicle hours to cover service hours.

Results suggest that the DRT system would achieve an efficiency of around 1.7 passengers per vehicle hour, an average wait time of 13.4 minutes and a maximum wait time of ~40 minutes for the most remote of trips. Greenhouse gas emissions from the DRT system would amount to about 20 tonnes of CO2 per year.

In terms of financial performance, this small-scale service would cost about €186,000 per year to run, with direct returns of €18,000 per year. This would equate to costs of €28.27 per trip. The return on investment (ROI) would be 0.09, with a further 0.01 of environmental ROI.

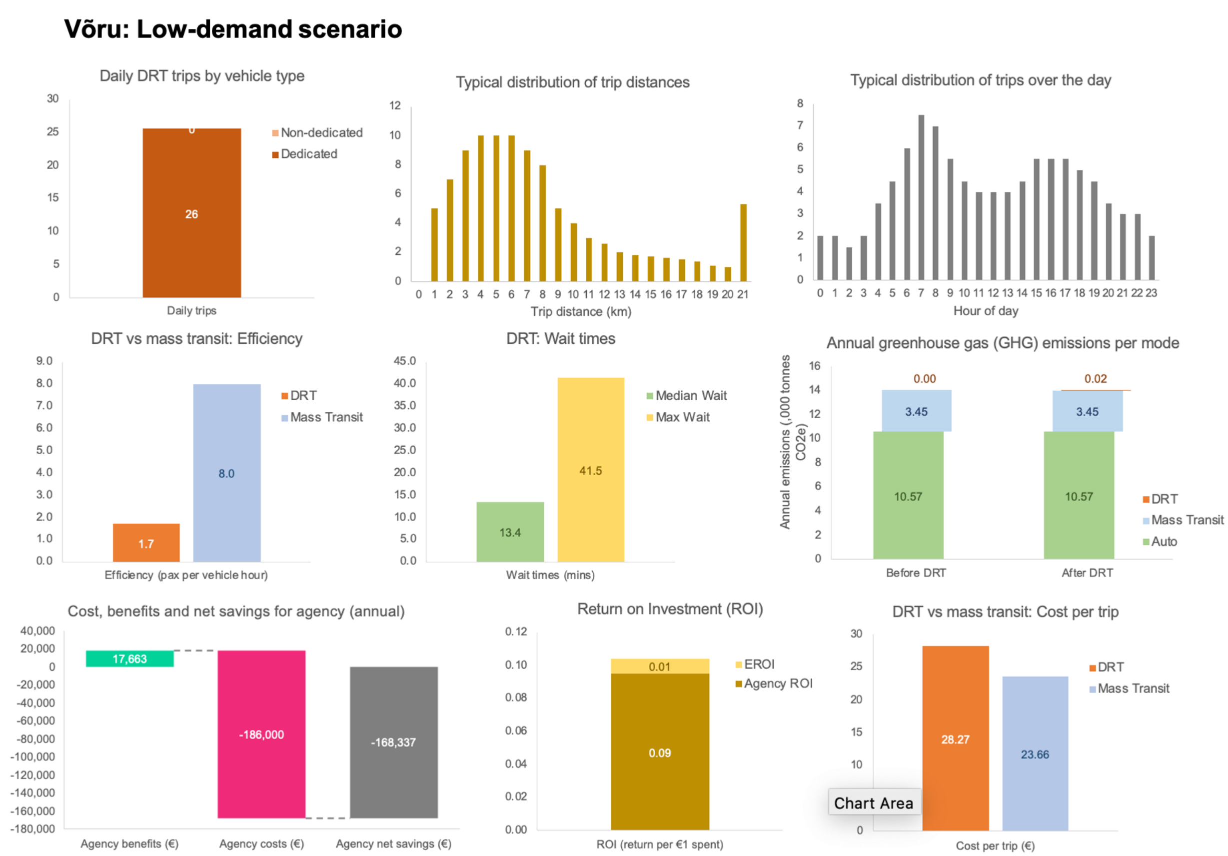

Figure 9. Model results for the low-demand scenario in Võru.

Scenario 2: Medium-scale DRT

In this scenario we assume most of the existing fixed route bus infrastructure will be replaced by DRT. Only high-demand, high-capacity fixed route bus lines would remain alongside DRT.

This medium-scale DRT system is estimated to generate about 85 trips per day (Figure 10). To achieve a target waiting time of 20 minutes, we assume 2 vehicles will be needed a day, equivalent to 24 vehicle hours.

Results suggest that the DRT system would achieve an efficiency of around 3.6 passengers per vehicle hour, an average wait time of 15.7 minutes and a maximum wait time of ~57 minutes for the most remote of trips. Greenhouse gas emissions from the DRT system would amount to about 60 tonnes of CO2 per year.

In terms of financial performance, this small-scale service would cost about €300,000 per year to run, with direct returns of €58,000 per year. This would equate to costs of €12.65 per trip. The return on investment (ROI) would be 0.20, with a further 0.02 of environmental ROI.

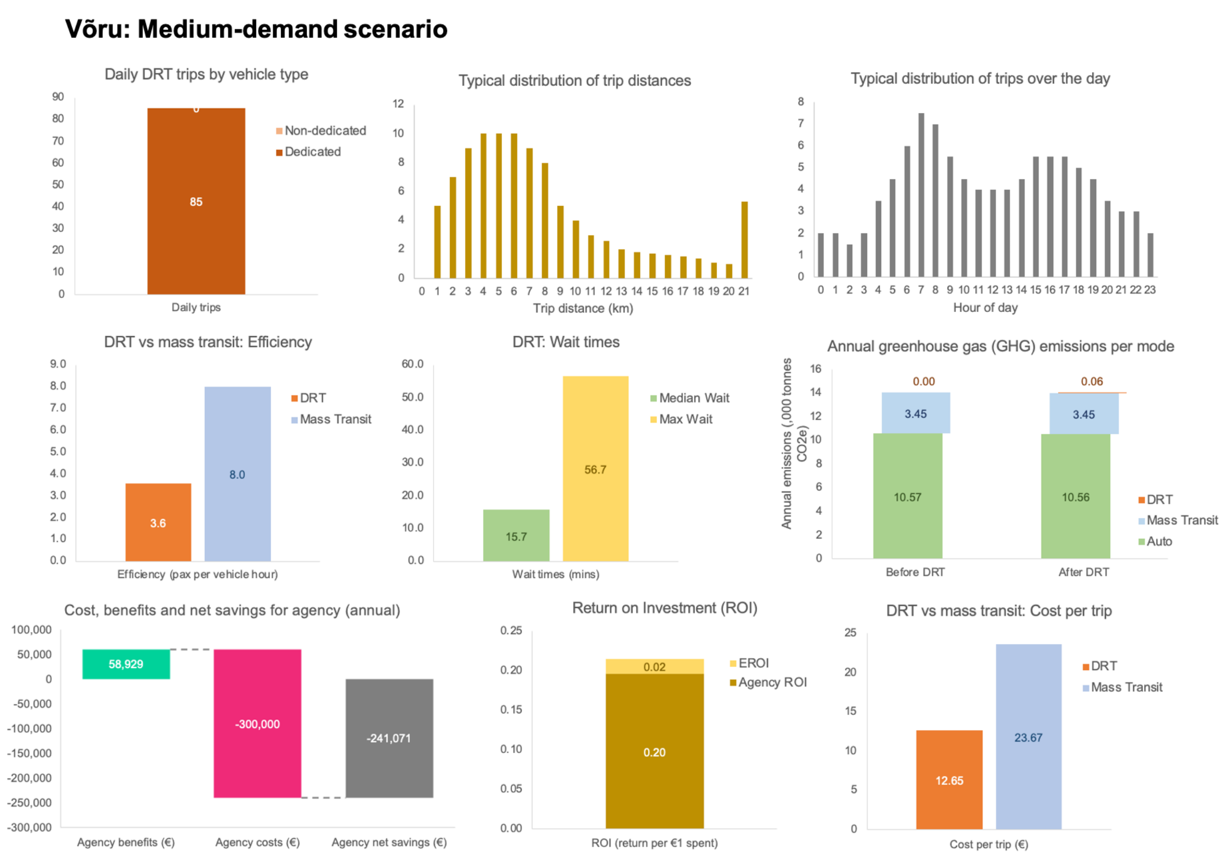

Figure 10. Model results for the medium-demand scenario in Võru.

Scenario 3: Large-scale DRT

In this scenario, we assume all existing public transport in Võru will be replaced by DRT. This is an extreme option that is rarely deployed in many systems around the world. The model underpinning the performance metrics prediction may therefore not be as accurate as for the low- and medium-demand scenarios.

This large-scale DRT system is estimated to generate about 430 trips per day (Figure 11). Achieving a target waiting time of 30 minutes in our model is difficult in this scenario, due to the extremely high ridership volume involved. However, based on basic scaling of a vehicle supply rule of thumb, we assume 10 vehicles will be needed a day across Võru, equivalent to 110 vehicle hours.

Results suggest that the DRT system would achieve an efficiency of around 3.9 passengers per vehicle hour, with an uncertainty around wait times. Greenhouse gas emissions from the DRT system would amount to about 320 tonnes of CO2 per year.

In terms of financial performance, this small-scale service would cost about €1,380,000 per year to run, with direct returns of €370,000 per year. This would equate to costs of €11.47 per trip. The return on investment (ROI) would be 0.27, with a further 0.02 of environmental ROI.

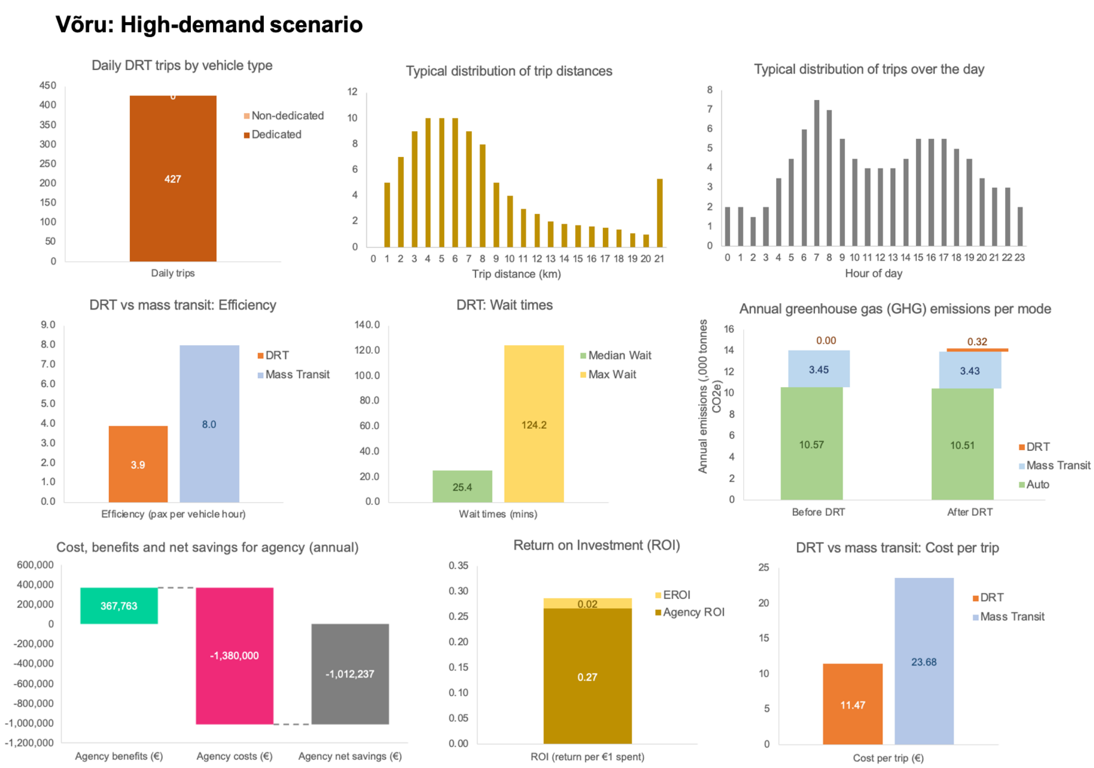

Figure 11. Model results for the large-scale, high-demand scenario in Võru.

Case study 3: Sunne, Sweden

Sunne is a 5-square kilometre rural locality and the seat of Sunne Municipality, Värmland County, Sweden. Roughly 13,000 people reside in the town, and the population density is 1,100 people per square kilometre.

Public transportation in Sunne is provided by the regional transportation authority, Värmlandstrafik. All bus and train traffic starts from the area around Sunne railway station, with buses and trains connecting to regional hubs including Torsby and Karlstad.

Sunne does not currently have a form of DRT available to the general public, but the Värmland region has been actively investigating the possibility of introducing DRT in the Värmland region. Indeed, Värmland featured as an active participant in the workshops led by Spare, and conducted some in-depth DRT zone simulation in Spare Realize (see Case Studies: Realize online platform section).

The Sunne case study is included here to outline how the demand prognostication model can provide some indication of how to make the public transportation system efficient for the agency, and to suggest any possible interventions for introducing DRT in the area.

Scenario 1: Small-scale DRT

In this scenario, we assume only a small part of the existing public transport infrastructure will be replaced by DRT. This low-demand, small-scale DRT system is estimated to generate about 11 trips per day (Figure 12). To achieve a target waiting time of 20 minutes or less, we assume 1 vehicle will be needed, equivalent to 10 vehicle hours to cover service hours.

Results suggest that the DRT system would achieve an efficiency of around 1.1 passengers per vehicle hour, an average wait time of 13.1 minutes and a maximum wait time of ~40 minutes for the most remote of trips. Greenhouse gas emissions from the DRT system would amount to about 10 tonnes of CO2 per year.

In terms of financial performance, this small-scale service would cost about €126,000 per year to run, with direct returns of €7,000 per year. This would equate to €46.84 per trip. The return on investment (ROI) would be 0.06, with a further 0.01 of environmental ROI.

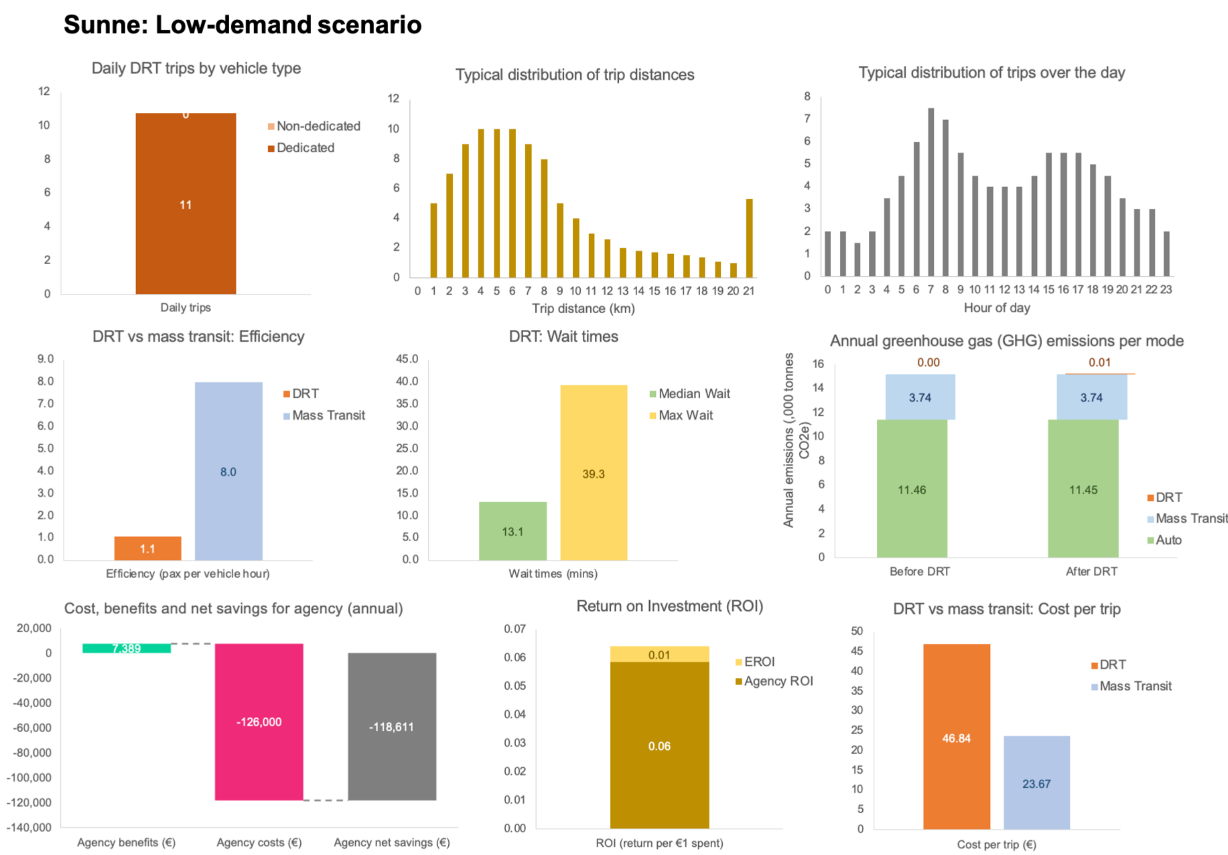

Figure 12. Model results for the low-demand scenario in Sunne.

Scenario 2: Medium-scale DRT

In this scenario we assume most of the existing fixed route bus infrastructure will be replaced by DRT. Only high-demand, high-capacity fixed route bus lines would remain alongside DRT.

This medium-scale DRT system is estimated to generate about 36 trips per day (Figure 13). To achieve a target waiting time of under 20 minutes, we assume 1 vehicle will be needed a day, equivalent to 15 vehicle hours.

Results suggest that the DRT system would achieve an efficiency of around 2.4 passengers per vehicle hour, an average wait time of 13.9 minutes and a maximum wait time of ~45 minutes for the most remote of trips. Greenhouse gas emissions from the DRT system would amount to about 30 tonnes of CO2 per year.

In terms of financial performance, this small-scale service would cost about €186,000 per year to run, with direct returns of €25,000 per year. This would equate to costs of €19.65 per trip. The return on investment (ROI) would be 0.13, with a further 0.01 of environmental ROI.

Figure 13. Model results for the medium-demand scenario in Sunne.

Scenario 3: Large-scale DRT

In this scenario, we assume all existing public transport in Sunne will be replaced by DRT. This is an extreme option that is rarely deployed in many systems around the world. The model underpinning the performance metrics prediction may therefore not be as accurate as for the low- and medium-demand scenarios.

This large-scale DRT system is estimated to generate about 179 trips per day (Figure 11). We assume 4 vehicles will be needed a day across Sunne, equivalent to 40 vehicle hours.

Results suggest that the DRT system would achieve an efficiency of around 4.5 passengers per vehicle hour, with an uncertainty around wait times. Greenhouse gas emissions from the DRT system would amount to about 140 tonnes of CO2 per year.

In terms of financial performance, this small-scale service would cost about €500,000 per year to run, with direct returns of €160,000 per year. This would equate to costs of €9.73 per trip. The return on investment (ROI) would be 0.32, with a further 0.02 of environmental ROI.

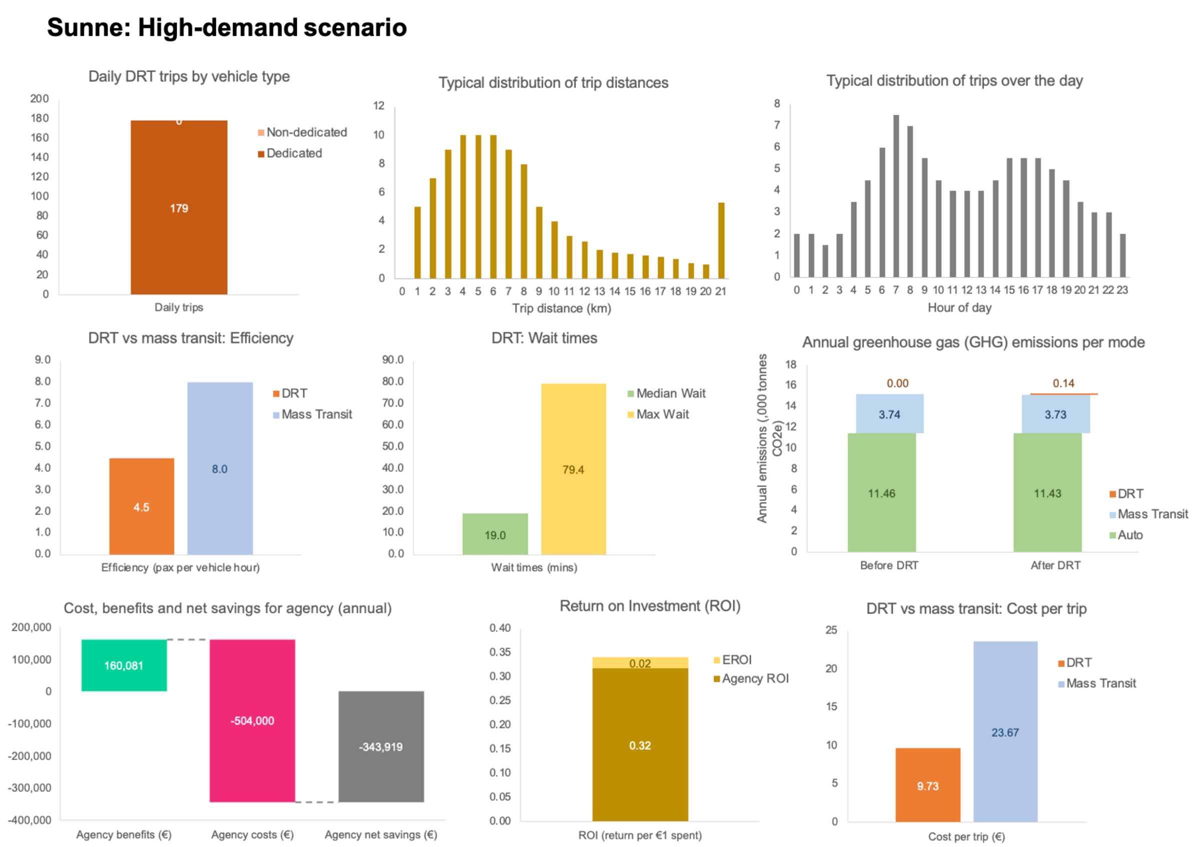

Figure 14. Model results for the large-scale, high-demand scenario in Sunne.

Conclusions for case studies

We provide brief conclusions and recommendations for what DRT service intervention could be most successful in each case study area. A summary of the results on which these conclusions are drawn is shown in Table 2.

Saaremaa, Estonia

It would likely not be advisable to opt for the large-scale DRT option on Saaremaa, not least due to the uncertainties around service performance. A hybrid approach, whereby DRT is used to supplement fixed-route mass transit in areas of low transit supply, or indeed some replacement of underperforming routes on the island, is the promising avenue for success on Saaremaa.

The small-scale DRT pilot project deployed in summer 2021 in Saaremaa proves there is great appetite among local residents for a digitised, on-demand mobility solution for the island. With per-trip costs ranging from €7.80–€11 in our scenarios, it appears that an island-wide service could lead to economies of scale that result in DRT trips costing almost 75% less than the costs reported for the pilot project.

Võru, Estonia

Thanks to its relatively small size and high population density, the large-scale DRT option would be a feasible alternative to a classic fixed-route public transportation system in Võru. The medium-scale option would also be a useful way to test out the appetite for DRT among local residents as a pilot project. The small potential demand in the small-scale scenario would likely not provide good return on investment for the local public transportation authorities.

It is difficult to compare the financial and operational efficiency of our proposed services to the existing social transport service provided by Southeastern PTC, because of the vastly different scales on which they operate. However, basic calculations suggest that the medium- and large-scale DRT options could cost about €1.20–€1.70 per kilometer, which is similar to the €1.23 per kilometer cost reported for the existing, popular service. This bodes well for the feasibility of a DRT system in Võru.

Sunne, Sweden

Like Võru, Sunne is small and relatively dense, so the medium- and large-scale DRT options could provide high performance for relatively little investment. Depending on the deployment locations of the low-demand options, a DRT system could help boost the equity for rural inhabitants of the city.

Unlike the first two case studies, the Sunne case study does not currently provide a DRT service to its residents. Värmlandstrafik representatives confirmed there is strong appetite from the public transportation agency to implement some form of DRT in the region, especially given the relatively high proportion of senior residents in rural locations with otherwise little access to regular and convenient public transportation.

Given the lack of a DRT system currently, there is fairly significant uncertainty around the actual adoption rate of DRT in and around the town. It is likely that uptake might be low at the start of the project, but popularity could quickly spread with appropriate marketing and customer pricing strategies. Spare would probably advise to begin with an assumption of demand between the low- and medium-scale DRT scenario proposed above (i.e. anywhere between 11 and 36 daily trips per day), and restrict the service to the densest parts of the town and surrounding suburbs, to prevent overstretching the service. Supplying one vehicle initially to this pilot system would result in very good waiting times for residents (between 13 and 15 minutes), and therefore encourage further uptake due to perceived convenience. A one-vehicle system would likely result in costs of $20–$40 per trip, which is relatively high for such systems, but this cost would drop as the popularity of the service increases over time.

Spare has worked with partners of similar size to Sunne in other parts of the Nordic region, and what has worked well is to first introduce a small-scale pilot program that can introduce the concept to local residents. Then, thanks to the digitized DRT management platforms offered by Spare and other mobility companies, it is simple to rapidly iterate on this concept, and expand or modify service coverage to respond to demand. The Considerations for implementing DRT section provides additional details on the merits of launching DRT pilot projects in this way.

Table 2. Summary of key results for each scenario in all three case study locations.

		Daily trips	No. of vehicles	Vehicle hours	Efficiency (PPVH)	Median wait time (mins)	Max wait time (mins)	Annual costs (,000 €)	Annual benefits (,000 €)	Cost per trip (€)	Agency ROI	Annual GHG emissions (tonnes CO2e)
Saaremaa	Small scale	213	4	40	5.3	20.8	91	500	180	7.84	0.36	230
	Medium scale	711	18	180	4	33.6	181	2,200	670	11	0.3	770
	Large scale	3557	70	700	5.1	-	-	8,820	3,330	8.33	0.38	3,840
Võru	Small scale	28	1	15	1.7	13.4	41.5	186	17	28.27	0.09	20
	Medium scale	85	2	24	3.6	15.7	56.7	300	59	12.65	0.2	60
	Large scale	427	10	110	3.9	25.4	124.2	1,380	370	11.47	0.27	320
Sunne	Small scale	11	1	10	1.1	13.1	39.3	126	7	46.84	0.06	10
	Medium scale	36	1	15	2.4	13.9	45	186	25	19.65	0.13	30
	Large scale	179	4	40	4.5	19	79.4	504	160	9.73	0.32	140

Case studies: Realize online platform

A dozen workshop participants actively used the online, commercial version of Spare Realize to design and test DRT zones in study regions of their choice. Here we report briefly on three case studies to illustrate the diversity of projects created by the users.

Sunne, Värmland (Sweden)

One participant simulated a 2-vehicle DRT service in Sunne, a small town of 10,000 inhabitants north of Karlstad, in Sweden (Figure 15). Realize predicted a demand of roughly 100 trips per day in this zone. When supplied with two shifts per day, the service would run at an efficient rate of 7 passengers per vehicle hour, and wait times would average at 17 minutes.

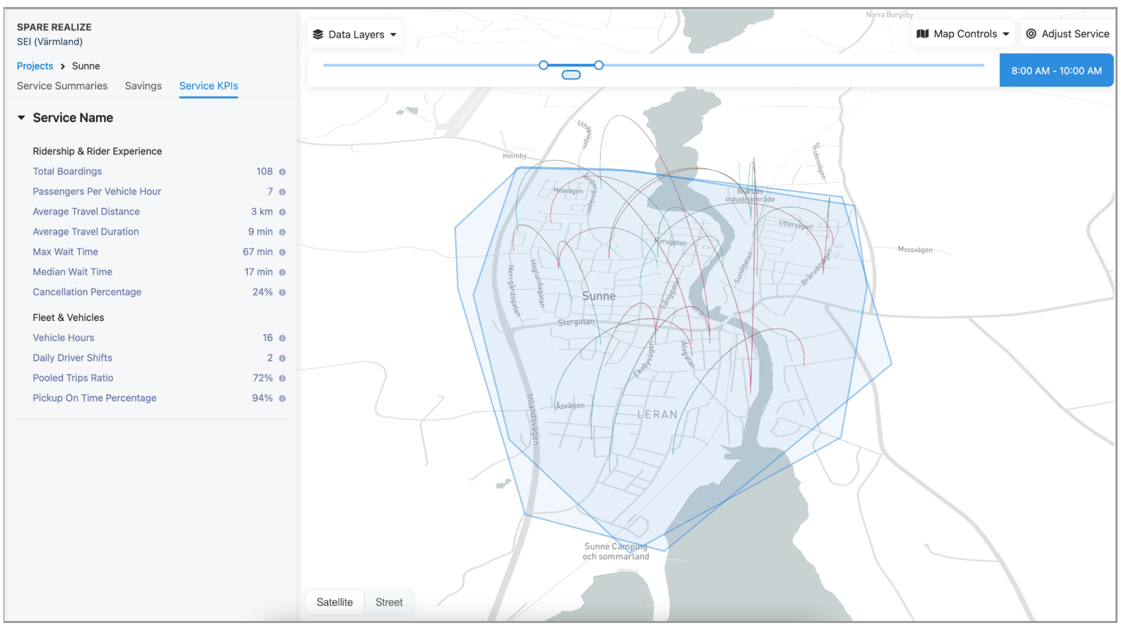

Figure 15. Simulated service zone in Sunne, Värmland.

Rakvere (Estonia)

One participant simulated a 1-vehicle DRT service in Rakvere, a town of 15,000 inhabitants and capital of Lääne-Viru County in Estonia (Figure 16). Realize predicted a demand of 24 trips per day in this zone. When supplied with a shift per day, the service would run at a fairly efficient rate of 3 passengers per vehicle hour, and wait times would average at 15 minutes.

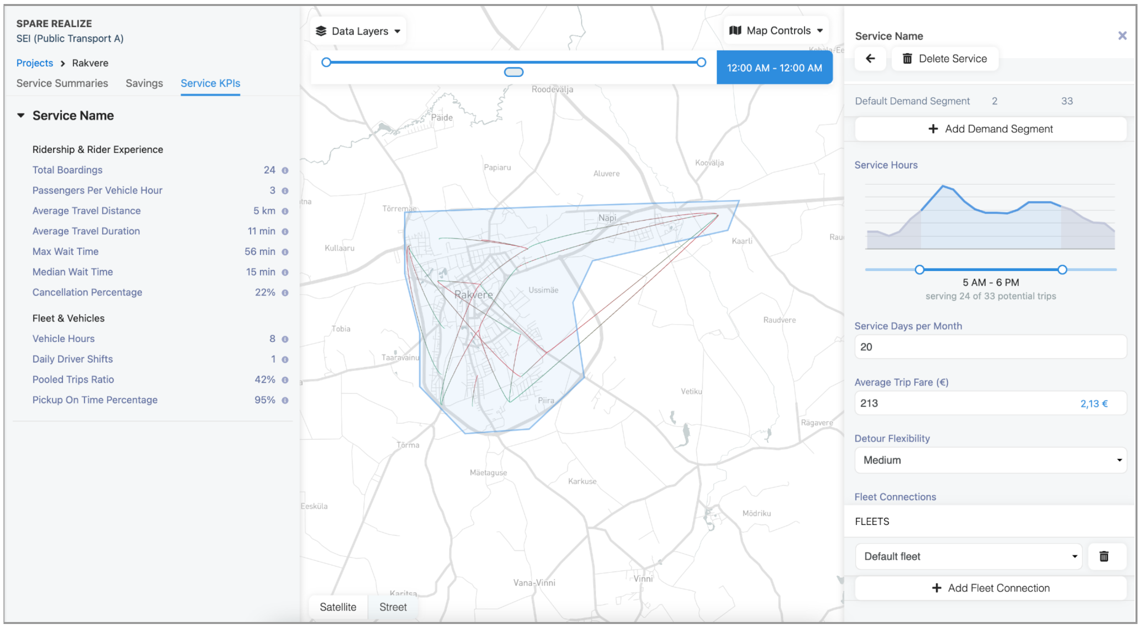

Figure 16. Simulated service zone in Rakvere, Estonia.

Rapina, Põlva (Estonia)

One participant simulated a multi-zone DRT service in the southeastern part of Estonia (Figure 17). One large rural zone, Rapina, was predicted to generate 54 trips per day, and the smaller zone around the town of Põlva would generate 13 trips per day. A variety of vehicle supply scenarios were tested for these services, to explore the potential for cost savings in the region.

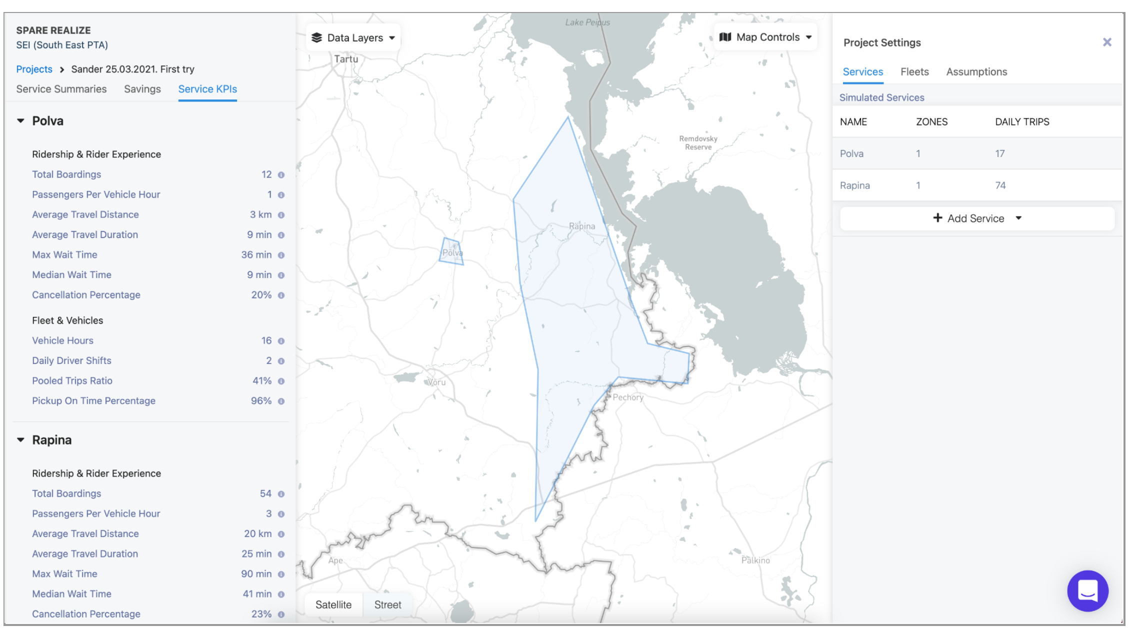

Figure 17. Simulated service zone in Rapina, Estonia.

Considerations for implementing DRT

By setting up DRT systems to serve their constituents, public transportation agencies can cement their position as passenger-centric organisations. We have provided some recommendations and general scenarios for each case study region already, but it is not within the scope of this study to comment on the strategic, procurement and legal framework for adopting DRT in each region, because these issues are so context-specific.

In this section we discuss key themes to consider when launching a DRT service, which are broadly applicable across a wide range of different public transportation contexts.

The power of mobility data

One of the main benefits of introducing DRT is the wealth of data it produces, allowing transportation agencies to rapidly improve their services to riders. Without readily available mobility data, it can be difficult to respond to demand fluctuations in the short term, or to conduct rigorous transportation planning in the long-term.

Historically, public transportation agencies have designed their fixed bus routes using imprecise historical data, anecdotal evidence, or even planners' gut feelings. By introducing DRT in certain areas, public transportation agencies can far better understand rider needs, and can use that knowledge to redesign their fixed routes. By continually monitoring service performance, agencies can 'fail fast and iterate quickly' to ensure the best configuration remains.

The rich datasets collected by a DRT software platform can also be used to identify precisely where transit demand exists for fixed-route planning. By highlighting the exact origins and destinations of preferred travel patterns, DRT data helps identify the best stop locations and timings for fixed bus routes. In areas where the volume and reliability of demand is high enough to run an efficient fixed route, the optimal option may involve launching timetabled buses or hybrid systems such as deviated fixed lines supplemented by DRT.

Non-dedicated trip brokering

The biggest contributor to the operational cost of a DRT service is the cost and allocation of labour. Dedicated, specialized, unionized labor often cannot compete with independent contractors on price. However, non-dedicated independent contractors, such as taxis and Transportation Network Companies (TNCs), often cannot compete with the reliability and consistency of dedicated labor.

By supplementing their services with non-dedicated transportation providers, public transportation agencies can begin to unlock true cost savings in public transit operations. A trip brokering model, where dedicated labour is used for the majority of demand with independent or non-dedicated labour during periods of peak demand, can offer the same high-quality service expected by customers, while allocating labor more efficiently across the demand spectrum. Instead of providing enough dedicated labor to always accommodate all demand in a timely fashion, agencies can maintain enough capacity to meet the majority of demand with a single provider, while brokering trips to other providers when required (Figure 18).

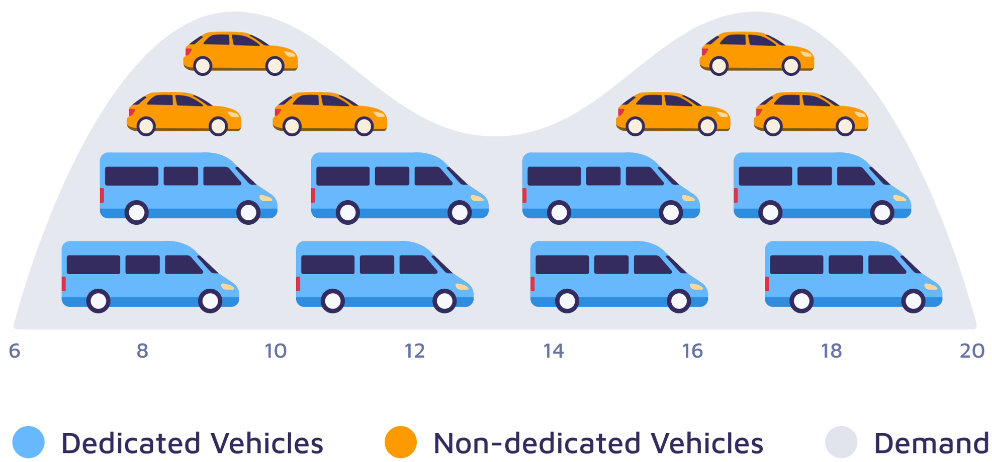

Figure 18. How a mixed-supply model enables transit agencies to slightly under-supply for any given demand, by brokering trips to non-dedicated operators during periods of high demand.

If public transportation agencies adopt a trip brokering model, they enable their systems to dynamically respond to demand spikes without having to pay for under-utilized capacity. Moreover, a non-dedicated trip brokering model is more equitable than relying purely on a single ride-hailing provider. Unlike private platforms such as Uber or Lyft, publicly-run trip brokering is all-inclusive and does not arbitrarily lock out local, competent operators.

Vehicle right-sizing

Although our model does not directly account for vehicle sizing, as this is too complex to integrate into the KPI prediction model, it can be important to consider what size and capacity of vehicle to launch a DRT system with. Suring many parts of the day, larger vehicles would remain unfilled, and it may be beneficial to scale down vehicle sizes to better match local demand patterns. This is known as 'vehicle right-sizing'.

Right-sizing transit vehicles can substantially lower costs to public transportation agencies as smaller vehicles cost less to purchase, operate, and maintain than traditionally sized buses. Smaller vehicles also tend to have lower-level licensing requirements than commercial transit vehicles, meaning that the labour pool from which agencies can recruit drivers would be larger and cheaper.

Of course, the potential cost savings from using smaller vehicles should be weighed against regulations and passenger preferences for accessible, comfortable, and safe vehicles. Many passengers of specialized mobility services may have medical and/or ambulatory limitations. In Spare's experience, less mobile passengers can be apprehensive about climbing into a small vehicle with strangers, although most passengers soon become accustomed to it.

Commingling different service types together

Traditionally, public transportation operations suffer from the static allocation of resources to specific, specialized services. For instance, in most transportation systems a 'special mobility' (or 'paratransit') vehicle cannot provide non-paratransit trips, even when it is idle and could be utilized elsewhere in the system. Similarly, two trips going to and from the same location at the same time will be allocated to separate vehicles if the riders are accessing different on-demand services.

To achieve truly scalable cost savings with on-demand transit, public transportation agencies could consider moving away from this outdated model, allowing different services to maintain their distinctive nature while sharing vehicle resources with each other. This novel approach, called 'commingling', respects different service configurations, rules and rider groupings, while continuing to provide the same quality of service expected by each rider. Commingling is a hallmark of efficiency in the airline and logistics industries, but its application to the transit industry is relatively nascent.

Implementing full-scale commingling would require coordinating multiple government departments (e.g. those responsible for paratransit, school transportation, senior communities), which may face political and bureaucratic hurdles. However, there is massive potential for a fully flexible commingled system to deliver unparalleled savings to public transportation agencies, and simultaneously create cutting-edge service for passengers.

Concluding remarks

This report has presented a new, bespoke demand prognostication model prepared by Spare Labs for the RESPONSE project, run by SEI and sponsored by Interreg. A detailed description of the model, its inputs and outputs, and its intended use were outlined for users. Then, three illustrative case studies were presented to illustrate how a DRT system might perform based on a variety of demand scenarios, and how many resources would be required to run it in a convenient and popular way for local residents. The exact inputs to recreate the findings presented for these case studies is presented in Appendix 1. The report concludes with a series of 'win themes' that public transport agencies in the Baltic Sea Region should consider when thinking about the implementation of DRT in their areas.

The case studies presented in this report demonstrate how the model can provide differential recommendations depending on the population dynamics and public transportation usage of a study area. In the case of Saaremaa, where there is proven appetite among local residents for a digitised DRT solution, the model suggests an island-wide service could lead to economies of scale that result in DRT trips costing almost 75% less than the costs reported for the pilot project. A hybrid approach, whereby DRT is used to supplement fixed-route mass transit in areas of low transit supply, or indeed some replacement of underperforming routes on the island, could result in per-trip costs as low as €7.80 for the island.

In the case of Võru, the model showed that the medium- and large-scale DRT options could cost about €1.20–€1.70 per kilometer based on 2–10 vehicles, which is similar to the €1.23 per kilometer cost reported for the existing, popular service offered by the Southeastern PTC. In the case of Sunne, whose demand is more uncertain given the lack of an existing DRT service, Spare suggests that installing a pilot service on the assumption that the low- or medium-scale DRT scenario could emerge, would require Värmlandstrafik to initially supply 1 vehicle to the system, with costs per trip dropping as the service becomes more popular.

The cost and demand prognostication model developed for this project will be publicly available and free of charge in the Baltic Sea region. The intention is to empower public transport authorities, local public transport service providers and public sector coordinators to assess the potential demand there might be in their area for DRT, and how to supply it with enough vehicular resources to achieve a service-based goal (e.g. based on waiting times, or costs per trip). Public transportation authorities often lack the capacity to address the challenges or capitalize on new technological opportunities to further develop public transport infrastructure and usability, and the model presented here helps them to fill the gap in their knowledge around DRT specifically. Additional tools and resources will be needed to empower them to make system-scale decisions around the entirety of their mass transportation systems, as well as active transportation such as cycling and walking infrastructure.

In this way, this project fits well into the broader remit of the RESPONSE project to develop, coordinate, and expand existing publicly funded transport services in the Baltic Sea region. By providing open access to mobility data, advising on the benefits of demand-responsive solutions and the digital revolution within public transportation, this project has fulfilled the RESPONSE project's mission to boost the use and uptake of best practice and new technological improvements within public transportation.

The RESPONSE project aims to outline and address the untapped potential of DRT solutions that have been developed in the Baltic Sea region since the 1990s, and improve the accessibility and reliability of transport in sparsely populated areas. Unlike fixed bus lines, it creates opportunities, DRT enables smoother journeys, digital business models and flexible demand-based service design, to allow services and user groups to be coordinated more cost-effectively than specialized transport services (such as medical transport).

Appendices

Appendix 1: Input parameters for case studies

We provide the complete sets of inputs for each case studies, which can be used to replicate the results presented in the Case Studies section. Note that we only provide a single demand scenario per case study (the 'Large-scale DRT' scenario in all cases), because inputs essentially stay the same across all scenarios, except for the 'Adoption rate of DRT' parameter.

Saaremaa, Estonia

GENERAL	
Average number of trips per person per day - all modes combined (#)	3
Social cost of carbon - CO2 ($/tonne)	120
ON-DEMAND TRANSPORTATION (DRT): SERVICE DESIGN	
Total population in zone (#)	31,000.00
Zone perimeter length (km)	400.00
Zone type	Rural
DRT service days per month (#)	20.00
Start hour of DRT service (hh)	5.00
End hour of DRT service (hh)	20.00
ON-DEMAND TRANSPORTATION (DRT): OPERATIONAL ASSUMPTIONS	
Adoption rate of DRT (% of all potential trips)	High
Proportion of DRT trips that are induced (%)	20.00
Proportion of trips taken with dedicated vehicles (%)	100.00
Proportion of trips taken with non-dedicated vehicles (%)	-
Does dedicated/non-dedicated split add up to 100?	TRUE
Number of dedicated vehicles (#)	70.00
Average driver shift length (hrs)	10.00
Average ratio of VKTs to passenger kilometers (#)	1.5
Average DRT vehicle speed (km/h)	30
Emissions factor - CO2 (g/km)	300
ON-DEMAND TRANSPORTATION (DRT): COSTS	
Monthly cost of running DRT technology per vehicle (€)	500.00
Hourly operational cost of running 1 dedicated vehicle (€)	50.00
Average cost per km of using a non-dedicated vehicle (e.g. taxi) (€)	1.50
Capital cost of 1 dedicated vehicle (€)	30,000.00
Average trip fare (€)	3.00
Depreciation period of dedicated vehicle (years)	5

FIXED-ROUTE TRANSPORTATION: OPERATIONAL ASSUMPTIONS	
Average passengers per vehicle hour (PPVH) (#)	8
Average trips per vehicle per day (#)	8
Average trip distance (km)	6
Average bus speed (km/h)	26
Emissions factor - CO2 (g/km)	820
FIXED-ROUTE TRANSPORTATION: COSTS	
Hourly operational cost of running 1 mass transit vehicle (€)	105
Capital cost of 1 mass transit vehicle (€)	550000
Average trip fare (€)	2.2
Depreciation period of mass transit vehicle (years)	15
AUTO	
Average trip distance (km)	9.7
Average occupancy rate of a private vehicle (people/vehicle/km)	1.7
Emissions factor - CO2 (g/km)	220
MODE SPLIT / MODE SHIFT: BEFORE DRT	
Mode split: Mass transit - bus (%)	10
Mode split: Mass transit - other (e.g. rail) (%)	5
Mode split: Auto (%)	65
Mode split: Cycling (%)	9
Mode split: Walking (%)	11
Does mode split add up to 100?	TRUE
MODE SPLIT / MODE SHIFT: AFTER DRT	
Mode split: Mass transit - bus (%)	10
Mode split: Mass transit - other (e.g. rail) (%)	5
Mode split: Auto (%)	65
Mode split: Cycling (%)	9
Mode split: Walking (%)	11
Does mode split add up to 100?	TRUE

Võru, Estonia

GENERAL	
Average number of trips per person per day - all modes combined (#	3
Social cost of carbon - CO2 ($/tonne)	120
ON-DEMAND TRANSPORTATION (DRT): SERVICE DESIGN	
Total population in zone (#)	12,000.00
Zone perimeter length (km)	12.00
Zone type	Suburban
DRT service days per month (#)	20.00
Start hour of DRT service (hh)	5.00
End hour of DRT service (hh)	20.00
ON-DEMAND TRANSPORTATION (DRT): OPERATIONAL ASSUMPTIONS	
Adoption rate of DRT (% of all potential trips)	High
Proportion of DRT trips that are induced (%)	20.00
Proportion of trips taken with dedicated vehicles (%)	100.00
Proportion of trips taken with non-dedicated vehicles (%)	-
Does dedicated/non-dedicated split add up to 100?	TRUE
Number of dedicated vehicles (#)	10.00
Average driver shift length (hrs)	11.00
Average ratio of VKTs to passenger kilometers (#)	1.5
Average DRT vehicle speed (km/h)	30
Emissions factor - CO2 (g/km)	300
ON-DEMAND TRANSPORTATION (DRT): COSTS	
Monthly cost of running DRT technology per vehicle (€)	500.00
Hourly operational cost of running 1 dedicated vehicle (€)	50.00
Average cost per km of using a non-dedicated vehicle (e.g. taxi) (€)	1.50
Capital cost of 1 dedicated vehicle (€)	30,000.00
Average trip fare (€)	3.00
Depreciation period of dedicated vehicle (years)	5

FIXED-ROUTE TRANSPORTATION: OPERATIONAL ASSUMPTIONS	
Average passengers per vehicle hour (PPVH) (#)	8
Average trips per vehicle per day (#)	8
Average trip distance (km)	6
Average bus speed (km/h)	26
Emissions factor - CO2 (g/km)	820
FIXED-ROUTE TRANSPORTATION: COSTS	
Hourly operational cost of running 1 mass transit vehicle (€)	105
Capital cost of 1 mass transit vehicle (€)	550000
Average trip fare (€)	2.2
Depreciation period of mass transit vehicle (years)	15
AUTO	
Average trip distance (km)	9.7
Average occupancy rate of a private vehicle (people/vehicle/km)	1.7
Emissions factor - CO2 (g/km)	220
MODE SPLIT / MODE SHIFT: BEFORE DRT	
Mode split: Mass transit - bus (%)	10
Mode split: Mass transit - other (e.g. rail) (%)	5
Mode split: Auto (%)	65
Mode split: Cycling (%)	9
Mode split: Walking (%)	11
Does mode split add up to 100?	TRUE
MODE SPLIT / MODE SHIFT: AFTER DRT	
Mode split: Mass transit - bus (%)	10
Mode split: Mass transit - other (e.g. rail) (%)	5
Mode split: Auto (%)	65
Mode split: Cycling (%)	9
Mode split: Walking (%)	11
Does mode split add up to 100?	TRUE

Sunne, Sweden

GENERAL	
Average number of trips per person per day - all modes combined (#)	3
Social cost of carbon - CO2 ($/tonne)	120
ON-DEMAND TRANSPORTATION (DRT): SERVICE DESIGN	
Total population in zone (#)	13,000.00
Zone perimeter length (km)	5.00
Zone type	Suburban
DRT service days per month (#)	20.00
Start hour of DRT service (hh)	5.00
End hour of DRT service (hh)	20.00
ON-DEMAND TRANSPORTATION (DRT): OPERATIONAL ASSUMPTIONS	
Adoption rate of DRT (% of all potential trips)	High
Proportion of DRT trips that are induced (%)	20.00
Proportion of trips taken with dedicated vehicles (%)	100.00
Proportion of trips taken with non-dedicated vehicles (%)	-
Does dedicated/non-dedicated split add up to 100?	TRUE
Number of dedicated vehicles (#)	4.00
Average driver shift length (hrs)	10.00
Average ratio of VKTs to passenger kilometers (#)	1.5
Average DRT vehicle speed (km/h)	30
Emissions factor - CO2 (g/km)	300
ON-DEMAND TRANSPORTATION (DRT): COSTS	
Monthly cost of running DRT technology per vehicle (€)	500.00
Hourly operational cost of running 1 dedicated vehicle (€)	50.00
Average cost per km of using a non-dedicated vehicle (e.g. taxi) (€)	1.50
Capital cost of 1 dedicated vehicle (€)	30,000.00
Average trip fare (€)	3.00
Depreciation period of dedicated vehicle (years)	5

FIXED-ROUTE TRANSPORTATION: OPERATIONAL ASSUMPTIONS	
Average passengers per vehicle hour (PPVH) (#)	8
Average trips per vehicle per day (#)	8
Average trip distance (km)	6
Average bus speed (km/h)	26
Emissions factor - CO2 (g/km)	820
FIXED-ROUTE TRANSPORTATION: COSTS	
Hourly operational cost of running 1 mass transit vehicle (€)	105
Capital cost of 1 mass transit vehicle (€)	550000
Average trip fare (€)	2.2
Depreciation period of mass transit vehicle (years)	15
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MODE SPLIT / MODE SHIFT: BEFORE DRT	
Mode split: Mass transit - bus (%)	10
Mode split: Mass transit - other (e.g. rail) (%)	5
Mode split: Auto (%)	65
Mode split: Cycling (%)	9
Mode split: Walking (%)	11
Does mode split add up to 100?	TRUE
MODE SPLIT / MODE SHIFT: AFTER DRT	
Mode split: Mass transit - bus (%)	10
Mode split: Mass transit - other (e.g. rail) (%)	5
Mode split: Auto (%)	65
Mode split: Cycling (%)	9
Mode split: Walking (%)	11
Does mode split add up to 100?	TRUE