Deliverable 5.4

RESILIENCE AND VULNERABILITY ASSESSMENT

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INTRODUCTION

Deliverable 5.4 describes the SmartHubs Resilience Tool (SHRT), developed within the SmartHubs project. The tool analyses the accessibility and network connectivity impacts of mobility hubs on the resilience of urban public transportation networks, and has been applied to the urban areas where SmartHubs Living Labs are located, including scenario analyses based on potential changes in the wider transport network.

The tool, which relies on public transport and bike-sharing data, is made up of two components: a first one providing network analysis-based indicators, such as efficiency and betweenness; a second one allowing to compute accessibility indicators – emerging from conventional spatial interaction/transport models – for the geographical area under analysis.

Transport connectivity and area accessibility are two concepts that are closely intertwined, as both influence the ease with which individuals can reach specific locations. A well-connected transport network can facilitate the movement of people (or goods), thereby reducing travel times and increasing efficiency, and in turn, improving area accessibility.

In this report, an evaluation of the cities associated to each of the SmartHubs Living Labs is provided, using the above-mentioned indicators. A network representation of the local urban public transport supply is developed, to which origin-destination (OD) matrices (when available) containing flows of mobility throughout each city is coupled. Flows are distributed over the public transport network, allowing us to observe more in detail potential critical aspects of the network. Moreover, station-based sharing services (shared bikes) are added to this network, further enriching the representation of mobility options through the cities.

Finally, scenarios are developed where, for each city, different types of disruptions or more generally changes to service (e.g. the introduction of further bike stations) are simulated. For each scenario, network and accessibility metrics are re-computed, therefore allowing to measure the effect of such disruptions on the network, with or without the presence of bike sharing services.

METHODOLOGY

The SHRT allows for resilience analysis through the examination of public transport network connectivity and local accessibility. It allows to quantify the change caused by disruptions and bike-sharing station addition/removal in terms of resilience. The tool consists of two separate components: a) one, developed in the form of `R` code for connectivity analysis, and b) SpinModel, which works as an interactive webpage, for accessibility analysis using spatial interaction models (SIMs). Within the scope of the SmartHubs project, the tool was designed to provide suggestions to urban planners, policymakers, and stakeholders on: a) the most suitable sites where to locate mobility hubs, b) the potential impact of mobility hubs on urban resilience.

More specifically, we measure urban resilience following disruptive events, in terms of the change in connectivity of the public transport network (integrated with bike sharing) and the change in accessibility of urban areas. To do this, we use four metrics: global efficiency, weighted global efficiency, betweenness centrality, and area accessibility. Global efficiency is a valuable indicator for public transport networks because it measures how efficiently passengers can travel across the network. A high global efficiency indicates that passengers can travel between any two points in the network with relatively few transfers. Weighted global efficiency provides a more nuanced understanding of the network's performance, by taking into account the varying strengths of connections between nodes in terms of travel demand. Routes with higher weights (e.g., higher demand) will have a greater impact on the network's efficiency. Nodes with high betweenness centrality are often critical for the robustness of the network. If such a node is disrupted, it can significantly impact the network's functionality and the travel time of passengers. The present deliverable focuses on how the values of these metrics change in response to hypothetical disruptive events on the public transport network and/or after removal/addition of bike-sharing stations. This change provides an indication of the degree of urban resilience.

In the tool, the public transport network is modelled as a graph wherein the nodes represent PT stops and the edges denote the connections between two successive stops or stops equipped by a bike-sharing station. Each edge is attributed a weight that indicates the time needed to traverse the distance between two nodes (*in-vehicle time*). When a journey includes transfers within the same mode of transport or to other modes of transport, the *transfer time* and the *waiting time* at the stop are considered. In the model underlying the tool, given the information on in-vehicle time, transfer time, and waiting time, individuals will always choose the fastest path to reach their destination.

We modelled shared-bike mobility by constructing a "bike-sharing" network and then connecting it to the public transport one. This procedure was carried out in two steps: (1) *Bike-public transport nodes integration* – the bike-sharing stops are aggregated to those of the public transport network if the former is within a circular buffer with radius less than or equal to 200m (Aultman-Hall and Kaltenecker, 1999; García-Palomares et al., 2012)[1]; (2) *Bike-public transport edge integration* – stops resulting from the integration between public transport network and bike-sharing are connected by an edge if they are within a circular buffer with radius less than or equal to 3km (Böcker et al., 2020)[2].

The SHRT uses three distinct kinds of data as input: general transit feed specification (GTFS), geographic information systems (GIS), and OD data. GTFS data contains information about routes, schedules, and geographic transit details, and allows retrieving link travel times and vehicle frequencies. GIS data are used to delimit the area of study, to connect bike-sharing with the public transport network, and for visualization purposes. OD data are used to calculate user flows for each network link, by means of an assignment procedure based on an All or Nothing Network Loading approach. Flows are then used as weights when computing the weighted global efficiency of the network.

To study urban resilience, disruptions and additions/removals of bike-sharing stations are applied. These events are referred to as *scenarios*. A disruptive event is defined as any event that may affect the planned/regular functionality of a public transport network. It's important to note that we are referring to unplanned events occurring at stops, whose effects (closures, interruptions, etc.) are temporary, i.e., such that they do not require the implementation of additional and/or replacement mobility services.

A disruption to the public transport network results in the removal of the nodes affected by the event and the connected links. The removal of a bike-sharing station reduces the number of available travel options. As a consequence, travel times may increase. The addition of a bike-sharing station produces the opposite effect, and may reduce the travel time between two nodes.

In this deliverable, we assume that disruptive events do not affect bike-sharing stations, but exclusively public transport stops. Following this assumption, by measuring the variations of the selected metrics, we can assess the potential impact of bike-sharing supply on urban resilience. We

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[1] Aultman-Hall, L., & M.G. Kaltenecker (1999). Toronto bicycle commuter safety rates. Accident Analysis & Prevention, 31(6), 675-686; García-Palomares, J.C., J. Gutiérrez, & M. Latorre (2012). Optimizing the location of stations in bike-sharing programs: A GIS approach. Applied Geography, 35(1-2), 235-246.

[2] Böcker, L., E. Anderson, T.P. Uteng, & T. Throndsen (2020). Bike sharing use in conjunction to public transport: Exploring spatiotemporal, age and gender dimensions in Oslo, Norway. *Transportation Research Part A: Policy and Practice*, *138*, 389-401.

define such potential impact as the contribution that the bike-sharing network could provide to public transport network robustness, measured as the percentage change in the global efficiency indicators.

FINDINGS

In this deliverable, urban resilience is discussed for four urban areas – the Brussels Capital Region, Munich, Vienna, and the Metropolitan Region Rotterdam-The Hague (MRDH) – and advice is provided to stakeholders concerning four main research questions:

1) How robust is the public transport network to the occurrence of disruptive events?
2) How does accessibility change after disruptive events on the public transport network?
3) What is the consequent potential impact of the bike sharing service on network robustness?
4) Which public transport stops are most suitable for the implementation of new bike-sharing stations, when the goal is to improve network robustness?

The scenarios simulated here have been proposed by the Living Lab (LL) leaders, considering the specificities of each area. Scenarios refer to nodes and/or edges removal or addiction.

The impact of a node's removal on a network's global efficiency is dependent on the network's specific structure and the node's role within it. For example, removing a highly connected node could increase average travel time and decrease global efficiency. Conversely, disconnecting a node might increase global efficiency as it could reduce average travel time, given that the disconnected node may have been part of longer paths in the network. Additionally, the betweenness centrality of the remaining nodes can change when a node is removed, as it may alter the network's shortest paths. If the removed node was part of many shortest paths, its removal can significantly change the betweenness centrality of other nodes. In essence, changes in global efficiency and betweenness centrality due to node removal are dependent on the network's specific topology and connectivity. This is a complex interplay of factors and cannot be generalized for all areas under analysis. Disruptive events on the public transport network not only alter the network's connectivity, but also the accessibility of urban areas. In fact, the variation in travel time resulting from an event can lead to a change in the accessibility of areas that are directly or indirectly impacted by it.

For the Brussels Capital Region case study, among the simulated scenarios, the highest loss of efficiency is observed when nodes close to the canal are disrupted. In this case, and due to the presence of the canal, which constitutes a sort of "geographical barrier", the part of the city beyond the canal results less connected to the rest of the city. In our simulation, the presence of the bike-sharing service in the city increases global efficiency significantly with respect to a scenario where the same service does not exist (approximately +40%). Moreover, the presence of the bike-sharing service seems to be important also in case of disruptions. In fact, when some public transport stops are unavailable, the presence of bike-sharing services seems to considerably increase the resilience of the network to disruptions. Finally, the addition of further bike-sharing stations may increase efficiency; with around 100 more stations, the network becomes approximately 8% more efficient.

For Munich, our simulations show how the interruption of a relevant rail station (Stammstrecke) could cause a loss of network efficiency. However, the moderate extent of this loss, can be interpreted as a sign that the public transport network is robust. However, results show that the presence of bike-sharing stations could allow to better absorb the impacts of the disruptions, by providing users with additional alternatives to reach their destinations and leading to a much more contained reduction in efficiency.

In our simulations for Vienna, the presence of the bike-sharing service in the city increases global efficiency significantly with respect to a scenario when the same service does not exist (approximately +20%). In the most disrupted scenarios, the most impacted areas are those in the South-East of the city.

For the MRDH case, our simulations show that a disruption to a relevant station (Hague Central) could cause a loss of network efficiency. However, the moderate extent of this loss can be interpreted as a sign that the public transport network is robust (and vast). On the other hand, when there is no train traffic possible between Schiedam Centrum and Rijswijk, the loss in global efficiency seems to be more relevant. The presence of the bike-sharing service in city seems to increase efficiency significantly with respect to a scenario when the same service does not exist (approximately +20%).

CONCLUSIONS

The objective of Task 5.4, reported in this document, was to analyse the relevance of network connectivity and accessibility in the dynamic analysis of public transport networks and mobility hubs. This was done, in particular, in the presence of possible shocks/disruptions which might change the former's configuration and efficiency.

From a theoretical viewpoint, a novel approach was adopted, combining spatial interaction, accessibility and network analysis, in the light of network resilience. Methodologically, this approach highlights the importance of considering connectivity and accessibility metrics in the dynamic analysis of a transport network, by analysing their impact on the network efficiency/resilience. In particular, the accessibility analysis adopted here is rather unique, since the related cost parameter is determined by the calibration on real flows instead of taking fixed values that may bias the accessibility ranking.

This multi-disciplinary approach linking transport models and network analysis has been empirically applied to case studies related to the SmartHubs Living Labs, in particular to the areas of the Brussels Capital Region, the MRDH metropolitan region, Munich, and Vienna.

The emerging results confirm the power of this approach in analysing the relevance of changes to the network, such as the introduction of bike-sharing stations, and in particular to the mobility hubs, where new transport modes can be adopted.

In addition, the application of this methodology to different geographical areas and cities, where transport data are available, shows the wide potential of this approach for further case studies. We provide then a useful tool for decisionmakers willing to exploit mobility hubs to improve transport resilience and sustainability. In future extensions, this tool could be fruitfully integrated within a multicriteria analysis decision-making support system, allowing to answer specific research questions (e.g. choosing between alternative locations of new mobility-hubs), also beyond the mobility hubs interest, and employing further data about socio-economic variables and amenities.

POLICY IMPLICATIONS

The analysis conducted allowed to make some evaluations on the robustness of a public transport network when disruptive events occur, and on accessibility changes after the occurrence of a disruptive events on the public transport network. Moreover, the SHRT allowed to determine the potential impact of the bike-sharing service on network robustness.

To make the system more efficient, the addition of further bike-sharing stations may be considered. The analysis performed can suggest locations where the introduction of additional ones could be more effective. The addition of bike-sharing stations could be permanent or temporary; in the latter case, stakeholders may plan, for example, the displacement of bikes from other docks in the city or from an emergency reserve, immediately after the disruption.

As shown by the betweenness analyses, when some nodes of the network face a disruption, the importance of other nodes changes, that is, new stops gain in importance. This means that, in such disruption scenarios, users redistribute and choose paths traversing new nodes, where, as a consequence, public transport loads increase. In this sense, when the goal is to improve the robustness of the public transport network, it could be meaningful to add bike-sharing stations in these locations, that is, in the proximity of stops acquiring a higher betweenness centrality.

The impact of a disruptive event on the public transport network can spill over to the accessibility of areas through the variation of travel times needed to move from one area to another. Also in this case, it is possible to provide indications on where to implement new bike-sharing stations. For instance, it might be useful to do so in those areas that, following the disruptive event, would predict a greater loss of positions in the accessibility ranking.

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SmartHubs

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