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Considering Spatial Factors in Promoting Active, Healthy Commuting

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Abstract

Although mobility is spatial by its very nature, spatial factors are rarely explicitly considered in the promotion of active commuting. However, active commuting bears great potential for increasing physical activity among employees and can thus contribute to health promotion. We argue that spatial models and analyses are building blocks for more efficient strategies in corporate mobility and health promotion measures. Specifically, we propose (a) a routing algorithm that optimizes commuting journeys in terms of health effectiveness; (b) assessment models, which express the suitability of workplace environments for active commuting; (c) spatial analyses that estimate the potentials of different modes for any given location, and (d) spatial analyses that support awareness-raising for active mobility. The elements are conceptualized on a generic level and then applied to a case study in Salzburg, Austria. In this case study, we demonstrate the integrative power of a geo-spatial approach which facilitates holistic perspectives on healthy commuting and has the potential to serve as an evidence base in targeted interventions.

Keywords:

health, active commuting, routing

1 Introduction

While premature deaths caused by infectious diseases have been decreasing over recent decades, the number of deaths caused by non-communicable diseases is on the rise. According to Wen and Wu (2012), sedentary lifestyles account for 5.3 million premature deaths globally per year (smoking accounts for 5.1 million premature deaths). Reducing physical inactivity by 25% could avoid 1.3 million deaths per year globally (Lee et al., 2012).

Preventive measures, such as the promotion of active mobility, are thus high on the agenda in order to increase public health and life expectancy. In addition to the promotion of activities at municipal level, for example in sports clubs or schools, the daily commute bears great potential to be used for health promotion. Journeys from the place of residence to the workplace are routine trips, which are commonly inevitable. Thus, converting these routine journeys into physically active units could contribute to a reduction of inactivity and the associated health threats.

However, changing commuting routines is no easy matter. As Yalachkov et al. (2014) discuss, commuting behaviour – which often means car use – is habitual, and hence tends to be resistant to change. The effect of addressing this resistance by purely rational interventions is minor. The provision of plain information is not sufficient to overcome what Innocenti et al. (2013) term car stickiness. Ogilvie et al. (2016) therefore analyse the parameters which actually shape commuting behaviour. According to their findings, the social and physical environment as well as people's attitudes and beliefs need to be considered when promoting active commuting.

Following Ogilvie et al. (2016), we regard holistic approaches in the context of corporate mobility (or travel plans) and health-related measures as promising for the promotion of active mobility. The working environment commonly offers opportunities to address commuters in various ways over a longer period. However, barriers to an extensive use of this potential still exist. For instance, despite the inherent spatial characteristics of mobility, the promotion of active mobility hardly ever considers the spatial environment, especially at the level of individual commuters. Consequently, recommendations for commuting actively might be reasonable at population level but not feasible for specific situations. Thus, systems recommending active commutes while taking both effects on health and the spatial environment into consideration would leverage existing health-promotion strategies.

In this paper, we propose a GIS-based approach that ensures both the positive health effects of routes and the feasibility of mobility options. For this, spatial models and analyses are merged with findings from medical research.

The remainder of the paper is structured as follows. In Section 2 we summarize existing knowledge on aspects of research that are relevant for our approach. The proposed spatially-sensitive method is then introduced in Section 3 before it is applied to a case study, which is discussed in Section 4. Conclusions are drawn and an outlook for future research is provided in the final section.

2 Literature review

The body of evidence for the beneficial health effects of active mobility is huge. Moreover, there is a consensus in the literature that the negative effects of active mobility, such as crash risk or exposure to air pollution, are significantly outweighed by the positive effects (Mueller et al., 2015, Tainio et al., 2016). The number of studies investigating the specific health effects of active commuting has increased substantially over the last five years. As in studies that consider people's entire mobility, the evidence for the positive health effects of active commuting is beyond any doubt. Martin et al. (2015) proved that switching from car commuting to walking, cycling or public transit (PT) significantly reduces the body mass index (BMI). Switching to active modes (walking, cycling) results in a reduction of 0.75 kg/m^2 for trips > 10 minutes and of up to 2.25 kg/m^2 for trips > 30 minutes. The effect of switching to public transport is smaller (a loss of 0.24 kg/m²) and depends on the distance to the next PT stop. These findings are supported by Costa et al. (2015), who determined commuters' physical energy consumption (expressed in metabolic equivalents, MET[1]). The median intensity for commutes ranged from 1.28 MET for car commuters to 6.44 MET for cyclists. In 2017 an extensive study from Glasgow (Celis-Morales et al., 2017), which investigated data from more than 260,000 participants, attracted a great deal of attention. The authors found that active commuting cut the risk for all-cause mortality massively. The results are especially striking for commuting by cycle: the hazard ratio for mortality due to cardio-vascular disease (CVD) is 0.48, the ratio for CVD incidents is 0.54, and the ratio for cancer mortality is 0.6, compared to non-active commuting (hazard ratio = 1).

Since the potential of active commuting for sickness prevention is evident, policy makers and employers increasingly seek to promote it. However, the evidence base for the efficiency of interventions in a workplace-related context (such as travel plans) is currently rather weak (Winters et al., 2017). In a systematic review of studies on organizational travel plans (OTP), Macmillan et al. (2013) could not find any evidence for a significant reduction in car use among commuters. According to their results, conversion rates were highest among employees who were already contemplating switching from car to alternative modes. Scheepers et al. (2014) concluded from a review analysis that approaches using multiple intervention tools were most promising. However, they observed an overall low quality of study designs and a lack of statistical significance in the results. This is in line with a more recent review study by Petrunoff et al. (2016), who pointed to the fact that no causal relation between any type of intervention and mode change can be drawn from currently available studies. According to their review analysis, work-related interventions tend to have the greatest effect, but statistically sound evidence is lacking.

There are only a few scientific studies which investigate the components of active mobility promotions. Thus, it is hard to determine the role of spatial information in current work-related initiatives. Heath et al. (2012) argue for site-specific interventions that take into account in their design the cultural and physical environment. However, spatial information (for route planning etc.) does not play a role. One systematic investigation of corporate mobility management comes from Belgium (Van Malderen et al., 2012). Here, spatial elements – such as distance to PT stop, commuting distance, topography, infrastructure etc. – are acknowledged as being critical. Nevertheless, they are not directly considered in any of the interventions investigated. In a recent review of travel plans, De Gruyter et al. (2018) mention the surrounding transport network and service as key elements. Nevertheless, the transport conditions are only used for a baseline survey and not as variables in specific recommendations.

The minor role of spatial factors in travel plans and other forms of promoting active commuting is astounding, when the huge body of literature on the influence of the physical environment on people's and specifically commuters' mode choice is considered. Frank et al. (2006) investigated the relation between zoning, walkability, active mobility and BMI in King County, Washington. The authors found walkability to have the strongest predictive power for active mobility when compared to several other demographic variables. A recent review

[1] For further explanations and tables, see Ainsworth et al. (2000).

study collected evidence for the influence of spatial factors on active mobility (Smith et al., 2017). Walkability, parks, playgrounds and adequate infrastructure for pedestrians and cyclists were found to directly contribute to a higher level of active mobility. However, the authors point to the fact that the effects might not be distributed equally but favour socio-economically advantaged groups. Smith et al.'s (2017) findings are confirmed by Sallis et al. (2016), who identified four variables directly related to physical activity, namely residential density, intersection density, public transport density, and number of parks within walking distance. The first two (residential and intersection density) are often used as indicators for walkability. Putting the focus more specifically on commuters, Dalton et al. (2013) related a large set of spatial exposure variables with commuters' mode choice. The distance between place of residence and workplace significantly influences the modal split of active modes. According to the authors, deterrents for active commuting are low frequency of public transport, low street connectivity, free parking at the workplace, and few facilities (shops, leisure facilities, schools) on the way. Adams et al. (2016) found that the perception of a walkable environment around the workplace stimulates higher levels of active commuting. Yang et al. (2015) investigated the combination of spatial variables and worksite incentives. Free or discounted PT tickets and recreational facilities at the worksite had the greatest effect on PT use and active mobility.

We considered four aspects in this literature review: the positive impact of active commuting on health, the role of health promotion in the context of workplace-related mobility management, spatial facets of interventions, and finally the spatial factors for commuters' mode choices. The evidence for the positive impact of active commuting and the spatial factors involved in commuters' mode choices is mounting. However, these two aspects are hardly ever considered in corporate mobility measures or travel plans. The aim of the approach presented in the following section is to address this lack, and to merge spatial information on commutes and the physical environment of workplace sites with health effects. The results can then be used as building blocks for multi-facetted, active commuting promotion in the context of corporate mobility and health promotion measures.

3 Method

We employ spatial models and analysis routines in order to achieve the following objectives:

a) Optimize commuting routes in terms of health benefits. This means that trips should have active components with a minimum duration of ten consecutive minutes (WHO, 2010). However, in order to recommend plausible trips, detour factors are limited (Krenn et al., 2014).
b) Consider the physical environment around the workplace site by calculating walkability, bikeability and PT quality indices.
c) Analyse current modal split statistics in relation to the commuting distance at local level.
d) Collect and map points of interest (POIs) around workplace sites and overlay these facilities with isolines of energy turnover (expressed in MET).

The methods and analysis routines developed for these features, which are intended to feed into an integrated overview, are presented in detail in the following sections.

Healthy routing

Routing algorithms and applications usually aim for a time-efficient solution to travel from A to B. Although a time-efficient solution is desired in most cases - especially for commutes - it often keeps people from active commuting, which is generally regarded as being more time-consuming. Thus, a general scheme for routing optimization has been developed, which results in journey recommendations that exhibit at least the minimum of health-effective physical activity of 10 minutes (see WHO (2010) for further details). The routing optimization focuses on health-enhancing, active mobility solutions, such as walking, cycling or public transport options with a significant share of active mobility for the first and/or last section of the journey.

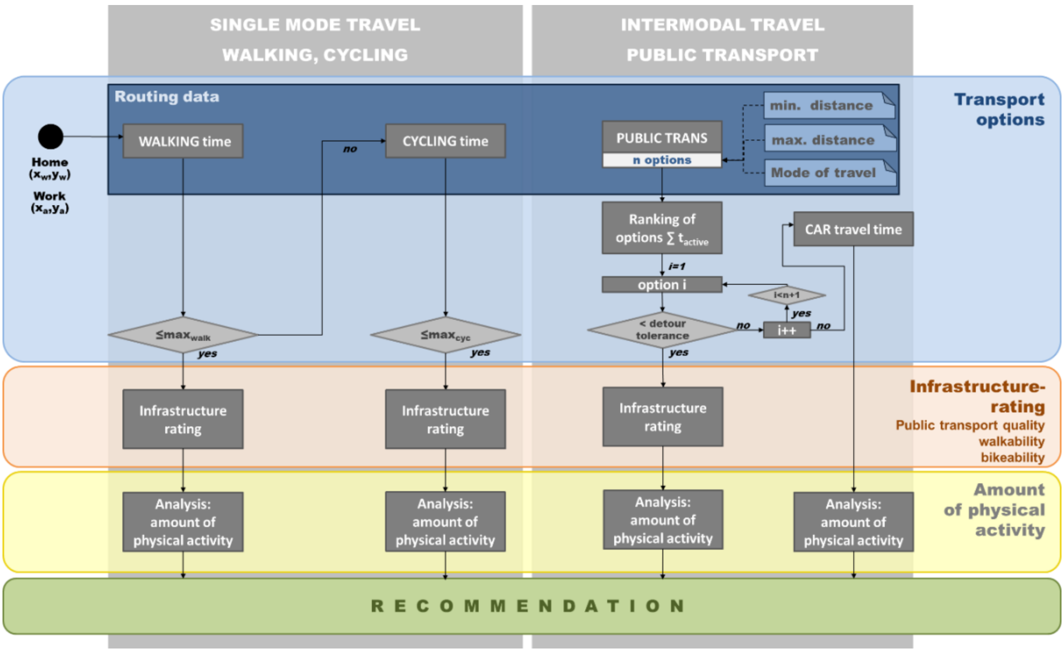

Figure 1: General scheme of the analysis of intermodal routing options for the selection of healthy routes to/from work.

Three modes of transport are considered in the assessment of the amount of physical activity during a commute: walking, cycling and public transport (intermodal routes). For each mode, a three-step process can be conducted to gain information about time efficiency, infrastructure and physical activity.

The optimization process for healthy commutes (Figure 1) is iterative and increases in complexity. In the first step, the feasibility for walking to work is checked. We propose a threshold of 2,500 metres for the maximum walking distance. In cases where the walking distance is less than 10 minutes and thus not health-effective, alternative opportunities for physical activity are recommended.

If the walking duration is above the defined threshold, the connection between place of residence and workplace is checked for cycling. The threshold for the maximum distance for cycling commuting is 10,000 metres. Intermodal trips, including ones using public transport (PT), are calculated for routes that are too long to walk or cycle. Here, routes can differ with regard to trip duration, number of changes, frequency of departures, and share of walking or cycling segments. These intermodal routes can be modelled differently, depending on the routing technology employed, and be used for optimization in terms of convenience and health effects (for instance, setting minimum and maximum thresholds for number of changes or distance of walking sections). Since commuters should be able to regard the recommended routes as feasible and convenient, we optimize PT trips in terms of time efficiency, while ensuring a minimum amount of physical activity in the trip chain.

Assessment of environment

Adequate infrastructure is fundamental for active modes. Therefore, the promotion of active commuting has to take the physical environment into account. For this, we identify crucial spatial factors, which serve as proxies for the quality of the environment in terms of suitability for walking, cycling and PT. These data are projected on a regular polygon raster (which serves as a common spatial reference) and are used for the assessment of the immediate environment of workplace sites.

Walkability

Walkability indices express the quality of the physical environment for pedestrians. Since data which accurately represent the road profile at a sufficient level of detail (for instance the existence and width of pavements) are lacking in most cases, walkability indices usually use proxies. These variables are commonly associated with a pedestrian-friendly environment. For the calculation of a walkability index, we propose the following variables (cf. Leslie et al. (2007) and Frank et al. (2010)): household density, intersection density, functional heterogeneity, green space density, maximum speed, and road category. All variables are then compiled in an equally-weighted model, using the z scores for each variable. Raster cells with walkability index values with +/-5 standard deviations from the mean were excluded as outliers.

$$
\begin{aligned}
Walkability = {} & z\left(\frac{Number\ of\ households}{Area}\right) + z\left(\frac{Number\ of\ intersections}{Network\ length}\right) \\
& + z(Number\ of\ categories\ of\ facilities) + z\left(\frac{Green\ space}{Area}\right) \\
& + z\left(\frac{\sum_{segment} Maximum\ speed}{\sum_{segment} Network\ length}\right) * -1 + z\left(\frac{\sum_{segment} Road\ category}{\sum_{segment} Network\ length}\right) * -1
\end{aligned}
$$

Finally, the values were transformed to the interval between 0 and 1, with lower values representing better walkability.

Bikeability

In a manner similar to walkability, bikeability expresses the quality of the road space for cyclists. Winters et al. (2013) propose a bikeability index for regular spatial aggregates. Loidl and Zagel (2014) developed a network-based assessment model which calculates an index for individual road segments. In order to facilitate easy comparisons and overlays with the walkability index, we adapt this index and aggregate index values to the common spatial reference. The following variables are considered: number of lanes, type of infrastructure for cycling, maximum speed, mean daily volume of motorized traffic, intersection complexity, gradient, parking spaces parallel to the road, pavement quality, road category, road width, and existence of signed cycle routes. Details for the index calculation have been published elsewhere (Loidl and Zagel, 2014).

PT quality

Public transport trips are intermodal by definition because of the first and last segments. By choosing active modes for one or more trip segments, the daily commute by public transport has an impact on health, especially if the duration of any active mobility section exceeds 10 minutes (WHO, 2010). Consequently, if the journey includes at least 10 minutes of walking or cycling, the quality of public transport at the destination is relevant in the context of promoting active commuting mobility.

An index reflecting PT quality is calculated for every raster cell. This index reflects the attractiveness of PT services at a high spatial resolution. Following Hiess (2017) and Handy and Clifton (2001), indicators can be identified which contribute to the quality and attractiveness of public transport: the means of public transport, the distance to the next PT station, the total number of departures from the station, and their variance over the day. Cycle racks and parking lots are further relevant factors, as well as aspects of security and comfort. The provision of and access to public transport services over space is assessed by aggregating these factors, weighted according to their relevance for the decision-making process.

Modal split commuters

The theoretical potential for different modes can be derived for any location by analysing commuting matrices, which are mapped as a raster with a high spatial resolution. For this, the distances from a given location (raster cell) to all other cells are calculated by overlaying the raster with a road graph. Next, the potential demand is estimated by using distance decay functions for walking, cycling and motorized modes, and the number of commuters stored in the commuting matrix.

In summary, the potential mobility demand at any raster cell serves as proxy for the number of employees working at the same business location. Moreover, a plausible 'ideal' modal split, in terms of commuting distance, can be derived. The estimated potential for walking, cycling or PT usage is provided as an additional spatial component in an integrated perspective for corporate mobility measures. Using the indices on walking, cycling and PT quality, decision makers can immediately derive potential improvements in the spatial environment of the workplace in order to increase active, healthy mobility.

Spatial information for raising awareness

Maps help to convert abstract recommendations for physical activity, such as 15 minutes walking with moderate intensity, into easily perceivable visualizations. We propose an isoline map in which thresholds for minimum distances and facilities in the proximity of workplaces are overlayed. This method of visualization is intended to assist employees and mobility managers in identifying convenient opportunities for fulfilling physical activity recommendations while carrying out everyday business (such as walking to the post office).

The visualization includes three essential map layers, each centered on a location (workplace):

1. Basemap for orientation
2. Isolines for minimal walking or cycling distances, which equal the WHO (2010) recommendations for physical activity
3. Points-Of-Interest (POIs), such as shops, bus stops, parking for cycles or cars, etc.

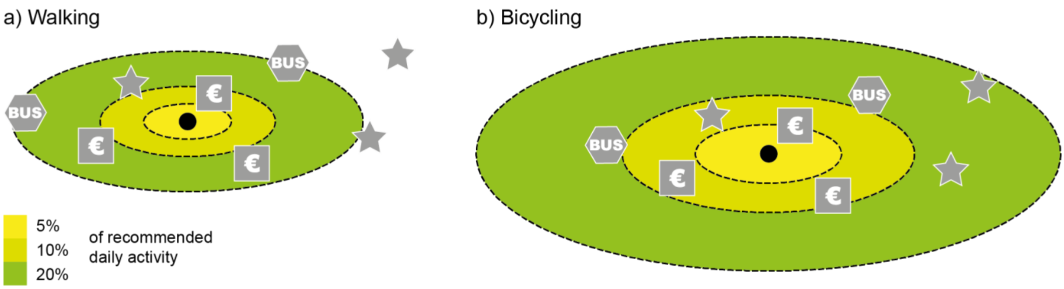

Figure 2: Concepts of 'activity-isolines' for (a) walking and (b) cycling, and points of interests.

Based on this visualization, questions such as the following can be formulated and answered: From/to where does a person need to walk or cycle to get to/from the workplace, in order to achieve a minimum amount of health-effective activity? Where should I park my car to do a minimum amount of walking? How much of the WHO recommendation would be covered if I got off the bus one stop earlier or later?

4 Case study

The method described for providing spatial information for promoting active commuting was implemented in a case study in Salzburg, Austria. The federal state of Salzburg has roughly 550,000 inhabitants, of whom 150,000 live in Salzburg, the capital city. Due to the central location of Salzburg and the numerous large employers, the city is a destination for many commuters. The nationally funded research project GISMO (Geographical Information Support for Healthy Mobility) aims to encourage active commuting as a mean of health promotion and to provide highly specific information for commuters, employers and mobility managers. In this context, we determined the effectiveness (in terms of positive health effects) of interventions which motivate employees to switch from cars to active commuting. Moreover, information tools were developed that optimize the share of active mobility in routing recommendations and contribute to awareness-raising and information.

Routing

Based on the concept described above, we developed and tested a logic for selecting and interpreting routes, using the XML-specification of the Austrian intermodal traffic information system (Verkehrsauskunft Österreich). The identification of health-efficient routing recommendations requires multiple steps:

1. **Optimization of direct walking route.** If the distance is below a parametric threshold (activities lasting less than 10 minutes are not health effective) for the minimum distance, the analysis process is terminated; i.e. the place of residence is too close to the workplace for health benefits to be derived from walking. For commutes of less than 2,500 metres, the route is optimized for walking.
2. **Optimization of direct cycling route**. The cycling route is only calculated if the walking distance exceeds the parametric threshold (in our case 900 metres) and the cycling distance is below an upper threshold of 10,000 metres. Again, the physical activity is calculated and recorded for relevant cycling routes.
3. **Optimization of intermodal PT routes.** The optimization of health-effective PT routes includes several sub-steps. First, all physical activities are extracted from all available PT connections. Based on this, the connection with the highest amount of activity is selected. If this route meets the minimum desirable amount of physical activity, it is recorded. If the amount of physical activity is too low, the route is modified by iteratively testing the effect of getting off at the next or earlier PT stops. As soon as a stop is found from which the distance to the workplace would provide a sufficient amount of physical activity, the route is recorded and returned as a recommendation.

After the route optimization, relevant recommendations are provided. Table 2 lists the attributes, which are provided together with each route.

Table 1: Attributes provided for each recommended route.

Total distance	Total distance of active mobility segments
Travel time	Total time of physical activity
Health-effective travel time	Total health-effective travel time
MET minutes	Metabolic equivalent minutes
Effective MET minutes	Metabolic equivalent minutes which contribute to health effects
Percentage	Percentage of daily WHO (2010) recommendations covered by commutes

Assessment of environment

Walkability and bikeability indices are calculated using publicly available data (Open Government Data and OpenStreetMap). For the calculation of the PT quality index, we combined spatial information with time schedules. All three indices (see Figure 3) are calculated for a regular polygon grid as a common spatial reference. For this, we used the 100-metre grid from the federal census bureau (Statistik Austria).

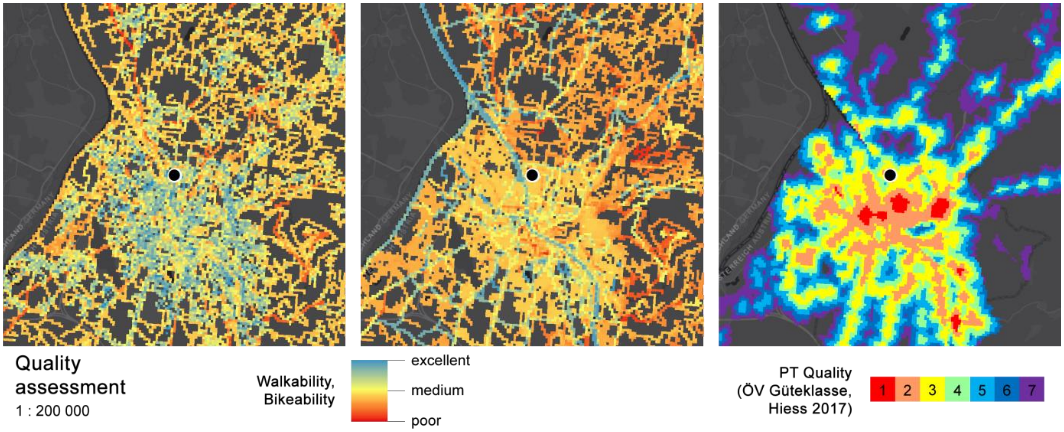

Figure 3: Visualization of walkability, bikeability and PT quality (from left to right).

Commuting data

The federal census bureau (Statistik Austria) provides a commuting matrix of employees and students based on statistical cells (250-metre resolution). The matrix includes information on start and destination cells as well as the number of commuters for each relation. Linking the commuter matrix with spatial information facilitates the generation of further datasets, which contain commuting distances and their relations in space. In the case study, the commuting distances were calculated network-wide for foot and cycle paths , derived from the Austrian standard road network graph (GIP). To enhance interpretation and computing performance, the information was aggregated in statistical cells with a resolution of 500m. In order to generate the potential modal split for each business location with respect to walking, cycling and PT, the commuting routes were classified by distance. For this, a maximum duration of 30 minutes for walking and cycling was assumed. Consequently, for each location the potential for walking, cycling and PT was estimated according to the corresponding distance thresholds of < 2.5km for walking, 2.5–10km for cycling, and >10km for using public transport (see Figure 4).

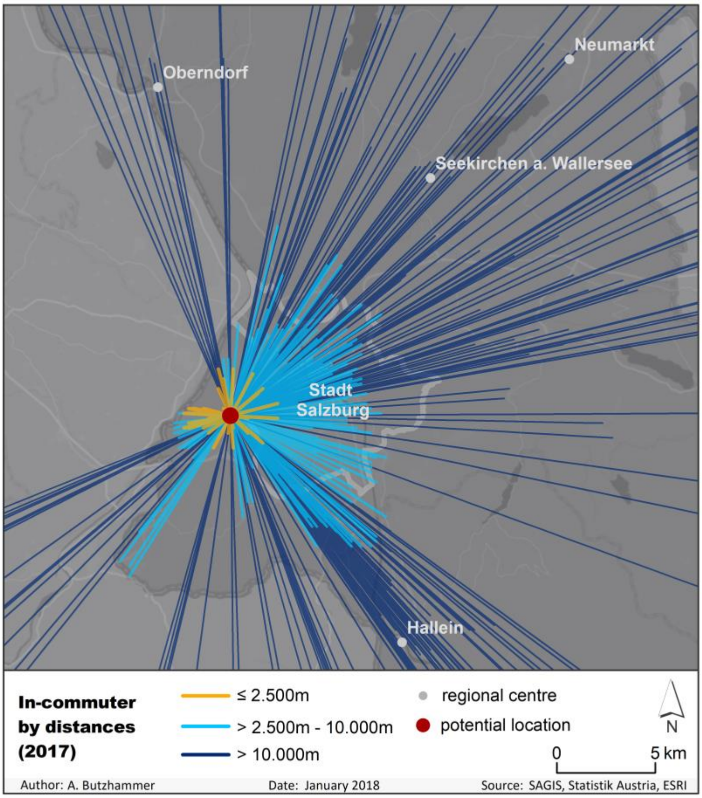

Figure 4: Visualization of commutes for a potential business location. The relation is classified according to the network-based distance in order to derive potential users for the different modes of transport.

Awareness-raising

The visualization concept described in 3.4 was put into practice by setting up a GeoJSON-based web service application. Isolines were generated by calculating catchment areas based on a topologically correct road graph (Figure 5).

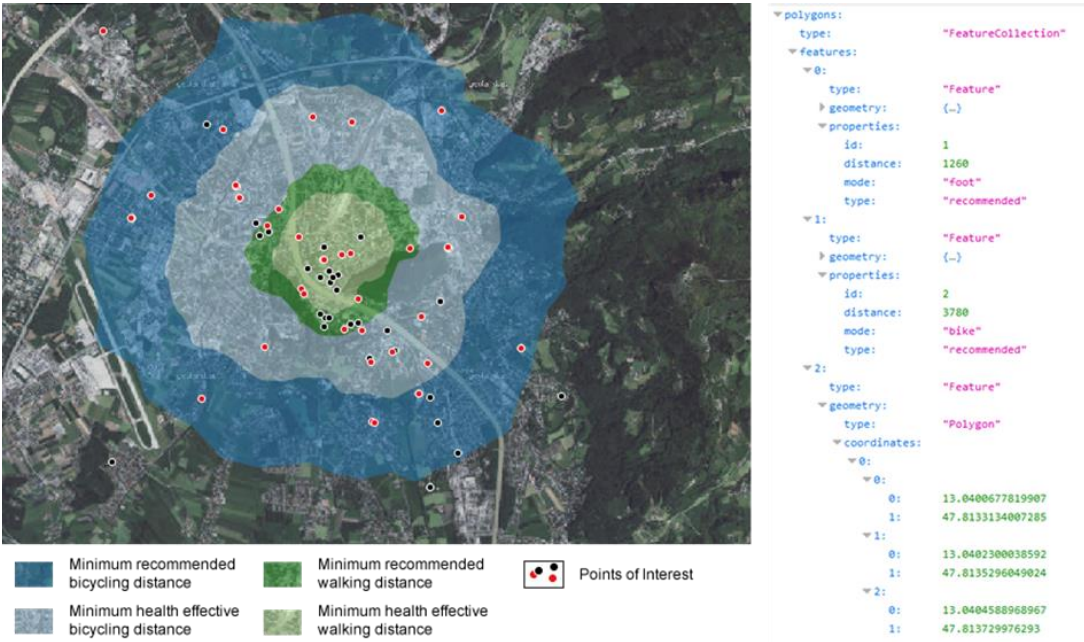

Figure 5: Visualization of isolines with minimum and recommended distances for cycling and walking (left). Screenshot of GeoJSON response to query (right).

In the demo web application, the isolines are overlayed with a basemap and POIs. These maps allow recipients to see immediately potentials for health-effective, utilitarian trips.

5 Conclusion

The method presented in this paper is a building block for bridging the gap between the obvious necessity to increase the level of physical activity and the potential of commutes for health promotion. Through spatial models and analyses, we were able to consider spatial factors for active, healthy commuting. Moreover, the proposed approach facilitates the generation of location-aware information for commutes and workplace environments. Thus, individualized, highly specific information can be delivered.

The method described in Section 3 is transferable to any geographical area. However, the approach requires a significant amount of data, as became obvious in the case study. The route optimization and assessment of the PT quality are tightly linked to an existing national routing API. However, commercial and open source alternatives with global availability exist and could be employed in similar applications. The same holds true for road-related and facility data, where for example OpenStreetMap can serve as a rich data source.

The approach proposed here will be integrated in an interactive information platform for mobility managers and commuters. By using geographical space as the common denominator for various information layers, we account for the complexity of mode choice and commuting habits. The overall goal is to provide all necessary information for encouraging active commuting as a means for health promotion.

The design of the spatial models and analyses could be improved and extended:

a) Walking and cycling trip recommendations could be improved by considering walkability and bikeability and additional variables, such as exposure to air pollution. Currently, native routing algorithms (in the case study we used the VAO routing engine) are used.
b) The increasing amount of detailed travel data will allow for a more precise calibration of the spatial models.
c) The spatial information generated by the proposed method could inform incentive programmes or competitions. In this way, the demand for holistic approaches in the promotion of active commuting could be better addressed.
d) As discussed in the introduction, the effect of corporate mobility management measures is not evident yet. We hypothesize that our integrated approach could contribute to increased awareness of active, healthy commuting and consequently stimulate behaviour changes towards active mobility. In order to test this, the resulting information platform will be subject to in-depth evaluation.

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