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Pro-Environmental Potential in Activity-Travel Routine of Individuals: A Data Driven Computational Algorithm

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Abstract

Informational interventions are considered important to bring positive changes in attitudes and perception about pro-environmental life styles among individuals. In relation to mobility aspects, it is vital to identify relatively easier changes that have potential to reduce negative impacts of mobility on environment and individual health. This paper provides a comprehensive methodological framework and developed a computation algorithm that helps identify such an easy changes in the travel behavior of an individual. The development of algorithm is based on a variety of different data sources such as activity-travel diaries and related constraint information, meteorological conditions, bicycle and public transport supply data. A variety of rules that are part of the computational algorithm are taken from the transport modelling literature, where constraints and factors were examined for various activity-travel decisions. Three major aspects of activity-travel behavior such as lesser car use, cold start of car engines and participation in non-mandatory outdoor activities are considered in assessing pro-environmental potential. The algorithm is applied to data collected, using citizens from Hasselt and their pro-environmental potential is determined, which has been found significant.

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Keywords: Pro-environmental potential, activity-travel behavior, informational intervention, computational algorithm

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1. Introduction

Many environmental problems such as urban air quality, global warming, environmental noise and continuous scarcity of resources (like water) are linked with the human behavior. The transport sector has contributed around 23% of the total CO₂ emissions, which is 2nd highest in Europe¹. Additionally, around 40 million people in the 115 largest cities in the European Union (EU) are exposed to at least one pollutant whose concentration values exceeds WHO air quality guidelines¹. Studies have shown that with a variety of physical and technical interventions, human behavior can be changed/managed to reduce the negative impacts of environment problems. Steg and Vlek² defined informational strategies as an approach to change perceptions, motivations, knowledge and norms, without disturbing the external context in which decisions are made. Information campaigns, use of social support and role models to influence the behavior of individuals can be categorized within this type of intervention approach. Sometimes informational strategies are used to complement the structural strategies (such as congestion charging, fare reduction, increased parking pricing, low emission zones etc.) for producing optimal results³.

Informational based strategies/interventions in relation to personal mobility aspects are scarce in the literature despite their advantages. Schultz⁴ mentioned that these interventions can influence change in the activity-travel behavior of individuals which are relatively easier and have high benefits. For example; reduced travel for non-mandatory activities, use of bicycle/walk for short trips, use of public transport where overall travel time does not have significant differences from other efficient travel modes etc. The informational interventions which provide suggestions to individuals to change their activity-travel behavior should focus on aspects in the activity-travel routine of individuals that can be easily changed. This paper answers the question by developing an algorithm to identify such aspects of an individual activity-travel behavior that are flexible and not strictly constrained by time pressure, family engagement and other constraints. These relatively easier activity-travel choices can be replaceable from more pro-environmental activity-travel choices, and therefore, the developed algorithm provides an assessment of a pro-environmental potential exists within an individual activity-travel routine. According to our knowledge, no such study exists that measured such potential in a comprehensive manner (i.e. by considering various constrained) as done in this study, however, the extent of car-based short trips in individuals travel patterns and their potential to reduce environmental impacts are studied^{5, 6}. The developed algorithm presented in this paper is part of a development process of an informational intervention (designed based on inputs from several studies^{3, 4, 7}) where individuals are provided information regarding the consequences of their activity-travel routine in three different aspects. These are as follows:

- 1) Customized information about their exposure to air pollutants based on recording their detailed activity-travel routine
- 2) Customized information about their contribution in GHG emission (based on their car use)
- 3) Customized information about their extent to contribute in physical activity (based on walking and bicycle use).

The intervention also provides suggestions to individuals that what they can change in their travel behaviour (which is based on the developed algorithm as presented in the later part of the paper) and how these changes can reduce the impacts of the three consequences defined above. Therefore, the algorithm that helps identify pro-environmental potential within activity-travel routine of an individual is a key component for overall effectiveness of the intervention. It is important to note that this paper does not provide details related to the development process of information intervention but the emphasis on the details of the data-driven based computational algorithm that is a key component of the intervention.

The remaining portion of the paper is arranged in the following sections. In Section 2, we give a brief overview of the methodological framework followed to develop such an algorithm. In section 3, we illustrate the algorithm in detail. Section 4 provides the demonstration of the algorithm based on the case study conducted using data collected from citizens of Hasselt city (Belgium). Section 5 provides the conclusion and next steps of the research.

2. Methodological Framework

This section provides details of the steps taken in order to develop an algorithm. There were two major steps in the process, which are as follows: 1) Pro-environmental travel behavior – definition and concepts, and 2) Formulating data requirements and their acquisition methods. More details of each step is provided in the following sub-sections.

2.1. Pro-environmental Travel Behavior – Definition and Concepts

There is no particular definition of the pro-environmental travel behavior exists in the literature. However, literature^{8, 9} indicated various ways which have potential to improve air quality and reduce GHG emissions. For example; lesser use of car, avoiding unnecessary cold start of vehicle engine, use of active travel mode (such as walk, bicycle and public transport) and, lesser participation in out-of-home non-mandatory activities. In order to motivate individuals regarding pro-environmental travel behavior, it is also important that constraints and factors on which individual activity-travel decisions are based should also be thoroughly investigated. Such as cycling and walking cannot be a preferred mode in extreme weather conditions (i.e. during cold and heavy rain), public transport can be preferred when the generalized cost of waiting time, number of transfers, fare, access and egress walk is significantly lower in relation to generalized cost of using a car or taxi. Therefore, the context within which individuals are making their travel decisions is important to understand as well. These factors and constraints are examined well in the travel behavior literature¹⁰. To develop our algorithm we have identified several factors and constraints in relation to complex activity-travel routine individuals are following on a particular day. Due to the limitation in space, we present here the factors/constraints that we found for bicycle use. These are as follows: *travel distance* (lesser is better), *terrain* (flat terrain increase the propensity to bicycling), *segregated bike paths* (more is better), *temperature* (range in between 5 -20 °C is found more suitable), *rain* (bicycling is not preferred when there is a heavy shower), *age* (not preferred for individuals higher than 60 years or lesser than 12 years), not preferred when trip involves carrying a large quantity of goods/groceries, preferred when travel needs to be performed alone.

2.2. Formulating Data Requirement and Acquisition Methodology

An algorithm which can identify pro-environmental potential requires a variety of datasets. On one hand it requires data from the individuals activity-travel routine (in the form of daily diaries), and on the other hand, it requires information about activity purpose, with whom they are travelling and whether they carry a large quantity of goods etc. Additionally, it also requires other third party datasets such as information about meteorological conditions (temperature and rain etc.), availability of public transport routes (their frequency, access and egress walking time) and bicycle paths etc. Therefore, acquisition and handling of such a variety of dataset require careful development of database and protocols under which these datasets are integrated to each other. Paragraphs below provides a summary of acquisition of these datasets.

Activity-travel diary information of an individual will be collected via GPS based smartphone application SPARROWS that has been developed by Transportation Research Institute (IMOB) at Hasselt University. The main idea of using the GPS based application is to avoid any misspecification of activity location data and to avoid missing information of short trips which is often not remembered by individuals when they are filling their previous day activity-travel routine in some other survey instruments. The smartphone app work in conjunction with a prompted recall web-survey, where, based on the processing of GPS traces obtained from an individual's smartphone in the form of stops and trips coupled with background google map environment are provided to individuals for their detailed annotation. This act as a memory prompt to the respondent thus allows the individual to respond to the asked questions regarding stops and trips without any difficulty. Fig. 1. provides the methodological details of the instrument. The questions include; activity purpose for 10 different categories (including waiting at bus/train/tram station), flexibility of activity start and end time (in terms of yes/no), travel modes, travelling with friends/family members (only adults or with kids as well) and whether the trip involves carrying a large quantity of goods.

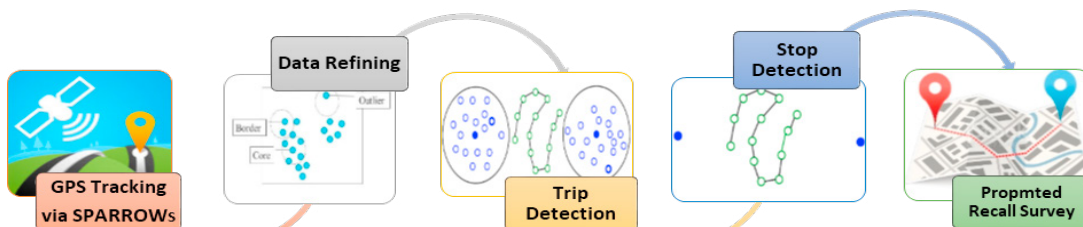


Fig. 1: Schematic Diagram representing steps involved in activity-travel diary collection

The other 3rd party data such as meteorological data in terms of temperature and precipitation data could be easily available in space and hourly units for dates when activity-travel routine of an individuals are recorded from online regional meteorological websites. They can easily integrate with each outdoor activity and trip in the as another attribute of trip and an activity. Public transport schedules, route information along with other relevant details can be obtained from General transit feed specification which can be easily integrated with the road network data (such a work has already been done for entire Flanders region) to identify a public transport route between an origin and destination along with its other details such as travel time, waiting time, transfer and access/egress distances to assess whether it can reasonable to replace a car trip. Bicycling infrastructure information is also important for our study, and therefore, it is acquired from available route planners website such as combing information from Google maps and Route-You (www.routeyou.com), where bicycle routes are classified in terms of recreational cycling routes and short routes with terrain information.

3. Algorithm Development

The development of an algorithm for assessment of pro-environmental potential is based on the norm identified in environment psychological literature^{3, 4}. This norm is based on the idea that from the entire daily activity travel pattern of an individual, it requires identifying such aspect of an individual travel behavior that can be relatively easy to change. This is because for an informational intervention the consequences of these easy behavior with and without their replacement with pro-environmental options can be quantified and presented, so that they can be encouraged to use such options. The pro-environmental potential in this study is considered based on our earlier discussion i.e. lesser use of a car, use of active mobility, lesser participation in out-of-home activities and lesser cold start of vehicle engines. The first necessary step is to identify threshold limits based on the factors/constraints for mode of travel, cold starts and outdoor non-mandatory activities. These are defined in section 3.1, 3.2 and 3.3.

3.1. Rules- Travel mode

We defined these rules based on the literature^{11, 12} and some reasonable assumptions. These rules are derived considering the basic notion. Active mobility is usually defined through a walk, bike and public transport. For each of these travel modes, we defined the rules as follows:

1) *Walk:*

- Trip is not part of a complex activity-travel tour, where an individual is using a personal vehicle to travel for other activities within the same tour.
- Distance travelled is maximum up to 1 km
- End time of activity at the origin or start time of the activity at the destination is flexible
- Weather conditions are reasonable (no heavy showers/ not very cold (i.e. less than 0 °C))
- Not carrying a large quantity of goods and activity at a destination is not of a pick-up type.
- Children (less than 6 years old) are not accompanying

2) *Bicycle*

- Trip is not part of a complex activity-travel tour, where an individual is using a personal vehicle to travel for other activities within the same tour.
- Distance travelled is maximum up to 1 km
- Segregated bike lanes are available (at least half of the path).
- End time of activity at the origin or start time of the activity at the destination is flexible.
- Age of an individual is in between 12 to 60 years.
- Weather conditions are reasonable (no heavy showers/ not very cold (i.e. less than 5 °C))
- Children (lesser than 12 years old) are not accompanying.
- Other accompanying adults and children can ride a bike and bike is available for all.
- Not carrying a large quantity of goods and activity at destination is not of a pick-up type.
- Bike gradient is lesser than 15%.
- Crossings in the bike path are limited to 3.

3) *Public Transport (Bus/Train/Tram):*

- Trip is not part of a complex activity-travel tour, where an individual is using a personal vehicle to travel for other activities within the same tour.
- Availability of public transport between the specific origin and destination.
- End time of activity at the origin and start time of the activity at the destination is flexible.
- Travel time difference between the used mode and public transport is no more than 30 minutes
- Access/Egress walk in total is maximum up to 1 km
- Waiting time is no longer than 10 minutes
- Number of transfer is limited to 1 only.
- Weather conditions are reasonable (no heavy showers/ not very cold (i.e. less than 0°C)).
- Not carrying a large quantity of goods and activity at the destination is not of a pick-up type.
- Children less than 6 year old are not accompanying.

It is important to note that the above rules are defined for normal and healthy individuals with no significant mobility related disability.

3.2. Rules- Cold starts of vehicle engine

Cold starts for car-related trips have been observed to emit significantly higher levels of air pollutant such as CO, HCs and NOx compared to hot starts. It is reported in the literature⁹ that trips following a parking duration in the range of 3-8 hours contain a cold start. This variation in the duration is dependent on the type of vehicle and engine it contains. For this study, we define the rules as follows:

- Cold start will be considered if the duration of activity preceding the car trip is equal or more than 4 hours.
- Cold start for the day-starting car trip and return trip after work activity will be ignored as the purpose is to curtail excessive cold starts.
- Work-based tours (usually for lunch) and home-based other tours performed by car may contain cold start, it will be considered excessive if the following conditions met
 - o One-way trip distance is less than 3 km (to replace it with bicycle) and 1 km (to replace it with walk)
 - o Overall time difference between the two car trips of the tour and with replaced mode should not be greater than 15 minutes
 - o Other general conditions for bikeability and walking as described in section 3.1 should also be observed.
- Possibility of reduction of separate home-based car tours by performing more complex car tours (chaining of activities), if the gap between the tours is longer than 4 hours. In such conditions the following should be met
 - o Activities that need to be chained are flexible in terms of their start time.

3.3. Rules- Participation in non-mandatory outdoor activities

Exposure of individuals to air quality pollutant is more when individuals are involved in performing certain activities in the outdoor environment compared to the indoor performance of these activities¹³. This is not identifiable from GPS based data, therefore a question has been asked from the individual about this. The rules for identifying this are as follows:

- Leisure, Social and other are considered as a non-mandatory activities.
- The above activities if performed in the outdoor environment are considered.
- Only 50% of such outdoor non-mandatory activities are considered for measuring pro-environmental potential
- If the non-mandatory outdoor activities are performed in a simple home-based or Work-based tour, both inward and outward trips are also reduced and counted in pro-environmental potential.
- If the non-mandatory outdoor activity is part of the complex pattern (e.g. making a stop way back to home after work activity), then the trips are not reduced, and it is considered as a single long trip without that

non-mandatory outdoor activity and route is also considered the same. The duration of next indoor activity was increased the same amount as of replaced non-mandatory outdoor activity.

3.4. Integration- Data and Rules

The next major step for the development of an algorithm is the integration of different datasets with the help of developed rules that can help in assessing pro-environmental potential. A computer software is written for this integration and the final output is in the form of pro-environmental potential. The skeleton of the software is depicted in the Fig. 2.

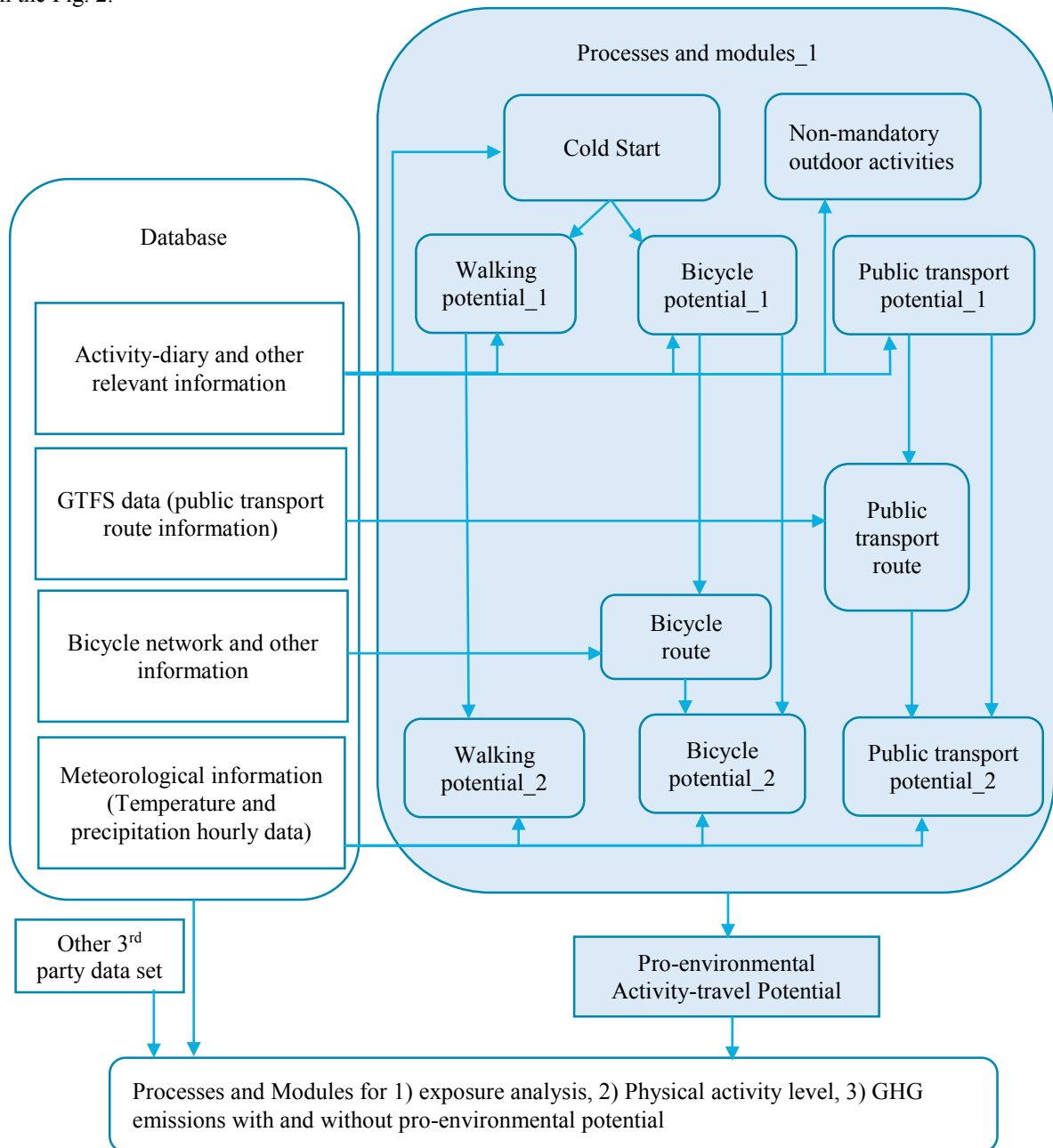


Fig. 2: Skeleton for assessment of pro-environmental potential and their impacts

The above skeleton is briefly described here. The initial database that contains four important datasets is used in developing processes and module_1, that are mainly related to the implementation of rules defined in section 3.1, 3.2 and 3.3. It is important to note that Walking_potential_1 and other similar modules are only based on the identification of replaceable potential utilizing only those set of rules that can only be a part of information within activity-diaries dataset. These initial potentials are then further examined based on the route characteristics information obtained from GTFS and bicycle network data respectively using their route modules (they can identify a route given an origin and destination). Finally, from the initial potentials and route modules, the finalized potentials for walk, bicycle and public transport are determined. Additionally, non-mandatory outdoor activity potential which mainly requires inputs from activity diaries is determined. The cold start potential also has rules which require examination of walkability and bikeability and therefore need to go through a similar chain of modules to reach finalized pro-environmental potential. As part of a larger motivation of this research, with the help of other datasets such as air quality pollutant concentrations, emission factors and car fleet information, and using other processes and modules (details of which are not provided in this paper) exposure, GHG and physical activity level is determined with and without pro-environmental potential to develop an informational intervention.

4. Case Study: HASSELT City

Hasselt citizens are recruited for a long term (two months) behavioral intervention study as a part of the larger research agenda. Hasselt is one of the urbanized Arrondissement in the Limburg province of Belgium. The initial dataset which is an activity-travel diary information for *one week* is obtained for 25 citizens. This data was collected in the month of August, 2017. Usually, during this part of the year, the temperature is ranging in between 10-22 °C and there are around 29% of the chances of the wet day (precipitation of at least 0.04 inches). Based on the collection of other datasets as identified in the methodological framework and algorithm development section the pro-environmental potential is determined. It is important to note that developed computation algorithm is simulating single individual at a time. The cumulative results obtained are presented and discussed as follows.

Table 1 provides some interesting insights regarding potential in terms of the walk, bicycle and public transport mode by replacing car trips. It should be noted that citizens are not using *car* for the trips which are limited to 1km or less, perhaps the availability of *car* creates a tendency to involve in trips which are of distance greater than 1 km. Furthermore, it is noted that a considerable number of trips are performed within 1- 3 km range, and there is a significant potential to replace them by bicycle. Similarly, car trips can be replaced by public transport. It is interesting to see that without having harder constraints, individuals are involved in choices which are not sustainable. These statistics show that there is a significant potential in terms of environmental benefits if individuals are encouraged to change their behavior. Therefore, this potential needs to be exploited.

Table 1: Participant Car Usage characteristics and its replaceable potential

Statistics	Car Trips					Public Transportation Potential
	Within 1 km	Walking potential	Within 3 km	Bicycle Potential	Total trips	
Sum	0	0	82	23	192	42
Mean	0	0	3.28	0.92	7.68	1.68

Table 2: Cold start and non-mandatory outdoor activities and its replaceable potential

Statistics	Cold Starts	Cold Starts Potential	Non-mandatory outdoor Activities	Non-mandatory outdoor activity Potential
Sum	115	39	52	26
Mean	4.61	1.56	2.08	1.04

Table 2 provides details of actual and replaceable potential of excessive cold starts of car and also individual participation in non-mandatory outdoor activities. It is important to note that non-mandatory outdoor potential is measured as 50% of the total. Again it can be seen that this potential is significant and if some percentage of this is reduced, it could be better for improvement of overall quality. Further results from the analysis can also be shown, such as what could be the advantages in terms of reducing GHG emission, reduction in individual exposure, increase in physical activity level if these identified potentials are to be followed. However, due to the space limitation we conclude our paper only with presentation of these initial results.

5. Conclusion

In this paper, an algorithm is presented which attempts to determine the pro environmental potential exists in an individual activity-travel behavior. The developed algorithm considers a variety of constraints and factors associated with individual travel decisions which are identified in the literature. The pro-environmental potential determined from the algorithm has a significance in designing an informational intervention, where information presented to the user will be customized, and provide a clear justification about advantages these changes will bring in terms of reduction of exposure, increase in physical activity level and reduction of their contribution in GHG emissions. The algorithm utilizes state-of-the-art data collection methodologies which provide essential details of an activity-travel routine of individuals such as GPS based smartphone application and prompted recall survey. The developed algorithm is tested for the data collected from Hasselt citizens and the results reported from such algorithm are encouraging.

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