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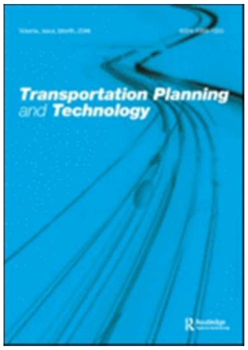

Investigating Micro-simulation Error in Activity-based Travel Demand Forecasting: A Case Study of FEATHERS Framework

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Investigating Micro-simulation Error in Activity-based Travel Demand Forecasting: A Case Study of FEATHERS Framework

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Abstract: Activity-based models of travel demand have received considerable attention in transportation planning and forecasting over the last decades. However, they use in most cases micro-simulation approach, thereby inevitably including a stochastic error that is caused by the statistical distributions of random components. As a consequence, running a transport micro-simulation model several times with the same input will generate different outputs, which to a great extent baffles practitioners in applying such a model and in interpreting the results. In order to take the variation of outputs in each model run into account, a common approach is to run the model multiple times and to use the average value of the results. The question then becomes: what is the minimum number of model runs required to reach a stable result (i.e., with a certain level of confidence that the obtained average value can only vary within an acceptable interval). In this study, systematic experiments are carried out by using the FEATHERS, an activity-based micro-simulation modeling framework currently implemented for the Flanders region of Belgium. Six levels of geographic detail are taken into account, which are Building block level, Subzone level, Zone level, Superzone level, Province level, and the whole Flanders. Three travel indices, i.e., the average daily number of activities per person, the average daily number of trips per person, and the average daily distance travelled per person, as well as their corresponding segmentations are calculated by running the model 100 times. The results show that the more disaggregated level is considered (the degree of the aggregation not only refers to the size of the geographical scale, but also to the detailed extent of the index), the larger the number of model runs is needed to ensure confidence of a certain percentile of zones at this level to be stable.

Furthermore, based on the time-dependent origin-destination table derived from the model output, traffic assignment is performed by loading it onto the Flemish road network, and the total vehicle kilometres travelled in the whole Flanders are computed subsequently. The stable results at the Flanders level provides model users with confidence that application of the FEATHERS at an aggregated level only requires limited model runs.

Keywords: Activity-based models; Micro-simulation; Stochastic error; Confidence interval; FEATHERS.

1. Introduction

Activity-based models of travel demand have received considerable attention in transportation planning and forecasting over the last decades. Relative to the conventional trip-based approach, such as the four-step model [McNally, 2007], the activity-based approach is a richer, more holistic framework in which travel is analyzed as daily or multi-day patterns of behaviour related to and derived from differences in lifestyles and activity participation among the population [Kitamura, 1988]. A full activity-based model of travel demand predicts which activities (activity participation) are conducted where (destination choice), when (timing), for how long (duration), which chain of transport modes is involved (mode choice), travel party (travel arrangements and joint activity participation) and which route is chosen (route choice), subject to personal, household, spatial, temporal, institutional and space-time constraints [Rasouli and Timmermans, 2012]. Since 1990s a rapid growth of interest in activity-based analysis has led up to the development of several practical models, including TRAMSIMS [Smith et al., 1995], RAMBLAS [Veldhuisen et al., 2000a], CEMDAP [Bhat et al., 2004], FAMOS [Pendyala et al., 2005], ALBATROSS [Arentze and Timmermans, 2000; 2004], and FEATHERS [Bellemans et al., 2010]. The main contribution of these activity-based models is to offer an alternative to the four-step models of travel demand, better focusing on the consistency of the sub-models and proving increased sensitivity to a wider range of policy issues [Janssens et al., 2008].

However, the activity-based models, focusing on activity-travel generation and activity scheduling decisions, use in most cases a micro-simulation approach, in which heterogeneity and randomness are fundamental characteristics since they simulate individual activity patterns by drawing randomly from marginal and conditional probability distributions that are defined for the various choice facets that make up an activity pattern [Kitamura et al., 2000; Timmermans et al., 2002; Arentze and Timmermans, 2005]. As a result, running a transport micro-simulation model several times with the same input will generate different outputs due to the random number seed used in each run. In order to address practitioners' concerns about this variation, it is natural to run the transport micro-simulation model multiple times, estimate the effects of stochastic error by analysing the variation of the outputs between the runs, and use the average value of these outputs for further analysis. The question then becomes: what is the minimum number of runs required to reach a stable result (i.e., with a certain level of confidence that the obtained average value can only vary within an acceptable interval)? In this respect, several relevant studies have been carried out, such as Benekohal and Abu-Lebdeh (1994), Hale (1997), Veldhuisen et al. (2000b), Esser and Nagel (2001), Vovsha et al. (2002), Castiglione et al. (2003), Ziems et al. (2011), Horni et al. (2011), and Cools et al. (2011). In particular, Castiglione et al. (2003) investigated the extent of random variability in the San Francisco model (a micro-simulation model system) by running the model 100 times at three levels of geographic detail, namely zone level, neighborhood level, and county-wide level. The analysis was then conducted by showing how quickly the mean values of output variables such as the number of trips per person converge towards the final mean value (after 100 runs) as the number of simulation runs increases. However, only two zones and neighborhoods were considered in that study, which to a large extent limits the generalization of the conclusions drawn in that paper. In this study, we focus on the same issue but look for the answer one step further, which is to find the minimum number of model runs needed to enable at least a certain percentile of zones at different levels of geographic detail to reach a stable result. Systematic experiments are carried out by using the FEATHERS, an activity-based micro-simulation modeling framework currently implemented for Flanders (Belgium). By running the model 100 times, three travel indices, i.e., the average daily number of activities per person, the average daily number of trips per person, and the average daily distance travelled per person, as well as their corresponding segmentations with respect to socio-demographic variables, transport mode alternatives, and activity types, are calculated at the six different geographical levels of Flanders (see Section 2). Furthermore, based on the time-dependent origin-destination table derived from the model output, traffic assignment is performed by loading it onto the Flemish road network. The variation of the total vehicle kilometres travelled in Flanders is investigated subsequently.

The remaining of this paper is structured as follows. In Section 2, we briefly introduce the FEATHERS framework and the levels of geographic detail of Flanders, followed by the detailed elaboration of the experiment execution in Section 3. In Section 4, the analysis results are presented and discussed. The paper ends with concluding remarks and future research topics in Section 5.

2. FEATHERS Framework for Flanders

FEATHERS (The Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS) [Bellemans et al., 2010] is a micro-simulation framework particularly developed to facilitate the implementation of activity-based models for transport demand forecast. Currently, the framework has been implemented for the Flanders region of Belgium, in which a sequence of 26 decision trees, derived by means of the chi-squared automatic interaction detector (CHAID) algorithm, is used in the scheduling process and decisions are based on a number of attributes of the individual (e.g., age, gender), of the household (e.g., number of cars), and of the geographical zone (e.g., population density, number of shops). For each individual person with his/her specific attributes, the model simulates whether an activity (e.g., shopping, working, leisure activity, etc.) is going to be carried out or not. Subsequently, the location, transport mode and duration of the activity are determined, taking into account the attributes of the individual. Based on the estimated schedules or activity travel patterns, travel demand can then be extracted and assigned to the transportation network. Currently, the FEATHERS framework is fully operational at six levels of geographic detail of Flanders, i.e., Building block (BB) level, Subzone level, Zone level, Superzone level, Province level, and the whole Flanders level. Figure 1 illustrates the hierarchy of the geographical layers with different granularities.

<Figure 1 here>

In recent years, a number of applications have been carried out using the FEATHERS platform (see e.g., Kochan et al. (2008), Kusumastuti et al. (2010), and Knapen et al. (2012)). However, like other activity-based models, the FEATHERS framework is based on micro-simulation approach. Stochastic error thereby inherently exists, which requires systematic investigation in order to better understand the variability of the simulation results and to facilitate the further development of this modelling framework.

3. Methodology

In this study, to estimate the impact of micro-simulation error of the FEATHERS framework at all of the six levels of geographic detail of Flanders, 100 successive model runs are performed based on a 10% fraction of the study area population. By considering only a fraction of the full population, computation time is kept within acceptable limits, but it still takes around 18 hours for a single model run at the BB level, the most disaggregated geographical scale.

After each model run, the prediction file, containing the whole activity travel pattern or schedule information for each individual, is generated, based on which the three travel indices (i.e., the average daily number of activities per person, the average daily number of trips per person, and the average daily distance travelled per person) can be computed. Moreover, segmentations of these travel indices based on socio-demographic variables, transport mode alternatives, as well as activity types can be obtained.

Recall the main objective of this study, which is to determine the minimum number of model runs needed to ensure a certain percentile of zones at different geographical levels to reach a stable result concerning the travel indices (i.e., with a certain level of confidence that the obtained average index value of each of these zones can only vary within an acceptable interval). Accordingly, the concept of confidence interval (*CI*) is adopted in this study, and the following equation is applied [Dowling et al., 2004]:

$$CI_{(1-\alpha)\%} = 2 \times t_{(1-\alpha/2),N-1} \frac{s}{\sqrt{N}} \tag{1}$$

where $CI_{(1-\alpha)\%}$ represents $(1-\alpha)\%$ confidence interval for the true average value; α is the probability of the true average value not lying within the confidence interval; $t_{(1-\alpha/2),N-1}$ is the Student's *t*-statistic for the probability of a two-sided error summing to α with *N*-1 degrees of freedom; *N* is the required number of model runs; and *s* denotes the estimated standard deviation of the results.

For the experiment, a 95% level of confidence is selected and the desired confidence interval, which acts as the predefined stable condition, is set as a 10% fraction of the final average value (after 100 runs) of the index (*X*) under study, i.e., $CI \le 0.1 \times \bar{X}_{100}$, where $\bar{X}_{100} = \sum_{i=1}^{100} X \big/ 100$. Also, the standard deviation of the results among 100 runs is used as the estimation of s.

Now, by using Eq. (1), an iterative process is applied for each zone to estimate the required minimum number of model runs in terms of the corresponding index under study. In short, it is necessary to iterate until the estimated number of model runs *N* matches the number of repetitions assumed when looking up the Student's *t*-statistic. In this way, the minimum number of FEATHERS runs needed to ensure a certain percentile of zones at different geographical levels to achieve stable results with respect to the corresponding index can be derived.

Furthermore, by considering the socio-demographic variables gender (two categories: male and female) and age (five categories: 18-34 years, 35-54 years, 55-64 years, 65-74 years, and 75+ years) as well as four types of transport modes (i.e., car as driver, car as passenger, slow mode, and public transport) and four types of activities (i.e., home-related activity, work-related activity, shopping activity, and touring activity), the required minimum number of FEATHERS runs with respect to these segmentations can be obtained, respectively.

In addition, based on the time-dependent origin-destination table derived from the model output, traffic assignment can be performed by loading it onto the Flemish road network, and the vehicle kilometres travelled at the whole Flanders can be studied subsequently.

4. Results

In this section, the results of the experiment on the average daily number of activities per person, the average daily number of trips per person, and the average daily distance travelled per person, as well as their related segmentations at all the geographical levels of Flanders are presented and discussed. The vehicle kilometres travelled on the Flemish road network after traffic assignment is provided subsequently.

4.1 Travel indices

According to Eq. (1), the required minimum number of FEATHERS runs for each zone at all the geographical levels can be calculated based on the predefined stable condition. Fig. 2 illustrates the minimum number of model runs needed to enable different percentiles of zones of each geographical level to reach the stability with respect to the average daily number of activities per person, the average daily number of trips per person, and the average daily distance travelled per person, respectively.

<Figure 2 here>

In general, the required minimum number of runs for the daily distance travelled is larger than that for the daily number of trips, which is in turn larger than that for the daily number of activities, especially for the lower geographical levels, such as the BB level, the Subzone level, and the Zone level. This can be mainly accounted for by the fact that in the FEATHERS framework, the type of activities is firstly scheduled, followed by the determination of activity locations. The stochastic error is therefore accumulated by executing each of the above procedures.

Moreover, for all the three indices, with a decrease in the geographical aggregation level, the required minimum number of model runs to enable the certain percentile of zones to achieve the predefined stable condition is increasing, which means that relative to a highly aggregated geographical level, it is more difficult for a lower level to make the same percentile of zones reach stability. In other words, with a certain number of model runs, a lower geographical level can only guarantee a smaller percentile of zones to reach stable status. Taking the daily number of trips as an example, at both the Flanders and the province levels, the sample mean of this index has negligible variation, thereby only a limited number of runs (less than 5) is needed to ensure all the zones in these levels to be stable. When it comes to the Superzone level, also few runs are needed if only 95% of the zones are required to be stable. However, if the stability of all the zones at this level is the requirement, the number of model runs has to be increased dramatically, which is around 180 runs. The situation becomes worse when even lower geographical levels are taken into account. At the final BB level, 180 model runs can only ensure 90% of the zones to be stable, and within 100 runs, only around 70% of the zones can be guaranteed in terms of their stability. It is therefore a dilemma to choose between on the one hand more detailed exploration and on the other hand more reliable results. One compromising solution is to set another relatively achievable confidence interval condition for the zones with high variation, especially when these zones are not involved in the study area.

4.2 Segmentations

In order to illustrate the impact of segmentations of the population on the required number of model runs, the above travel indices are disaggregated based on socio-demographic variables (gender and age), transport mode alternatives, as well as different activity types. The results are presented and discussed in the following sections.

4.2.1 Gender

Fig. 3 illustrates the results of gender segmentation related to the average daily number of trips per person and the average daily distance travelled per person. As can be seen, the required minimum number of model runs for either male or female is a little bit larger than that of the overall travel indices for each percentile due to the classification by gender. Moreover, the female group needs a relatively larger number of runs for each percentile of zones to reach the predefined stability than the male group, especially for the lower geographical levels. It can be partly attributed to the fact that as a whole the female group in Flanders generates a relatively smaller number of trips and distance travelled than the male group.

<Figure 3 here>

4.2.2 Age

When age categories are considered with respect to the same travel indices analyzed in Section 4.2.1, the required minimum number of model runs for different percentiles is significantly increased, especially at the highly disaggregated geographical levels. Whereas at the Flanders and the Province levels, less than 5 runs are needed for both indices, even when the full percentile is under requirement (see Tables 1 and 2). Moreover, concerning the lower geographical levels, it is interesting to see that the required number of runs for the first two age categories (i.e., 18-34 years and 35-54 years) are apparently less than that for the following two age categories (i.e., 55-64 years and 65-74 years), which are further less than that of the last age category, i.e., over 75 years. This dissimilarity between different age groups can be explained by the fact that the first two age groups involve a larger population in Flanders than the age groups 55-64 years and 65-74 years, which also involve a larger population than the eldest age group (see Tables 1 and 2). Such a situation potentially increases the instability of the index under concern with respect to the elder age group because less population normally implies a lower number of trips and distance travelled as well.

<Table 1 here>
<Table 2 here>

4.2.3 Transport modes

In addition to the socio-demographical variables, research on the mode split is also important from the practitioner's point of view. In this study, four different transport modes, i.e., car as driver, car as passenger, slow mode, and public transport are considered. The results are shown in Table 3 and Table 4. We find that the most frequently used transport mode in Flanders, i.e., the car as driver, needs the lowest number of model runs to reach the predefined stable condition for both the trip and the distance related indices at any geographical level and for any required percentile of zones. On the contrary, the public transport appears to be the mode with the highest variation since the largest number of model runs are needed to achieve the predefined confidence interval.

<Table 3 here>
<Table 4 here>

4.2.4 Activity types

Concerning the activity-related index, the FEATHERS framework defines 10 different activity types. The results of four common activity types in our daily life are listed in Table 5. They are home-related activity, work-related activity, shopping activity, and touring activity, respectively. Regardless of the most stable geographical levels, i.e., the Flanders and Province levels, home-related activity needs a lower number of model runs to reach stability in comparison with work-related activity, which in turn requires fewer runs with respect to shopping activity. Touring activity, however, requires the highest number of model runs among these four types. Such an ordering appears to be quite consistent with the frequency of these activities taking place in our daily life.

<Table 5 here>

4.3 Total vehicle kilometres travelled on the Flemish road network

As we can see from the above analysis, the whole Flanders, i.e., the highest level of geographic detail in this study, always reaches the predefined confidence interval fastest. Even taking the segmentations into account, limited number of FEATHERS runs are enough for the index under study to achieve the stable condition (i.e., $CI \le 0.1 \times \overline{X}_{100}$). In this section, we investigate the variation of the vehicle kilometres travelled on the Flemish road network by carrying out traffic assignment 100 times. Specifically, after each model run, we obtain the predicted activity travel patterns of each agent, based on which the time-dependent origin-destination (OD) matrices (between 8 a.m. to 9 a.m.) can be derived. Afterwards, the traffic flow and the vehicle distance travelled on each network link can be simulated. Thus, at the whole Flanders level, the total vehicle kilometres travelled as well as the vehicle kilometres travelled for eight different route link types can be computed. Now, based on the 100 traffic assignment results, the required minimum number of model runs can be identified. The results are shown in Table 6.

<Table 6 here>

As can be seen, 2 FEATHERS runs are enough to meet the requirement of the confidence interval for the total vehicle kilometres travelled on the Flemish road network. Considering the eight route link types (Linktypes1-8 in Table 6), highway (Linktype1) appears to be the most frequently used road type and is relatively easier to achieve the requirement. Nevertheless, even for the one with the lowest amount of vehicle kilometres travelled, i.e., Linktype4, 7 model runs would satisfy the stable condition. Such a result provides users with great confidence that application of the FEATHERS at an aggregated level only requires limited model runs.

5. Concluding Remarks

Activity-based models of travel demand generate outputs in most cases from microsimulation-based forecasts. Therefore, stochastic errors due to the statistical distributions of random components are inherently included in such models. Analysis of their impacts on the model outputs thereby becomes one of the vital steps for the reliable transportation planning and forecasting. In this study, the effect of stochastic error in the FEATHERS framework, an activity-based micro-simulation travel demand modeling framework particularly developed for Flanders (Belgium), was investigated, in which six levels of geographic detail were taken into account. The concept of confidence intervals was applied with the purpose of determining the required minimum number of model runs to ensure at least a certain percentile of zones in each geographical level to reach the predefined stability.

By successively running the activity-based model inside FEATHERS 100 times based on a 10% fraction of the full population, the variation of three travel indices including the average daily number of activities per person, the average daily number of trips per person, and the average daily distance travelled per person, as well as their corresponding segmentations with respect to socio-demographic variables (gender and age), transport mode alternatives, and activity types, were estimated. The results indicated a consistent phenomenon, i.e., for a given percentile of zones, the index under study at a higher aggregated level was normally easier than at a lower level to achieve the predefined stable condition. Here, the degree of the aggregation not only referred to the size of the geographical scale, but also to the detailed extent, i.e., the segmentation of the population, of the index under study.

Concerning the geographic scales, only a limited number of model runs was required at the highly aggregated levels (such as the whole Flanders and the province levels) to ensure all the zones (i.e., the 100 percentile) in these levels to be stable with respect to all the indices and their segmentations. By calculating the vehicle kilometers travelled on the Flemish road network after traffic assignment, similar conclusion could be drawn. All this provides model users with confidence that application of the FEATHERS at an aggregated level only requires limited model runs.

However, when it came to the BB level, the most disaggregated geographical level in this study, more than 200 model runs were usually required to enable all the zones to satisfy the stable condition for any index. And within 100 runs, normally only 70% or even 50% of the zones could guarantee stable model results. It is therefore a dilemma to choose between more detailed exploration and more reliable results. One compromising solution is to set another relatively achievable confidence interval condition for the zones with high variation, especially when these zones are not involved in the study area.

With regard to the different segmentations of the population, it was found that the required number of model runs was relatively lower for the particular target segments which potentially involved more trips or activities. Specifically, the male group which generated a relatively larger number of trips and distance travelled in Flanders needed a relatively lower number of model runs than the female group in order to reach the predefined stability for each percentile of zones. Also, the required number of runs for the younger age categories (i.e., 18-34 years and 35-54 years) apparently seemed to be lower than that for the other higher age categories (i.e., 55-64 years, 65-74 years, and over 75 years). Furthermore, the most frequently used transport mode in Flanders, i.e., the car as driver, required the lowest number of model runs, when compared with the other transport modes, in order to satisfy the predefined stable condition for both the trip and the distance related indices. Concerning the index of activity, home-related activity as the most frequently executed activity in our daily life needed fewer model runs to reach stability when compared with the other activity types. Finally, the analysis of the vehicle kilometres travelled on the Flemish road network also showed similarly that the vehicle kilometres travelled on highways---the most frequently used road type---were relatively easier to meet the requirement than the other road types.

With the growth of micro-simulation in travel demand modeling, analysis of the variance of the simulation results becomes particularly important due to the highly stochastic nature of such systems. The results obtained in this study can thus be consulted as a reference for those who plan to use the FEATHERS framework. In the future, more aspects could be investigated. First of all, the impact of the population fraction on the stochastic error should be studied. New insights could probably be gained by repeating the experiment based on the full population instead of the 10% fraction used in this study. Moreover, based on the model outputs, other valuable travel indices could be taken into account as well, such as the index on travel time. In addition, apart from looking at the stochastic micro-simulation error in FEATHERS, exploration on other potential uncertainty due to phenomena like input variability and model specification is also worthwhile. Finally, it should be noticed that this study only focused on one modelling framework. Generalization of the findings to other activity-based travel demand models should therefore be a meaningful future research direction.

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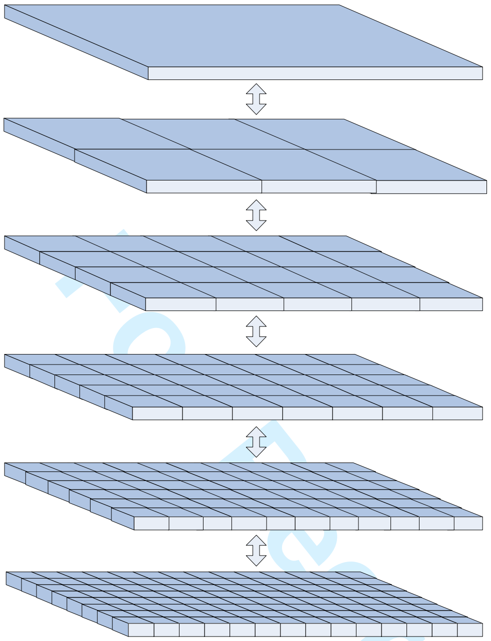

Geographical Level	Number of zones	Average area (km^2)
Flanders	1	13709.24
Province	6	2284.87
Superzone	327	41.93
Zone	1145	11.97
Subzone	2386	5.75
BB	10521	1.30

Fig. 1 Six levels of geographic detail of Flanders used in the FEATHERS

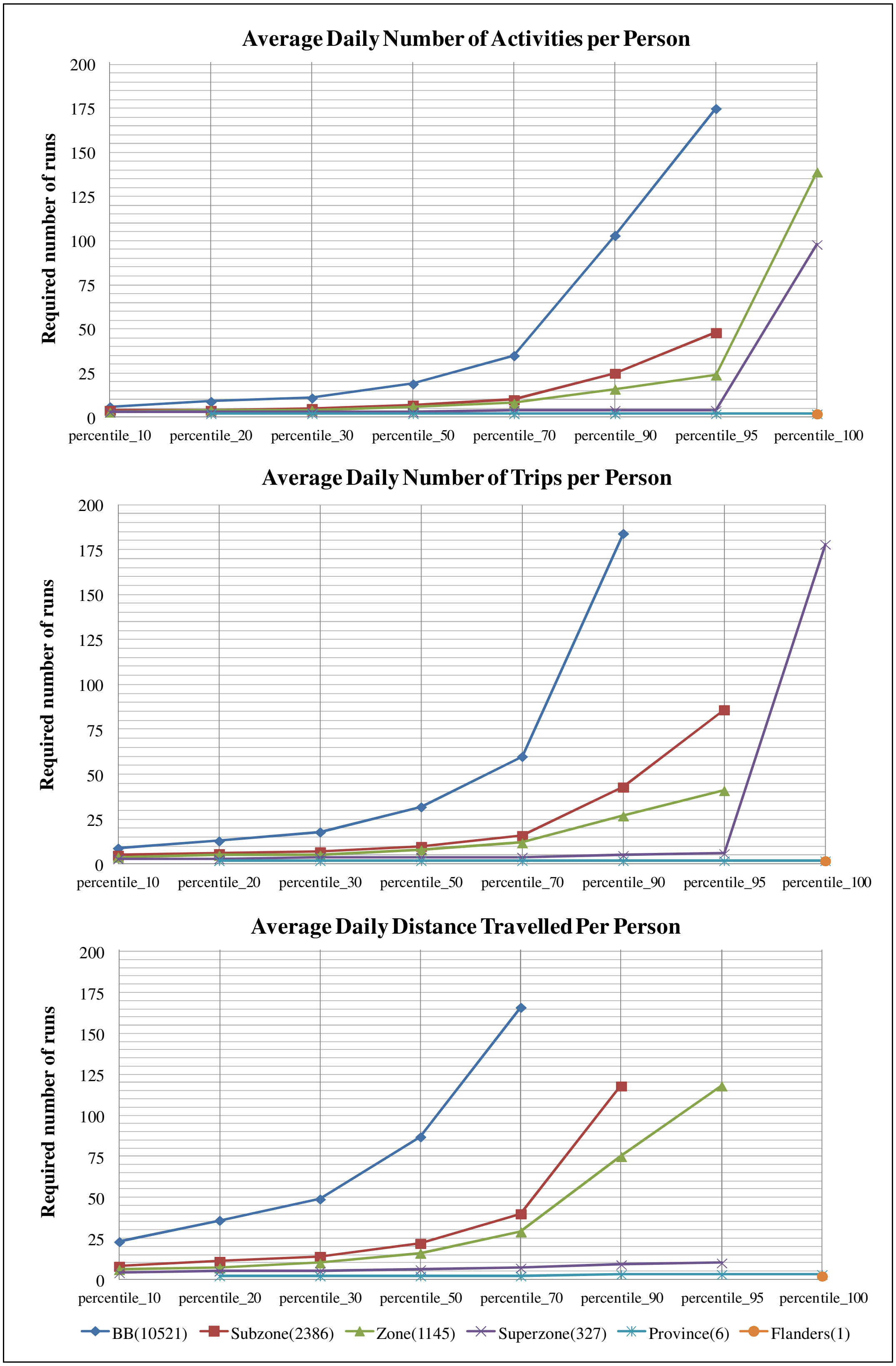

Fig. 2 The required minimum number of model runs for different percentiles of stable zones at 6 geographical levels on three travel indices

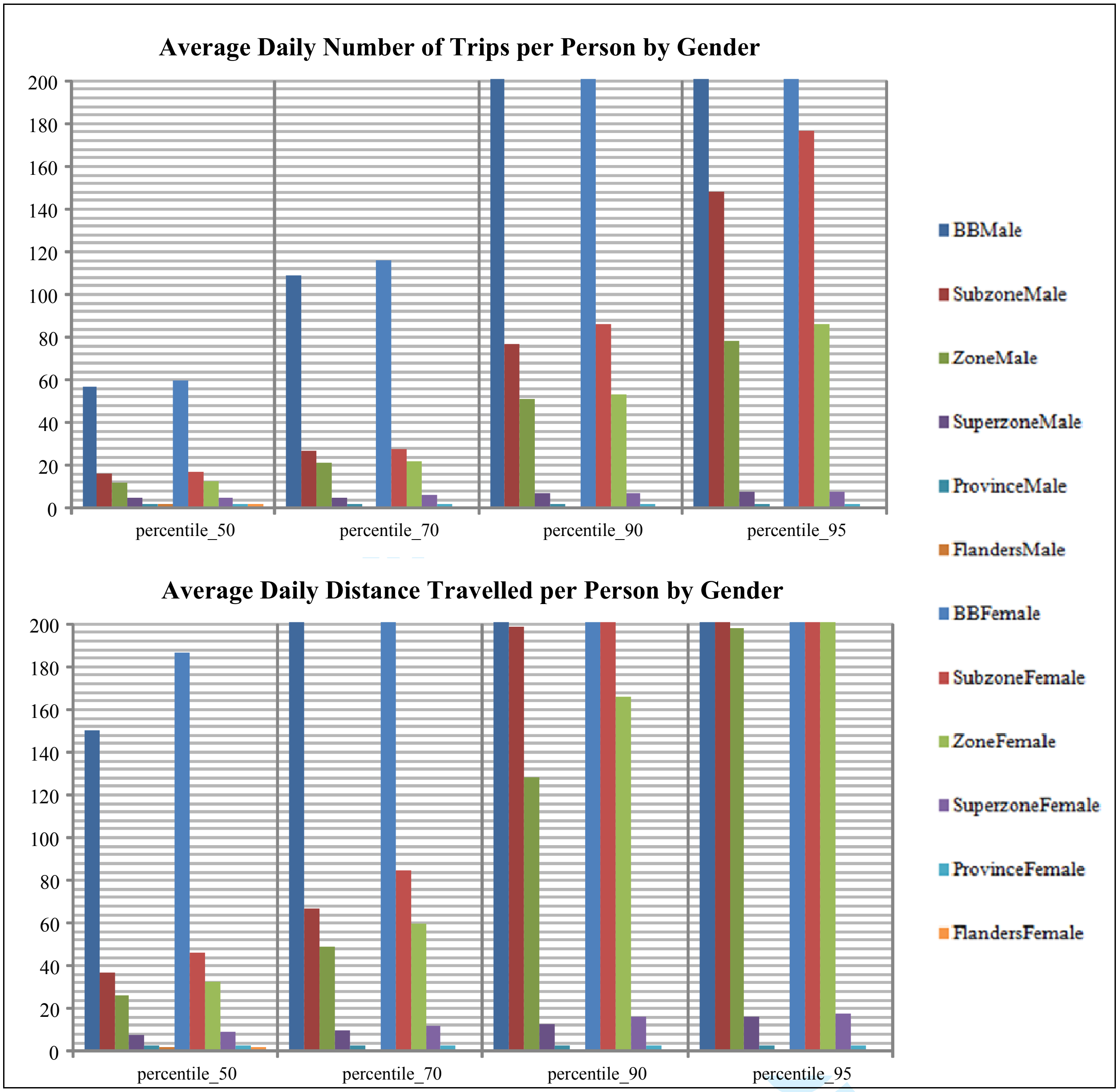

Fig. 3 The required minimum number of model runs for different percentiles of stable zones at 6 geographical levels by gender on average daily number of trips and distance travelled per person

Table 1 The required minimum number of model runs for different percentiles of stable zones at 6 geographical levels by age on average daily number of trips per person

BB (10521)	Nr. of persons	required minimum nr of runs				**Subzone (2386)**	Nr. of persons	required minimum nr of runs			
		p_50	p_70	p_90	p_100			p_50	p_70	p_90	p_100
18-34	119657	81	161	>200	>200	18-34	119657	26	47	138	>200
35-54	181022	59	113	>200	>200	35-54	181022	17	31	84	>200
55-64	67781	143	>200	>200	>200	55-64	67781	53	94	>200	>200
65-74	63261	186	>200	>200	>200	65-74	63261	70	129	>200	>200
75+	47409	>200	>200	>200	>200	75+	47409	127	>200	>200	>200
Zone (1145)	Nr. of persons	required minimum nr of runs				**Superzone (327)**	Nr. of persons	required minimum nr of runs			
		p_50	p_70	p_90	p_100			p_50	p_70	p_90	p_100
18-34	119657	20	36	98	>200	18-34	119657	7	8	10	42
35-54	181022	13	23	61	>200	35-54	181022	5	6	8	>200
55-64	67781	41	77	>200	>200	55-64	67781	10	13	21	>200
65-74	63261	52	103	>200	>200	65-74	63261	13	17	26	>200
75+	47409	91	180	>200	>200	75+	47409	23	30	45	>200
Province (6)	Nr. of persons	required minimum nr of runs				**Flanders (1)**	Nr. of persons	required minimum nr of runs			
		p_50	p_70	p_90	p_100			p_50	p_70	p_90	p_100
18-34	119657	2	2	3	3	18-34	119657	--	--	--	2
35-54	181022	2	2	2	2	35-54	181022	--	--	--	2
55-64	67781	3	3	3	3	55-64	67781	--	--	--	2
65-74	63261	3	3	3	3	65-74	63261	--	--	--	2
75+	47409	3	3	3	3	75+	47409	--	--	--	3

Note: In this table, p_50 represents percentile 50. Similar definitions hold for p_70, p_90, and p_100. At the Flanders level, there is only one geographical zone, therefore the concept of p_50, p_70 and p_90 is not applicable.

Table 2 The required minimum number of model runs for different percentiles of stable zones at 6 geographical levels by age on average daily distance travelled per person

BB (10521)	Nr. of persons	required minimum nr of runs				**Subzone (2386)**	Nr. of persons	required minimum nr of runs			
		p_50	p_70	p_90	p_100			p_50	p_70	p_90	p_100
18-34	119657	>200	>200	>200	>200	18-34	119657	69	124	>200	>200
35-54	181022	158	>200	>200	>200	35-54	181022	41	77	>200	>200
55-64	67781	>200	>200	>200	>200	55-64	67781	156	>200	>200	>200
65-74	63261	>200	>200	>200	>200	65-74	63261	>200	>200	>200	>200
75+	47409	>200	>200	>200	>200	75+	47409	>200	>200	>200	>200
Zone (1145)	Nr. of persons	required minimum nr of runs				**Superzone (327)**	Nr. of persons	required minimum nr of runs			
		p_50	p_70	p_90	p_100			p_50	p_70	p_90	p_100
18-34	119657	50	97	>200	>200	18-34	119657	13	16	22	127
35-54	181022	29	56	156	>200	35-54	181022	9	10	15	>200
55-64	67781	113	>200	>200	>200	55-64	67781	25	34	54	>200
65-74	63261	166	>200	>200	>200	65-74	63261	38	49	76	>200
75+	47409	>200	>200	>200	>200	75+	47409	70	95	149	>200
Province (6)	Nr. of persons	required minimum nr of runs				**Flanders (1)**	Nr. of persons	required minimum nr of runs			
		p_50	p_70	p_90	p_100			p_50	p_70	p_90	p_100
18-34	119657	3	3	3	3	18-34	119657	--	--	--	2
35-54	181022	3	3	3	3	35-54	181022	--	--	--	2
55-64	67781	3	3	3	3	55-64	67781	--	--	--	2
65-74	63261	3	3	4	4	65-74	63261	--	--	--	3
75+	47409	4	4	4	5	75+	47409	--	--	--	3

Note: In this table, p_50 represents percentile 50. Similar definitions hold for p_70, p_90, and p_100.

At the Flanders level, there is only one geographical zone, therefore the concept of p_50, p_70 and p_90 is not applicable.

Table 3 The required minimum number of model runs for different percentiles of stable zones at 6 geographical levels by transport modes on average daily number of trips per person

BB (10521)	required minimum nr of runs				**Subzone (2386)**	required minimum nr of runs			
	p_50	p_70	p_90	p_100		p_50	p_70	p_90	p_100
Car as Driver	62	119	>200	>200	Car as Driver	16	29	87	>200
Car as Passenger	>200	>200	>200	>200	Car as Passenger	74	136	>200	>200
Slow Mode	184	>200	>200	>200	Slow Mode	47	88	>200	>200
Public Transport	>200	>200	>200	>200	Public Transport	161	>200	>200	>200
Zone (1145)	required minimum nr of runs				**Superzone (327)**	required minimum nr of runs			
	p_50	p_70	p_90	p_100		p_50	p_70	p_90	p_100
Car as Driver	12	22	54	>200	Car as Driver	5	6	7	>200
Car as Passenger	50	99	>200	>200	Car as Passenger	13	17	24	>200
Slow Mode	35	68	174	>200	Slow Mode	9	12	17	>200
Public Transport	112	>200	>200	>200	Public Transport	25	33	50	>200
Province (6)	required minimum nr of runs				**Flanders (1)**	required minimum nr of runs			
	p_50	p_70	p_90	p_100		p_50	p_70	p_90	p_100
Car as Driver	2	2	2	2	Car as Driver	--	--	--	2
Car as Passenger	3	3	3	3	Car as Passenger	--	--	--	2
Slow Mode	3	3	3	3	Slow Mode	--	--	--	2
Public Transport	3	3	3	3	Public Transport	--	--	--	3

Note: In this table, p_50 represents percentile 50. Similar definitions hold for p_70, p_90, and p_100. At the Flanders level, there is only one geographical zone, therefore the concept of p_50, p_70 and p_90 is not applicable.

Table 4 The required minimum number of model runs for different percentiles of stable zones at 6 geographical levels by transport modes on average daily distance travelled per person

BB (10521)	required minimum nr of runs				**Subzone (2386)**	required minimum nr of runs			
	p_50	p_70	p_90	p_100		p_50	p_70	p_90	p_100
Car as Driver	139	>200	>200	>200	Car as Driver	33	61	188	>200
Car as Passenger	>200	>200	>200	>200	Car as Passenger	143	>200	>200	>200
Slow Mode	>200	>200	>200	>200	Slow Mode	>200	>200	>200	>200
Public Transport	>200	>200	>200	>200	Public Transport	>200	>200	>200	>200
Zone (1145)	required minimum nr of runs				**Superzone (327)**	required minimum nr of runs			
	p_50	p_70	p_90	p_100		p_50	p_70	p_90	p_100
Car as Driver	24	44	119	>200	Car as Driver	7	9	12	>200
Car as Passenger	100	190	>200	>200	Car as Passenger	22	31	44	>200
Slow Mode	160	>200	>200	>200	Slow Mode	34	49	74	>200
Public Transport	173	>200	>200	>200	Public Transport	38	50	79	>200
Province (6)	required minimum nr of runs				**Flanders (1)**	required minimum nr of runs			
	p_50	p_70	p_90	p_100		p_50	p_70	p_90	p_100
Car as Driver	3	3	3	3	Car as Driver	--	--	--	2
Car as Passenger	3	3	3	3	Car as Passenger	--	--	--	2
Slow Mode	3	3	3	4	Slow Mode	--	--	--	3
Public Transport	3	3	4	4	Public Transport	--	--	--	3

Note: In this table, p_50 represents percentile 50. Similar definitions hold for p_70, p_90, and p_100. At the Flanders level, there is only one geographical zone, therefore the concept of p_50, p_70 and p_90 is not applicable.

Table 5 The required minimum number of model runs for different percentiles of stable zones at 6 geographical levels by activity types on average daily number of activities per person

BB (10521)	required minimum nr of runs				**Subzone (2386)**	required minimum nr of runs			
	p_50	p_70	p_90	p_100		p_50	p_70	p_90	p_100
Home-related Activity	11	19	53	>200	Home-related Activity	5	7	14	>200
Work-related Activity	58	113	>200	>200	Work-related Activity	16	28	85	>200
Shopping Activity	175	>200	>200	>200	Shopping Activity	44	79	>200	>200
Touring Activity	>200	>200	>200	>200	Touring Activity	191	>200	>200	>200
Zone (1145)	required minimum nr of runs				**Superzone (327)**	required minimum nr of runs			
	p_50	p_70	p_90	p_100		p_50	p_70	p_90	p_100
Home-related Activity	4	5	10	68	Home-related Activity	3	3	3	51
Work-related Activity	12	22	60	>200	Work-related Activity	5	6	7	>200
Shopping Activity	31	60	151	>200	Shopping Activity	9	11	15	>200
Touring Activity	133	>200	>200	>200	Touring Activity	28	40	57	>200
Province (6)	required minimum nr of runs				**Flanders (1)**	required minimum nr of runs			
	p_50	p_70	p_90	p_100		p_50	p_70	p_90	p_100
Home-related Activity	2	2	2	2	Home-related Activity	--	--	--	2
Work-related Activity	2	2	2	2	Work-related Activity	--	--	--	2
Shopping Activity	3	3	3	3	Shopping Activity	--	--	--	2
Touring Activity	3	3	3	3	Touring Activity	--	--	--	2

Note: In this table, p_50 represents percentile 50. Similar definitions hold for p_70, p_90, and p_100.

At the Flanders level, there is only one geographical zone, therefore the concept of p_50, p_70 and p_90 is not applicable.

Table 6 The required minimum number of model runs at the whole Flanders level on vehicle kilometers travelled on the Flemish network.

Flanders	100 runs Average (*10^5 kilometer)	minimum nr of runs required (CI<=0.1*average value)
overall	72.312	2
Linktype1	30.063	2
Linktype2	1.596	3
Linktype3	18.991	3
Linktype4	0.071	7
Linktype5	9.036	3
Linktype6	1.985	3
Linktype7	9.343	3
Linktype8	1.228	2

Note: Linktypes1-8 represent the route link type of Flemish road network.