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Indices of pedestrian behavior in shopping areas

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Abstract

A number of indices to describe and compare sets of pedestrian routes in shopping environments will be introduced. The first set of indices is related to characteristics of the trajectories and the second set to visiting outlets. These statistics can be used to assess the performance of models predicting individual routes in shopping areas. Another application may be to compare pedestrian behaviour in different shopping environments. The latter will be done in this study. Routes observed in the downtown shopping area of Eindhoven will be compared with observed routes in the Maastricht downtown shopping area.

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Keywords: Pedestrian behaviour; Shopping areas; Routes; Outlets; Indices

1. Introduction

Traffic passing a store or establishment is an important quantity in order to assess turnover figures in these outlets or to estimate the value of retail real estate. In pedestrianized shopping areas, traffic consists of pedestrians. Different types of models have been developed to assess the likely effects of policy measures on pedestrian flows in shopping areas. An early example is the model by Sandahl and Percivall[1]. They regressed the number of pedestrians in a particular zone against variables such as retail floor area, parking and public transport facilities. Space syntax[2] is a technique to assess the 'integration' of streets in a network, which often is related to pedestrian movement[3]. However, such models do not describe decision making regarding route choice and visiting outlets. Borgers and Timmermans[4] proposed one of the first models predicting complete individual routes in downtown shopping areas. The performance of such models can be determined by comparing aggregated link loadings and number of visitors

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per (type of) shop[5,6]. However, such aggregated results do not provide insight in individual decision making.

Therefore, the purpose of this paper is to introduce a number of indices that describe pedestrian behaviour in pedestrianized shopping environments at the individual level and to aggregate these indices taking into consideration the variety among shoppers. Such indices may be used to describe observed individual shopping trips in shopping areas or to get better insight in the performance of models predicting individual shopping trips.

In the next section of this paper, a number of indices describing individual trajectories used in the literature will be described. Then, in the third section, the data used to demonstrate the indices will be described. In section 4, the indices used in this paper will be explained and demonstrated. Section 5 concludes the paper.

2. Literature

Two types of indices will be considered; first, some popular metrics of movement used in the literature will be summarized. Next, heuristics related to shopping behaviour in a shopping area will be discussed. In the field of biology, models and metrics to describe and analyse animals' paths have been developed. For example, Benhamou[7] discusses the straightness index, the sinuosity index, and the fractal dimension as an estimator of the tortuosity of an animal's path. Torrens et al. [8] used movement metrics to test different models of pedestrian walking behaviour in agent based models.

Usually, a trajectory is represented by edges and vertices. At the global level, path length along the trajectory, straightness, and the correlation between consecutive angles may be of interest. If time was registered, speed and acceleration can be derived as well. Straightness can be measured as the ratio between the straight-line distance between the origin and the destination locations and the length of the observed path between the two locations. Alternatively, path straightness can be measured by the mean cosine of the turning angles over the entire path. If the mean cosine equals 1, the path is straight. The correlation between successive angles measures the tendency to keep turning into a particular direction. If the correlation is close to zero, such tendency does not exist.

At the local level, metrics are commonly related to the turning angle between two consecutive edges. The sinuosity s at a particular vertex v is computed as a ratio of the length of the incoming and outgoing edge to the length of the beeline between the previous v-1 and next v+1vertex. The length of the edges and the beeline can be computed given the x- and y-coordinates of the corresponding vertices. The sinuosity ranges from 1 (if the pedestrian keeps walking in a straight line) to infinity (if the pedestrian returns to the previous vertex), but will rarely exceed 2[9]. The sinuosity value s, also called Length Ratio, can be transformed into the unit [0,1] interval, for example by $s'=\sqrt{[1-(1/s^2)]}$. Instead of the previously mentioned v-1 and next v+1 vertex, the vertices v-2 and v+2, or more in general v-k and v+k, can be taken into consideration. To obtain a more robust measure, Dutton [9] suggests to calculate s for a small range of k (e.g. k=1,2,3) and average the s-values. Another local metric related to turning angels is the fractal dimension (fractal d) [10].

Although the local metrics are calculated at the level of vertices, they can easily be aggregated into global measures, e.g. by calculating mean values and standard deviations. In turn, individual trajectories can be aggregated into moving crowds. Then, spontaneous phenomena like lane formation may occur[11]. Such phenomena occur in real world situations as well; therefore they may be considered as indicators of pedestrian movement[8]. However, this study does not consider moving crowds.

Pedestrians visiting more than one outlet in the shopping area may visit these outlets in different sequences. Hayes-Roth and Hayes-Roth[12] suggested that shoppers will first choose the nearest location, then the nearest location from there, and so on. This locally-minimizing-distance (LDM) heuristic was tested by Säisä and Gärling[13]. They found that individuals do not choose their destinations according to this LDM heuristic if this sequence would result in a substantially longer walking distance (see also[14]). In such cases, the shopper may optimize the sequence of outlets to be visited in order to reduce the total distance. Finding the most optimal sequence is equivalent to solving the travelling salesman problem. The corresponding heuristic is called the total distance minimizing (TDM) heuristic (if both the sequence is optimal and the shortest paths between the locations were selected) or the global distance minimizing (GDM) heuristic (if the sequence is optimal, but the distance between successive locations is not minimized) [15]. In addition, heuristics concerning the choice whether to first visit the nearest outlet or the outlet located farthest away from the entry point were introduced. The corresponding heuristics are the nearest destination oriented (NDO) heuristic and the farthest destination oriented (FDO) heuristic[15,16].

3. Data

Data were collected in the downtown shopping areas of the Dutch cities of Eindhoven (approximately 200.000 inhabitants) and Maastricht (approximately 120.000 inhabitants). The Eindhoven and Maastricht downtown shopping areas are mainly open air shopping areas, including department stores and some indoor shopping arcades. Especially the cores of these areas are virtually completely occupied by shops. In the fringe of the areas, shops, services, offices, and residential facilities are mixed. The core areas are completely pedestrianized, (restrained) motorized traffic is allowed in the fringe. Maastricht has a historical downtown shopping area and a relatively complex network of small shopping streets. It attracts a substantial number of tourists, especially from Belgium and Germany. Eindhoven has a rather modern downtown shopping area with a relatively simple network of shopping streets. In both cities, the main railway station is located near the down town shopping area, although the distance between the railway station and the core of the shopping area is considerable shorter in Eindhoven than in Maastricht.

Data were collected by means of personal on-street interviews. Interviewers were assigned to exit points to intercept potential respondents leaving the shopping area. Only respondents who confirmed having finished shopping were invited to participate. Respondents were asked by which travel mode they travelled to the shopping area, where they parked their car or bike or left public transport, which path they walked through the shopping area, and which outlets they visited. For each outlet, the name and type (shop, bar/restaurant, entertainment, service, other) was asked. The route and the locations of the visited outlets were drawn on a map.

In Eindhoven, data were collected in March 2002 during two consecutive days, a Friday (including late night shopping) and a Saturday. In Maastricht, late night shopping is on Thursdays. Therefore, interviews were conducted during a Thursday night from 18:00 to 21:00 hrs; a Friday and a Saturday. Data collection took place in November 2003. A third set of data was collected in Eindhoven in March 2007. In 2005, a large multi-level mall in the northern part of the downtown shopping area was opened. All three datasets were collected under relatively mild weather conditions for the time of the year (spring and autumn).

Table 1. Gender and age.

	Eindhoven 2002		Eindhoven 2007		Maastricht 2003	
GENDER	#	%	#	%	#	%
Female	338	49	244	42	278	62
Male	269	39	198	34	174	39
Female + Male	67	10	130	22	-	-
Missing	20	3	15	3	-	-
AGE	#	%	#	%	#	%
< 18	35	5	24	4	5	1
18 – 55	554	80	455	78	333	74
> 55	85	12	91	16	114	25
Missing	20	3	17	3	-	-
Total	694	100	587	100	452	100

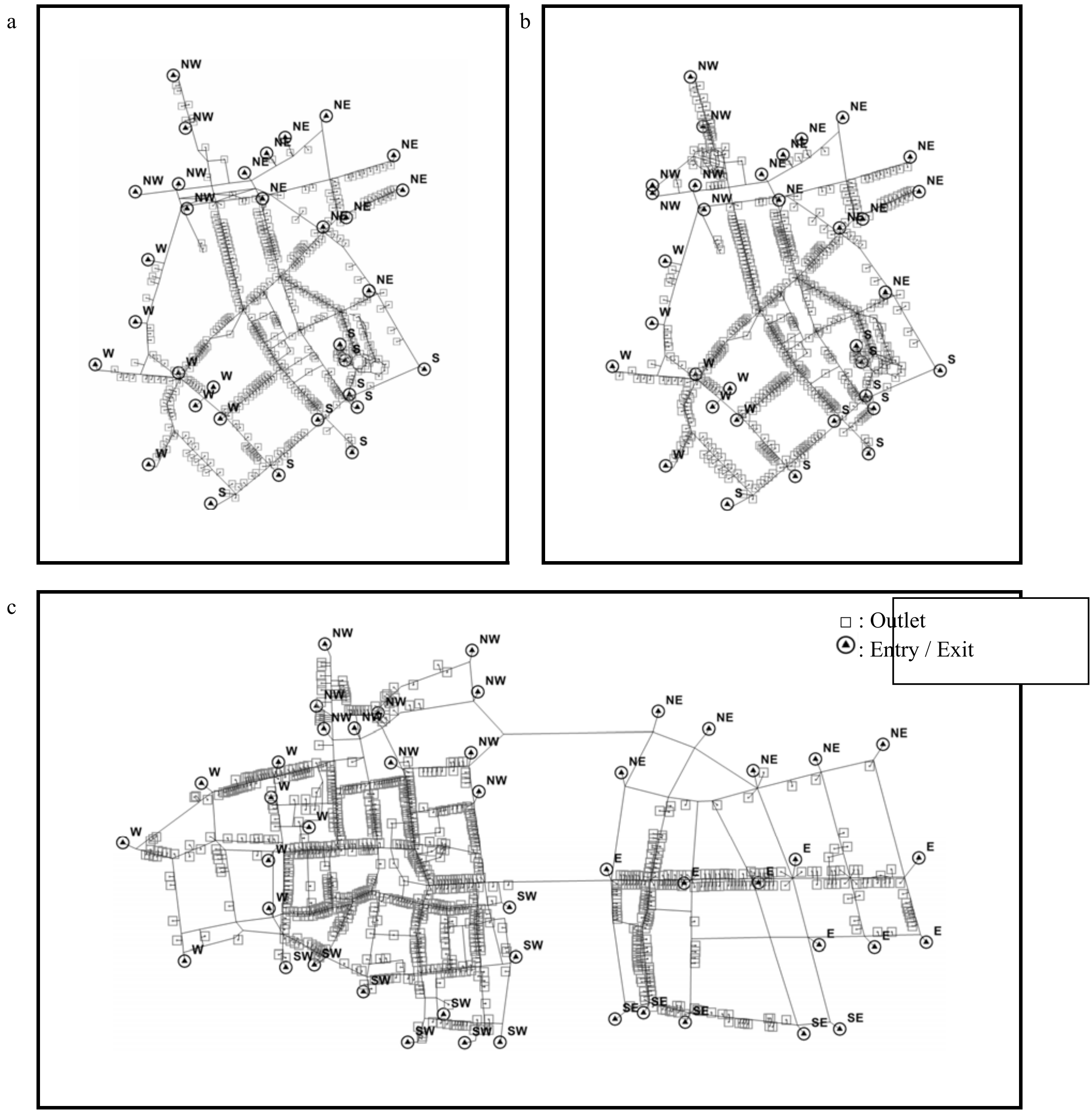

Fig. 1. Networks and main exit-points (a) Eindhoven 2002; (b) Eindhoven 2007; (c) Maastricht 2003.

In this study, only circular pedestrian routes are taken into consideration. After cleaning the data, 694 valid routes were stored in the Eindhoven 2002 dataset. In Maastricht, this number is equal to 452 and the Eindhoven 2007 dataset contains 587 routes. In total, the number of collected routes is 1733. Age and gender distributions are reported in Table 1. In Eindhoven, couples responding together were registered as ‘Male+Female’. The share of females and respondents older than 55 is higher in Maastricht than in Eindhoven.

a b c

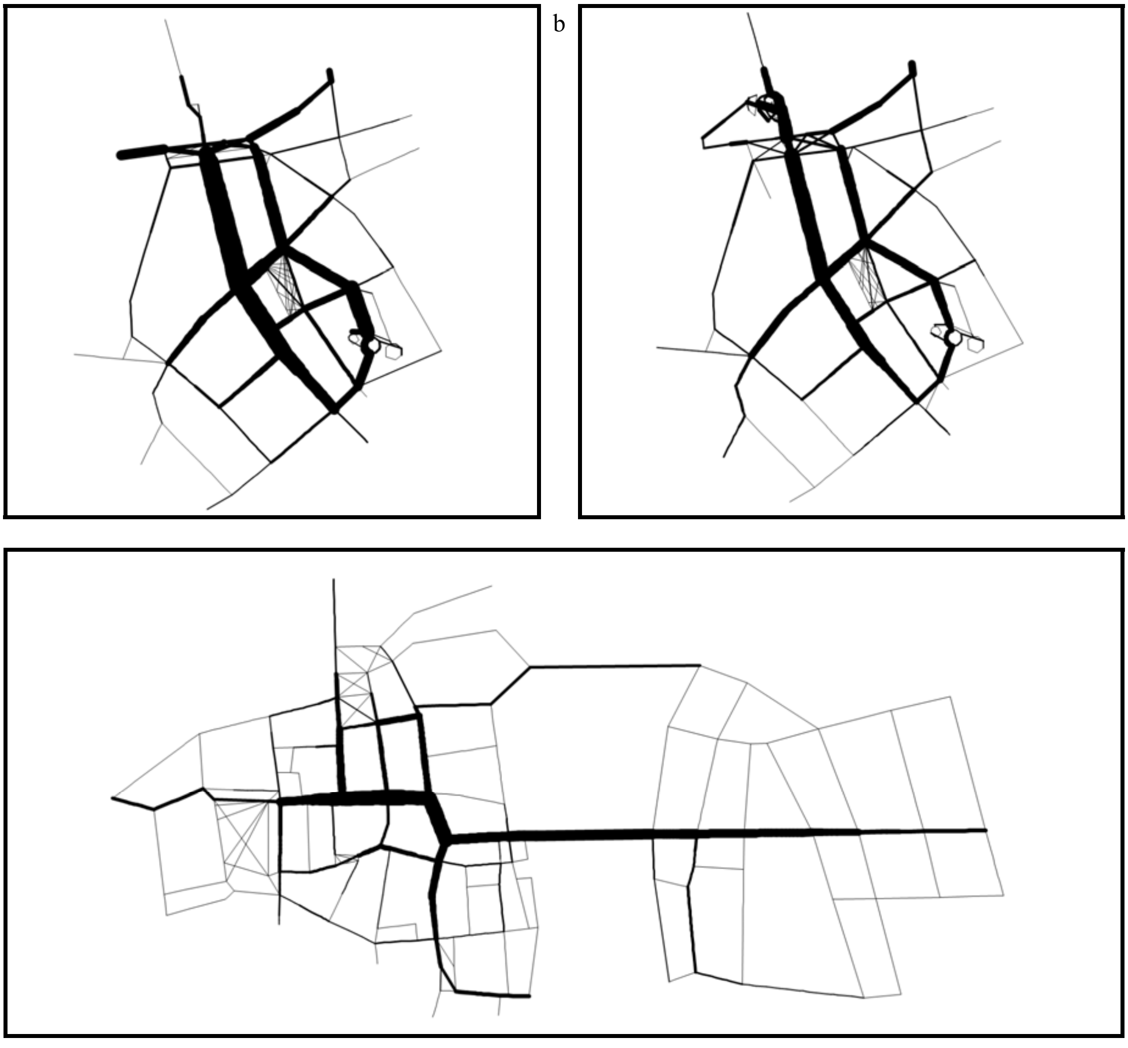

Fig. 2. Link loadings (a) Eindhoven 2002; (b) Eindhoven 2007; (c) Maastricht 2003.

To store the collected data, the shopping areas were represented by means of a network of shopping streets. Each network consists of primary nodes (representing the main intersections of shopping streets) with segments in between, secondary nodes (connecting the outlet-nodes to the segments), and entry/exit nodes, representing parking facilities, public transport stops and other points where pedestrians can enter or leave the shopping area. Segments also represent staircases/elevators/escalators and diagonals across squares. Pedestrian trajectories can easily be stored in such networks by means of sequences of nodes. Note that we did not observe walking behaviour in shopping streets, like for example zigzagging while traversing a segment. In Figure 1, the networks and the entry/exit-points are shown. Exit-points are labelled in terms of wind directions. Table 2 presents the distribution of pedestrians by direction. Aggregated link loadings and number of visits per outlet are represented in Figures 2 and 3.

a b c

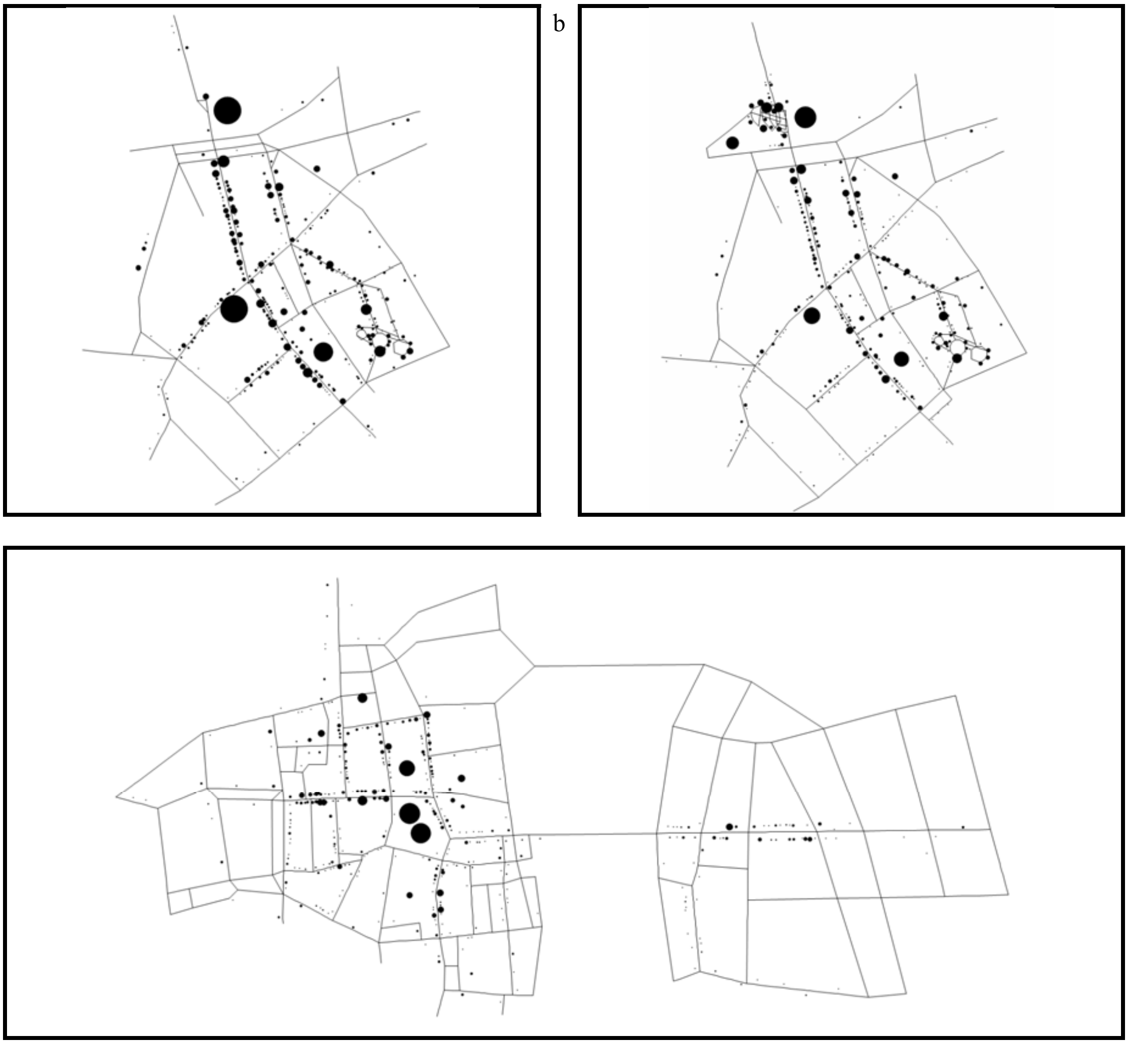

Fig. 3. Visits per outlet (a) Eindhoven 2002; (b) Eindhoven 2007; (c) Maastricht 2003.

Table 2. Number of respondents by exit direction per dataset.

	Eindhoven					Maastricht	
	2002		2007			2003	
direction	#	%	#	%	direction	#	%
NE	205	30	211	36	NE	55	12
S	190	27	76	13	E	86	19
W	104	15	111	19	SE	64	14
NW	195	28	189	32	SW	84	19
					W	70	15
					NW	93	21
Total	694	100	587	100		452	100

4. Application

Although the selection of indices used in this paper is inspired on the literature discussed in section 2, some indices had to be adapted to the data structure described in the previous section. First, indices related to characteristics of the trajectories will be discussed, followed by indices related to visiting outlets.

4.1 Indices related to trajectories

Although metrics describing animals' paths in natural settings may be less appropriate to describe pedestrians' paths in shopping areas, metrics like path length, mean absolute angle and the correlation between consecutive angles are still of interest. Table 3 provides information about the length of the pedestrians' paths, the number of segments entered, the correlation between consecutive angles, and the mean absolute angle. The length of a pedestrian's path through the shopping area is measured from the entry point to the exit point. Moving into an outlet, inside the outlet, and leaving the outlet has not been taken into consideration, even when the outlet is left at an exit different from the entrance. Note that pedestrians may walk considerable distances before entering the shopping area and after leaving the shopping area if they, for example, parked their car at a remote parking facility. These distances are not taken into consideration in this study. The length of staircases, escalators, and elevators has been set to 10m to include an extra penalty for changing storeys. This value was chosen in the absence of relevant literature in the context of shopping. Daamen et al. [17] observed route choice behaviour in two Dutch railway stations. They estimated the effect of travel time on different types of infrastructure (level element, stairs, escalator, and ramp) and found an effect roughly 2-3 times for ascending escalators and stairs relative to level elements.

The mean path length of pedestrians shopping in the Eindhoven downtown area is about 1.1 km, significantly less than the 1.5 km path length of shoppers in Maastricht. The explanation is straightforward: walking distances from the entry points to the core of the shopping area are longer in Maastricht; pedestrians entering the shopping area on the east side have to cross the river the Meuse (approx. 200 m) to reach the core. In addition, the railway station is located further away from the central shopping area in Maastricht than in Eindhoven.

Table 3. Trajectory indices.

	Eindhoven				Maastricht		p=
	2002		2007		2003		
	mean (N)	sd	mean (N)	sd	mean (N)	sd	
Length (m)	1096 (694)	527	1076 (587)	609	1538 (452)	725	0.000
Correlation between consecutive angels	-0.175 (615)	0.278	-0.150 (497)	0.279	-0.159 (440)	0.253	0.275
Mean abs. angle	42.6 (646)	16.9	41.8 (524)	15.5	34.2 (445)	14.7	0.000
# Segments entered	15.5 (694)	7.7	16.7 (587)	10.1	25.3 (452)	11.4	0.000

At each primary node, the pedestrian may, or is forced to change direction. At standard intersections, a pedestrian may decide walking straight on, turn to the left or to the right, or to walk back. For each pedestrian the angles† between the incoming and outgoing segment at primary nodes are calculated. These angles are used to determine the mean absolute angle and the correlation between the angles at successive primary nodes per pedestrian. This correlation is only calculated if there are at least 3 valid pairs of turns for the pedestrian under consideration. Both metrics are averaged across the pedestrians.

The mean correlation between two consecutive angles is negative and ranges between -0.15 and -0.175 (Table 3). The standard deviations are relatively high and the mean correlation does not differ significantly between the cities. A negative mean correlation means that the pedestrians have a tendency to turn alternately left and right.

The mean absolute angle gives an indication of the straightness of the trajectories. The mean absolute angles differ significantly between the cities. In Eindhoven, the mean absolute angle is 42-43°, while it is 34° in Maastricht. The lower sinuosity of routes in Maastricht may partially be explained by the fact that the busiest part of the busiest shopping street in Maastricht (Grote Staat) consists of 4 segments while the busiest street in Eindhoven (De Demer) is just one segment. If pedestrians walk along these streets, those in Maastricht generate a number of 0° angles, decreasing the average absolute angle. This is confirmed by the distribution across types of turns at primary nodes in Table 4. A turn of max 30° to the left or right is considered as walking straight on, turns between 31 and 149° are defined as normal turns while turns between 150 and 179° are defined as sharp turns, A 180° turn is a complete turn. This way, six classes of turns can be distinguished. In Maastricht, if a pedestrian approaches a primary node, the probability of moving straight on is 68%. In Eindhoven, this probability is 52-55%. Also Zacharias[18] found that visitors exploring the underground system in Montreal prefer the forward option. Note that complete (180°) and especially sharp turns occur infrequently. However, it should be stressed that turns upon leaving an outlet are not taken into account here.

Related to the length of the route is the total number of segments entered by a pedestrian. In Maastricht, the mean number of segments entered per pedestrian is significantly higher than in Eindhoven (Table 3). This is probably due to the more complex network in Maastricht. The standard deviations indicate considerable variation in route characteristics.

Entering a segment does not automatically imply that the segment will be left at the end of the segment. A pedestrian may decide to walk into a segment, enter an outlet and walk back to the primary node the pedestrian came from. In such a case the segment is not fully traversed. The share of full segments is defined as the ratio of fully traversed segments to the total number of segments entered by the pedestrian.

Table 4. Type of turns (in %).

	Eindhoven 2002		Eindhoven 2007		Maastricht 2003	
	#	%	#	%	#	%
No turn (straight on)	4865	51.8	4453	54.9	6979	63.8
Normal turn to the right	2163	23.1	1748	21.6	1856	17.0
Normal turn to the left	2179	23.2	1727	21.3	1996	18.3
Complete turn	177	1.9	124	1.5	96	0.9
Sharp turn to the right/left	0	0.0	55	0.7	6	0.1
Total	9384	100	8107	100	10933	100
p=0.000						

† Note that in this study, angles are measured in degrees: walking straight on implies an angle of 0°, angles between 0 and 180° represent turns to the left (anti-clockwise) and angles between 0 and -180° represent turns to the right (clockwise). Staircases, elevators, and escalators are excluded from these calculations. The reason is pragmatic: staircases, elevators, and escalators are not correctly represented by means of a 2D geographic information system.

Table 5. Use of segments (in %).

	Full segments			Different segments			Retraced segments		
Proportion	Ehv02	Ehv07	Mtr03	Ehv02	Ehv07	Mtr03	Ehv02	Ehv07	Mtr03
[0.0]	3.2	5.3	0.7				10.8	12.4	6.9
<0.0, 0.1]							2.9	2.4	3.3
<0.1, 0.2]							11.7	7.3	8.0
<0.2, 0.3]							11.1	6.3	6.9
<0.3, 0.4]							10.5	12.3	10.4
<0.4, 0.5]							11.2	9.9	11.3
<0.5, 0.6]							6.6	8.5	6.4
<0.6, 0.7]	2.3	3.6	0.9	0.1	0.0	0.0	5.8	10.9	11.9
<0.7, 0.8]	7.3	5.1	2.4	0.4	1.2	0.0	8.9	7.5	8.0
<0.8, 0.9]	15.9	19.3	12.6	2.6	2.2	1.3	5.3	7.7	9.1
<0.9, 1.0>	36.6	37.5	52.9	5.9	5.8	13.9	5.9	6.5	13.5
[1.0]	34.7	29.3	30.5	90.9	90.8	84.7	9.2	8.3	4.4
N	694	587	452	694	587	452	694	587	452
p=		0.000 (ndf=10)			0.000 (ndf=6; <0.6, 0.9] merged into one category)			0.000 (ndf=22)	

While moving around in a shopping area, pedestrians may enter segments they already entered before. The share of different segments measures the pedestrian's tendency to avoid segments entered before. As segments are directed links between primary nodes, the share of retraced segments can be determined by counting the number of segments traversed in both directions.

Table 5 presents information about traversing full segments, entering different segments and retracing segments. Approximately one third of all pedestrians traverse all segments they enter completely. Less than 15% of the pedestrians traverse less than 80% of the segments they enter on their route completely. There are even pedestrians who don't fully traverse one segment. Probably, they move directly into an outlet in the first segment and return to the exit point. Most pedestrians traverse 80-99.9% of the segments they enter completely, indicating that they at least once return to their previous primary node when they leave an outlet.

From the second part of Table 5, it can be concluded that the majority of respondents does not enter a segment more than once. In Eindhoven, this holds true for approximately 90% of the pedestrians; in Maastricht for 85%. Anyway, for more than 95% of the respondents, at least 90% of the segments in their routes were entered only once. In his study on visitors exploring the underground system in Montreal, Zacharias found that visitors almost always opt for a different direction when they find themselves at the same intersection a second time[18,19].

According to the last part of the Table 5, 10-12% of the Eindhoven pedestrians never enter a segment that was entered from the opposite side. In Maastricht this is only 7%. On the other hand, 8-9% of the Eindhoven pedestrians and 4% of the Maastricht pedestrians backtrack completely along the same path: each traversed segment was traversed in the opposite direction as well. For the remaining respondents, the share of retraced segments is more or less evenly distributed between these two extreme classes.

In 2002, one multi-level shopping arcade was part of the Eindhoven shopping area and in 2005, a second multi-level shopping mall was opened. In the Eindhoven 2002 dataset, 19% of the pedestrians used a staircase, elevator, or escalator at least once; in 2007 this percentage was equal to 28. Note that the use of staircases, elevators, and escalators inside stores is not taken into consideration as these do not belong to the public domain. In Maastricht, all entrances/exits are located at ground floor level.

4.2 Indices related to visiting outlets

The number of visited outlets per pedestrian is reported in Tables 6 and 7. The number of visited outlets per pedestrian ranges between 0 and 16 (Table 6), although visiting 10 or more outlets is rather exceptional. The difference between cities is significant: in Eindhoven, two-thirds of the pedestrians visit 0-3 outlets, while this holds only for half of the pedestrians in Maastricht. According to Table 7, the mean number of outlets visited in Eindhoven is 3.0-3.3; in Maastricht this is 3.8. Although many types of outlets can be distinguished, in this paper the following classification is used: 1) department stores, 2) fashion stores (clothes, footwear, jewels), 3) other stores, 4) restaurants & bars, 5) entertainment & services (e.g. cinema, library, hairdresser, travel agent, bank).

According to Table 7, the department stores, fashion and other stores are much more popular than restaurants &

bars and entertainment & services. The latter type of outlets is only visited by approximately one out of ten pedestrians. The mean numbers of visits per type of outlet differ significantly between the cities.

Table 6. Distribution of number of visited outlets.

	Eindhoven 2002		Eindhoven 2007		Maastricht 2003	
# visited outlets	#	%	#	%	#	%
0	10	1.4	5	0.9	4	0.9
1	178	25.6	153	26.1	87	19.2
2	147	21.2	116	19.8	75	16.6
3	133	19.2	101	17.2	61	13.5
4	97	14.0	65	11.1	75	16.6
5	49	7.1	50	8.5	49	10.8
6	33	4.8	39	6.6	31	6.9
7	19	2.7	24	4.1	32	7.1
8	8	1.2	11	1.9	15	3.3
9	9	1.3	3	0.5	11	2.4
10 or more	11	1.6	20	3.4	12	2.7
Total	694	100	587	100	452	100
p=0.000						

Table 7. Mean number of visited outlets per pedestrian.

	Eindhoven				Maastricht		p=
	2002		2007		2003		
	mean	sd	mean	sd	mean	sd	
Department stores	0.85	0.85	0.68	0.82	0.97	1.04	0.000
Fashion stores	1.04	1.49	1.25	1.78	1.04	1.47	0.033
Other stores	0.84	1.09	1.06	1.23	1.40	1.37	0.000
Restaurants & bars	0.20	0.45	0.26	0.50	0.26	0.52	0.030
Entertainment & services	0.10	0.32	0.07	0.28	0.13	0.36	0.017
Total	3.03	2.12	3.33	2.52	3.81	2.44	0.000

The heuristics related to distance minimizing (LDM, GDM, TDM) assume that the pedestrian decided about the locations to be visited when entering the shopping area. At that point, the pedestrian must have a plan in order to optimize the route through the shopping area. Although this is debatable, the heuristics may give insight in the efficiency of the shopping trip. The following distances[‡] will be calculated:

- D^{obs}: the length of the observed trajectory (= path length).
- D^{sp}: the length of the shortest paths between the successively visited outlets (plus the shortest path from the entry point to the first outlet plus the shortest path from the last outlet to the exit point).
- D^{LDM}: the length of the shortest path from the entry point to the nearest outlet plus the length of the shortest path from this outlet to the next nearest outlet, if any and so on. The length of the path from the last outlet to the exit point is not included.
- D^{sp*}: the length of the shortest paths between the successively visited outlets plus the shortest path from the entry point to the first outlet. It does not include the length of the path from the last outlet to the exit point.
- D^{GDM}: the length of the shortest paths between the outlets if the outlets are visited in the most optimal sequence (plus the length of the shortest paths from the entry point and to the exit point).

[‡] Note that shortest distances are determined according to the shortest path through the network, not as Euclidean distances.

- D^{GDM*}: the length of the shortest paths if the outlets are visited in the least optimal sequence (plus the length of the shortest paths from the entry point and to the exit point).

Note that except for D^{obs}, calculating these distances does not make sense if the pedestrian has visited no outlets at all. For D^{sp}, at least one outlet must be visited. To calculate D^{LDM} and D^{sp*}, at least two outlets are needed. Furthermore, as almost all pedestrians leave the shopping area at the entry point (exit point = entry point), the calculation of the GDM distances only makes sense if at least three outlets are visited. To calculate D^{GDM} the optimal sequence of the visited outlets has to be determined. To find this optimal sequence, all possible permutations of the observed sequence have to be tested. As this is a time consuming process, D^{GDM} (and D^{GDM*}) will not be computed for pedestrians visiting more than 8 outlets.

The ratio D^{obs}/D^{sp} indicates how efficient the pedestrian walked along the outlets from entry to exit point given the observed sequence of outlets. If the ratio equals 1, the pedestrian walked along the shortest path to the destinations. To allow for measurement errors, the range 1.0-1.05 is considered as optimal. Table 8 shows that for approximately half of the respondents the ratio is (almost) equal to 1.0. Overall, less than 10% of the pedestrians walk more than 1.5 times the length of the shortest path. The results differ significantly between the cities: pedestrians in Maastricht seem to behave suboptimal compared to the pedestrians in Eindhoven.

Table 8. Ratio observed path length – shortest path length; observed sequence of outlets.

	Eindhoven 2002		Eindhoven 2007		Maastricht 2003	
ratio	#	%	#	%	#	%
[1.0, 1.05]	318	47.9	304	54.4	183	43.1
<1.05, 1.25]	205	30.9	164	29.3	151	35.5
<1.25, 1.50]	64	9.6	60	10.7	54	12.7
<1.50, 2.00]	53	8.0	21	3.8	27	6.4
<2.00, 5.00]	19	2.9	7	1.3	9	2.1
<5.00, → >	5	0.8	3	0.5	1	0.2
Total p=0.004	664	100	559	100	425	100

D^{LDM} represents the distance of the shortest path if the sequence of the visited outlets corresponds with the LDM heuristic. As this heuristic does not consider the path from the last outlet to the exit point, the length of this path is not included. If $D^{LDM}/D^{sp*} = 1.0$, the observed sequence of outlets corresponds with the LDM-sequence. If D^{LDM} is larger (smaller) than D^{sp*}, the pedestrian used a more (less) efficient strategy than the LDM heuristic. The ratio is approximately equal to 1 for 35-40% of the pedestrians, indicating that the sequence of their visits satisfies the LDM heuristic (Table 9). However, the majority of pedestrians apparently do not apply this heuristic (see also [13]), possibly because they also take into consideration the distance from the last outlet to the exit point. Differences between the cities are not significant at the α=0.05 level.

Remember that the GDM distances are only determined for pedestrians visiting 3-8 outlets. By scaling D^{sp} between D^{GDM} and D^{GDM*} $[(D^{sp} - D^{GDM}) / (D^{GDM*} - D^{GDM})]$, a score between 0 and 1 indicates how optimal the observed sequence of outlets is. If the score is 0, the pedestrian visited the outlets in the most optimal sequence (GDM). If in addition

D^{obs}/D^{sp} is equal to 1, the pedestrian followed the most efficient path possible given the set of visited outlets. Then, the pedestrian applied the Total Distance Minimizing heuristic. GDM scores ranging from 0.0 to 0.05 are considered optimal. It appears that roughly 60% of the pedestrians visit the outlets in the most optimal sequence (Table 10). For less than 10% of the pedestrians, the GDM score is larger than 0.5. Although many pedestrians choose the optimal order of outlets, only 25-30% choose both the optimal order and the shortest paths between the destination (Table 11). There are no significant differences between the cities.

To assess whether a pedestrian used the NDO or FDO heuristic, at least two visited outlets are required. To determine which heuristic is used, the minimum (D^{min}) and maximum (D^{max}) shortest distance from the entry point to the visited outlets will be computed. If the shortest distance to the first outlet is equal to D^{min} the NDO heuristic is used; if it is equal to D^{max}, the FDO heuristic is used. Note that neither heuristic may be used. The results in Table 12 show that approximately half of the pedestrians first visit the nearest outlet; they apply the NDO heuristic. The FDO heuristic is less popular; it is used by about 20% of the respondents. The NDO heuristic appears to be somewhat less frequently used in Maastricht where pedestrians start more often with an outlet in between the nearest and the farthest.

Table 9. Ratio shortest path length, LDM – shortest path length, observed sequence of outlets.

	Eindhoven 2002		Eindhoven 2007		Maastricht 2003	
ratio	#	%	#	%	#	%
[0.25, 0.50]	11	2.2	6	1.4	3	0.8
<0.50, 0.65]	77	15.2	63	14.7	41	11.4
<0.65, 0.75]	75	14.8	62	14.5	48	13.3
<0.75, 0.85]	79	15.6	61	14.2	81	22.4
<0.85, 0.95]	70	13.8	57	13.3	55	15.2
<0.95, 1.05]	185	36.6	173	40.3	127	35.2
<1.05, 2.00]	9	1.8	7	1.6	6	1.7
Total	506	100	429	100	361	100
p=0.148						

Table 10. Distribution of GDM scores.

	Eindhoven 2002		Eindhoven 2007		Maastricht 2003	
GDM score	#	%	#	%	#	%
[0.00, 0.05]	204	60.4	176	60.7	154	59.0
<0.05, 0.15]	42	12.4	45	15.5	34	13.0
<0.15, 0.25]	30	8.9	19	6.6	27	10.3
<0.25, 0.50]	33	9.8	29	10.0	18	6.9
<0.50, 0.95]	13	3.8	10	3.4	14	5.4
<0.95, 1.00]	16	4.7	11	3.8	14	5.4
Total	338	100	290	100	261	100
p=0.672						

Table 11. TDM versus non-TDM.

	Eindhoven 2002		Eindhoven 2007		Maastricht 2003	
TDM	#	%	#	%	#	%
Yes	83	24.6	85	29.3	65	24.9
No	255	75.4	205	70.7	196	75.1
Total	338	100	290	100	261	100
p=0.335						

Table 12. NDO versus FDO.

	Eindhoven 2002		Eindhoven 2007		Maastricht 2003	
Heuristic	#	%	#	%	#	%
NDO	265	52.4	214	49.9	160	44.3
FDO	105	20.8	87	20.3	77	21.3
Neither	136	26.9	128	29.8	124	34.3
Total	506	100	429	100	361	100
p = 0.114						

For each visited outlet, it can be determined how many times the pedestrian passed the outlet before entering it and how many times the outlet was already visited before. Pedestrian behaviour after leaving an outlet may also be of interest to examine. For each pedestrian visiting at least one outlet, the following indices were determined: the number of times the pedestrian

- passed the outlets before visiting the outlets divided by the number of outlets visited
- visited the outlets before divided by the number of outlets visited
- returned to the previous primary node when leaving the outlets divided by the number of outlets visited
- left multiple exit outlets at the location of entrance divided by the number of multiple exit outlets visited
- left multiple storey outlets at the storey of entrance divided by the number of multiple storey outlets visited
- used a passageway between two outlets divided by the number of outlets visited with a passageway.

Table 13. Indices related to visiting outlets.

	Eindhoven				Maastricht		p=
	2002		2007		2003		
index	mean (N)	sd	mean (N)	sd	mean (N)	sd	
passed before	0.103 (684)	0.206	0.115 (582)	0.206	0.193 (448)	0.269	0.000
visited before	0.003 (684)	0.028	0.004 (582)	0.029	0.003 (448)	0.026	0.765
returned	0.434 (684)	0.369	0.475 (582)	0.368	0.377 (448)	0.341	0.000
exit = entrance	0.812 (451)	0.351	0.772 (400)	0.364	0.766 (273)	0.377	0.159
storey exit = storey entrance	0.884 (43)	0.324	0.832 (191)	0.346	0.784 (216)	0.411	0.193
passageway	--	--	--	--	0.108 (216)	0.206	--

These individual indices are averaged across the pedestrians in each dataset. The results are presented in Table 13. It appears that, on average, in Eindhoven one out of ten and in Maastricht two out of ten pedestrians who visit a particular outlet already passed this outlet on their trajectory through the shopping area. The probability that a pedestrian visits an outlet multiple times is very small; less than 1%. Upon leaving an outlet, approximately 45% of the pedestrians in Eindhoven return to the primary node they came from. In Maastricht, this percentage is smaller (38%). This may be due to the more complex network of shopping streets in Maastricht. Remember that less than 2% of the turns at primary node are complete turns (Table 4). Apparently, leaving an outlet is the occasion to decide to turn back.

Roughly two-thirds of the pedestrians visiting shops, visit at least one multiple exit outlet (i.e. an outlet with exits on different sides of the building). Just over three-quarters of these pedestrians leave the outlet on the side they entered it. Considerably less pedestrians visit outlets with exits on multiple storeys. Approximately 10-20% of the pedestrians visiting such an outlet use an internal staircase, elevator, or escalator to move to another storey and leave the outlet. In Maastricht, the two major department stores are connected by means of a passageway on their top floor. The probability this passageway is used when leaving one of the outlets is 11%.

5. Conclusions and discussion

In this paper, a number of indices describing individual shopping behaviour in pedestrianized shopping areas were described and applied to observed routes and shopping behaviour of pedestrians in the downtown shopping areas of Eindhoven and Maastricht, the Netherlands. Both indices related to routes and visiting outlets were applied. To summarize, the average route length is 1 to 1.5 km, but there is considerable variation in route length. Pedestrians tend to walk straight on at intersections and avoid entering a segment (in a particular direction) twice. However, retracing part of the route is no exception at all. Regarding visiting outlets, the average number is 3 to 4 outlets, again with a considerable deviation. Fashion stores seem to be the most popular outlets. About half of the pedestrians walk along the shortest path to their destinations. Approximately 60% of the pedestrians visiting 3-8 outlets visit the outlets in the optimal order. However, only a quarter of these pedestrians reveal both optimal sequencing and path minimization. Furthermore, about half of the pedestrians visiting at least two outlets, start with the outlet nearest to their entry point. 10-20% of the pedestrians visit an outlet they already passed previously during their trip in the shopping area. Finally, the average probability the pedestrian returns to the previous direction when leaving an outlet varies between one-third and a half. Overall, there is considerable variation in shopping behaviour.

Note that the indices presented in this paper do not consider sequences of types of outlets visited by a pedestrian. For example, Brown[20] observed strong links between similar types of retail outlets. Also, aspects related to time (dynamics, duration[21]) were not taken into account. When it comes to comparing observed and predicted routes, measures like proportion of overlap between two routes may become of interest.

It should be taken into consideration that differences between cities may be caused by different reasons. For example, a turn to the left or right at a primary node may be a conscious decision of the pedestrian, heading for a particular outlet. On the other hand, the primary node may represent a T-junction, not allowing walking straight on. Similarly, visiting outlets may be related to the supply and location of outlets and where pedestrians enter the shopping area. To predict individual decision making in pedestrianized shopping areas, models describing such behavior have to be developed. Such a model will be presented in the near future.

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