Bicyclists' braking profile on typical urban road pavements

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Abstract: - This study examines the bicyclists' braking profile on four typical pavement types in the urban road environment: asphalt, concrete plate, concrete bricks and thermoplastic material. The experiment took place in the city of Volos, Greece, in a pedestrian area provided with a bikeway across the port, under good weather conditions. Five volunteer bicyclists, men and women of different physical weight took part in the experiment, riding a brand new city bike. The experiment was conducted with the use of state of the art equipment: VBOX (Racelogic, UK) that could trace the bicyclists' movement and collect data of position, speed etc using GPS signal. Each participant accelerated the bike on 15km/hr or 20km/hr, kept the speed steady riding the bike in straight line and then applied the brakes with maximum force until the bike stops. This test was revised for each pavement type. After the data analysis, we estimated the braking time and distance for each pavement type for the two speed levels according to the bicyclists' weight. Finally, we concluded that the shortest braking distance was noticed on the pavement made from asphalt. Furthermore, we concluded that a 5km/hr rise of bicyclists' speed resulted to a much longer braking distance.

Key-Words: - Bicycle, Pavement, Braking profile, Time, Distance, VBOX

1 Introduction

This study examines the bicyclists' braking profile on four typical pavements in the urban road environment in city of Volos, Greece. One of the most important factors for the bicyclists' road safety is their ability to stop their bike in a short distance. The type of the road pavement where the bicyclist rides his bike and its smoothness and maintenance level influences the braking time and distance. The criteria for the selection of the bikeway pavement material should serve both aesthetic and road safety issues.

1.1 Bicycle as a sustainable transport mode

The promotion of bicycle as a transport mode in urban areas is a main target for many countries around the world. Sustainable transportation is the ability to meet the needs of society to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values today or in the future.

Bicycle is a sustainable transport mode. It is affordable with benign environmental effects. Promoting the use of bicycle can also benefit nonbicyclists. Bicycling and walking conserve roadway and residential space; avert the need to built, service and dispose for autos; and spare users of public space the noise, speed and intimidation that often characterize motor vehicle use. The use of bicycle as a transport mode in urban areas can address transportation challenges because of its flexibility, speed and affordability.

Bicycle can be integrated in the supply chain transport network improving business and investments in urban areas and wider in global standards [1]. Health benefits of habitual, daily activity as bicycling is well documented [2]. It is also more cost effective than highly vigorous and structural activities [3]. It is important to mention that promotion of bicycling may not always be an appropriate solution to transportation problems due to physical and geographic characteristics of an urban area. Planners and city officials can address these concerns with efforts such as good design and enforcing traffic rules. The urban transport network is a large-scale system and every management effort should consider methods of simulation and evaluation that are not consuming time while maintaining accuracy [4].

There are five main characteristics in order to promote bicycling in urban areas: the bicyclists' road and personal safety and the accessibility, convenience and attractiveness of the urban road environment and bicycle infrastructure. These characteristics can be summarized as the "bikeability" level of a selected route, an urban area or even an entire city [5].

1.2 The characteristics of bicycling

Bicycle is a transport mode which is useful for recreation or commuting trips in urban or suburban areas. In the USA, according to the National Household Travel Survey (2001) the 40% of total auto trips are shorter than 3.2 km [6]. The 50% of personal shopping and 22% of the work trips are shorter than 1.6 km and the 70% of personal shopping and 39% of the work trips are shorter than 3.2 km. Bicycle is not only a transport mode useful for utilitarian trips but also common as an exercise or recreational activity. About 15% of the adults in the USA and 24% of the adults in Canada are cycling at least once a week for recreation or exercise purpose [7], [8]. According to the International Bicycle Fund, in many countries of Northern Europe like Netherlands and Denmark, bicycle trips are the 20-30% of the daily trips in urban areas [9]. On the contrary, in Southern European countries like Italy and Greece, bicycle trips are less than 5% of the daily trips in urban areas.

Bicycle is a popular transport mode among male, younger adults and citizens who are already physically active [10]. In the USA, the 27% of the adult citizens aged 16 or older, rode their bikes at least ones in a month during the summer. More males (34%) rode their bikes than females (21%). According to the Bureau of Transportation Statistics (2004), the youngest age group (16-25 years old) presented the highest rate of cycling (39%), while the oldest age group (65 or older) presented the lowest rate of cycling (9%) [11].

The main factors that the researchers consider to be associated with the use of bicycle as a transport mode are the following ones:

- Individual factors: Bicycling preference and riding comfort and skills.
- Social environment factors: Bicycling community factors.
- Physical environment factors: Functional, safety, aesthetics and destination features.

The functional feature relates to the physical attributes of the street and bikeways that reflect the fundamental structural aspects of the local environment. Factors that influence this feature include: the specific attribute of the bikeways, the type and width of the street and the bikeways, the volume, speed and type of traffic and the directness of routes to destinations. The safety feature reflects the need to provide safe physical environment for bicyclists. The aesthetic feature includes: the presence, condition and size of trees, the presence of parks and private gardens, the level of pollution and the diversity and interest of natural sights and architectural designs within the routes. The destination feature relates to the availability of community and commercial facility. Where there are appropriate local destinations there is an increased chance that people will ride their bikes. Relevant facilities include post boxes, parks, schools, shops and transport facilities such as bus stops and train stations.

1.3 Bicyclists' road safety

Bicyclists are vulnerable road users due to their higher risk for their road safety. According to the European Road Safety Observatory (2008), presenting data from 14 countries of the European Union (EU) in 2006, resulted that the bicyclists' fatalities were 1188 ones, 34% lower than the year 1997 [12]. Bicyclists' fatalities present a peak point in age groups of around 15 years old and over 65 years old. The 55% of the bicyclists' fatalities were noticed in urban areas. In Greece, this percentage raised to 71%, where intersections were considered to be the most dangerous sites in urban road network for the bicyclists' road safety.

In USA, according to the National Highway Traffic Safety Administration (NHTSA), 687 bicyclists lost their lives in 2007, 14% less than the year 1997 [13]. In 2007, the injured bicyclists were 43.000 ones, 26% less than the year 1997. In USA, according to the Insurance Institute for Highway Safety (2007) seven times more men than women lost their lives riding their bike [14]. The 92% of the bicyclists did not wear protective helmets, which is proven to be very important tool for their road safety in case of an accident. Alcohol is also considered to be a major factor for the bicyclists' road safety because it influences the bicycling behaviour. In 33% of the bicycle accidents, either the vehicle or the bicycle driver had consumed alcohol.

1.4 Bicycling infrastructure

The construction of an integrated, comprehensive network of well-maintained, well-designed bicycling facilities such as bike paths and lanes is a key element in any package of policies to promote bicycling [15]. The separate bicycling facilities should not be the only approach to encourage more bicycling and making it safer. Except from constructing bicycling facilities more measures are necessary, such as:

• Improving roadway design to facilitate bicycling on roads without separate bicycling facilities (clearing of debris, wide shoulders, bike-friendly drain grates, etc).

- Ample bike parking, including secure and sheltered facilities.
- Integration of bicycling with public transport.
- Traffic education and training of both bicyclists and motorists.
- Severe penalties for motorists who endanger bicyclists, especially in those cases resulting in serious injury or death.
- Traffic priority for bicyclists at intersections, combined with various intersection design modifications to mitigate car-bike conflicts at crossings.
- Promotional, marketing and informational events to generate public support for bicycling
- Restriction of car use especially in residential neighbourhoods and city center.
- Increased taxes and fees on car ownership, use and parking to reflect the high external costs of the motorized transport modes.
- Land use policies that discourage lowdensity suburban sprawl and foster compact, mixed-use developments that generate shorter and thus more bikeable urban trips.

The construction of separate bicycling facilities within cities, where almost all daily trips are noticed is not the best answer to the problem of integrating bicycle in the urban transportation system. There are many different kinds of bicycling facilities which vary in location, design and degree of separation from other transport modes [16]. Depending on cost, space availability and roadway traffic conditions, different facilities are appropriate in different situations. Worldwide, there is no consensus on the exact terminology but the general categories of bicycling facilities are the following ones:

- Bicycle only on-road lanes protected from motor vehicle traffic by barriers of various sorts. Such bicycle tracks provide separation from both pedestrians and motor vehicles while keeping bicyclists in view of motorists.
- On-street bike lanes that are not protected by physical barriers and are often blocked by double-parked cars, delivery vehicles and endangered by car doors being opened into the path of the in-coming bicyclists. The main advantage of such bike lanes is that they are cheaper and easier to construct, maintain, operate and place the bicyclists in close view of the motorists. Their main disadvantage of such bike lanes is that they

provide to the bicyclists no physical protection from the motorists.

- Protective lane striping for bicyclists, which are similar to bike lanes but narrower and are demarcated by dashed striping instead of a solid stripe. They provide less protection than a full bike lane but help signal the presence of bicyclists to the motorists.
- Combined bus-bike lanes, which are extrawide lanes for accommodating both buses and cyclists. They are very common in many northern European cities.
- Bike paths on sidewalks, constructed with a distinctive pavement or colour to demarcate them from the footpath.
- Off-road bike-only paths parallel to urban roads but set off from the roadway and completely separate from footpaths.
- Bike-only paths through parks and open space, sometimes referred to as green bicycle tracks.
- Shared-use paths that are separated from motor vehicle traffic but permit use by pedestrians, joggers, skaters and other non-motorized users.
- Traffic-calmed residential streets, which reduce vehicles' speed limits to 30km/hr in Europe, both by posting reduced speed limits and by various kinds of physical modifications to roadway to prevent high speed use by motor vehicles. The greatly reduced speed and light traffic flow volume make these traffic calmed streets ideal for bicycling without any special bicycling facilities.
- Super traffic-calmed residential streets, called "Woonerf" in the Netherlands or "Home Zones" in the United Kingdom. The vehicles' speed is further reduced to the walking speed (7km/hr).
- Bicycle traffic signals, special marking, coloration of bike lanes and various other intersection modifications.

Separate bicycling facilities are not a panacea for bicycling but combined with other bikeability features can promote bicycling levels. All citizens should be able to ride their bicycle and not only the ones who are physically fit or well trained as vehicular cyclists, biking in mixed traffic conditions.

One of the basic features of bikeability is the convenience of bicycling which is a key feature in bikeability checklists [17]. The bicyclists desire smooth and properly maintained pavements with providence of ramps when their route elevation changes. The road grade and slope should be as flat as possible in order the bicyclists to consume the lowest level of physical effort. Furthermore, the design of the bikeways should be according to the norms. Other issues of convenience include the continuing presence of bikeways and the absence of obstacles across the route [18].

A wide range of bikeway pavement materials is available (Table 1). A smooth transition between different pavements is very important for the convenience of the bicyclists. A variety of types of coloured surfacing is available, with differences on skid resistance, surface texture, durability and colour – fastness. They can be naturally coloured aggregate materials, coloured bituminous macadam, or veneer coats laid on top of hot rolled asphalt (HRA), stone mastic asphalt (SMA) or other bituminous wearing courses. Colour is usually provided in anti-skid surfaces adding the appropriate pigment to the resin, whatever type the resin may be, epoxy, polyurethane or thermoplastic.

Table 1: Bikeway pavement materials

Table T. Dikeway pavement materials						
Bikeway material	Comments					
Stone mastic	Normal main road surface,					
asphalt (SMA)	good for cycling					
Hot rolled asphalt	Normal main road surface,					
(HRA)	good for cycling					
Bituminous	Normal minor road and					
macadam	footway surface material					
(bitmac)	good for cycling					
Fine cold asphalt	Footway surfacing material,					
	smooth and good for cycling					
Concrete	Good for cycling if the joints					
	and slabs are in good					
	condition, but surface					
	markings are not clearly					
	marked					
High friction	Normally good for cycling					
surfacing (Anti -	but laying methods resulting					
skid)	in ridges should be avoided					
	Specialist coloured surfaces					
Coloured Veneer	in green, red etc, laid on to					
Coat	wearing courses, normally					
	anti-skid					
	A cheap maintenance layer,					
Surface dressing -	good for cycling if the stone					
Granite Stone	size is not too large (10-					
	14mm)					
Surface dressing -	A cheap maintenance layer,					
Pea - Shingle (6-	good for rural/park situations,					
8mm stone)	lower skid resistance, was					
ommistorie)	used on country roads					

Slurry Sealing	A cheap maintenance layer, suitable for temporary use only
Brick or Block Paving	Acceptance for cycling on, cycling resistance can be low on some brick paving
Granite Sets	Too rough for some bikes, but if laid flush can be acceptable in limited areas. Can polish with use and be slippery when wet.
Natural Stone blocks	May be suitable if bedded on mortar/concrete and surface is not uneven or smooth and has good skid resistance.

2 Methodology

2.1 Objective

This study examines the bicyclists' braking profile on four different types of urban pavements in the city of Volos, Greece. Bicyclists can ride their bikes in mixed traffic flow with cars and motorcycles in the streets or with pedestrians on the sidewalks and pedestrian areas. In these areas the bicyclists are forced to use the existing road space and the different road pavements. In order to analyse the bicyclists' road safety in the issue of braking profile, we tried to simulate the movement of a bicyclist in some of the most representative pavement types. We examined the following pavements:

- Asphalt
- Concrete bricks
- Concrete plates
- Thermoplastic coloured surface (bikeway)

2.2 Study area

The experiment took place in a pedestrian area across the city's port, where a bikeway was also presented (Fig.1, 2). This area was ideal for the conduction of the experiment because of the presence of different and representative pavement types (Fig.3). Furthermore, the bicyclists' road safety was high because they did not conflict with other road users, especially motorists. The pedestrian traffic flow was too low to influence the bicyclists' movement. Finally, the study area had no barriers like trees or buildings that could hamper the GPS signal and the operation of the instrument (Fig.3).



Fig.1: Experiment site



Fig.2: Experiment area



Fig.3: Typical bikeway pavement

2.3 Instrument

In order to estimate bicyclists' braking profile we used a state of the art instrument: VBOX (Racelogic, UK). This instrument uses a GPS data logger for the estimation of the current speed and position of a moving vehicle like a bicycle in a frequency of 20Hz. It is able to register the following data:

- Satellites
- UTC Time
- Latitude
- Longitude
- Velocity
- Heading
- Height
- Vertical Velocity, etc

The resolution of the bicyclist speed was 0.01 km/hr and the accuracy 0.1 km/hr. Furthermore, the resolution of the route length was 1cm and the accuracy 0.05%. The data analysis was conducted with the use of the software VBOX Tools (Racelogic, UK). The VBOX instrument set consists of the following (Fig.4, 5):

- VBOX
- Battery
- Battery charger
- GPS antenna
- SD card
- Card reader
- USB cable



Fig.4: Complete instrument set (VBOX)



Fig.5: Instrument set (VBOX)

2.4 Selection of the participants and bicycle

The first step of the experiment was the selection of the participants. Five bicyclists, three men and two women participated in the experiment. The age of the participants was between 20 and 25 years old. It was not necessary the bicyclists to be experienced because of the ease of the experiment and the high level of the road safety in the study area. A necessary factor was the physical condition of the participants. All of them were university students and volunteered for the conduction of the bicyclists was their allocation of weight into five categories:

- 50kg (woman)
- 60kg (woman)
- 70kg (man)
- 80kg (man)
- 90kg (man)

The second step of the experiment was the selection of the bicycle. In order to have more reliable results we used a brand new city bike (Giant: Sedona), representative of the bicycle type that is used from bicyclists in Greek cities.

Before the conduction of the experiment the bicyclists rode the experiment bike in the study area for 5-10min. The bicyclists should get familiar with the bicycle so that no problem related to the bicycle ride occurs.

2.5 Conduction of the experiment

The third step was the conduction of the experiment. It was necessary that during the experiment procedure the weather conditions were good enough, without winding or raining. We put the antenna on the bicycle and the VBOX in a bag that was carried from the bicyclist. After the GPS signal detection, the bicyclist activated the VBOX and started riding the bike. After reaching the proper speed of 15km/hr or 20km/hr, he/she kept this speed steady for some seconds moving in a straight line and checking a speedometer. Finally, they applied the brakes with maximum force in a site where we had previously marked (Fig.6). As soon as the bicyclist stopped the bike, we removed the SD Card and through the card reader we transferred the registered data into a notebook.

The concept of the abrupt braking was that the bicyclist had suddenly faced an obstacle or an incoming vehicle. We tried to conduct the experiment as naturalistic as possible. Due to that fact we did not strictly mark the acceleration and steady speed distance that depended on the bicyclists' choice but we marked only the start point. The total length of the acceleration and steady speed distance was about 100-120m (Fig.8). The biking distance in the speed of 20km/hr was longer because we considered that the bicyclists should not worry about the distance they needed to reach the proper speed and maintain it until they reach the braking point that was similar in both speed cases.

This procedure was revised of every participant three times for each type of the examined pavements. So, each bicyclist revised the route about 12 times before complete his participation. Some of the routes were revised due to abrupt presence of a pedestrian across the route or a failure in the data registration from the instrument. The routes were one way in order to simplify the process (Fig.6). As soon as the bicyclists stopped the bike, they returned to the starting point and revised the experiment.



Fig.6: Bicyclist route

3 Results

For each pavement type we estimated the average of the bicyclists' braking distance (Table2), braking time (Table 3) and the final braking profile (Table 4). We formed diagrams of speed-time (Fig.7), speed-distance (Fig.8), time-distance (Fig.9) and acceleration-distance (Fig.10) for each pavement type and each weight category of the bicyclists.

Table 2: Bicyclists' braking distance

Bicyclists' braking distance (m)					
Weight	50kg	60kg	70kg	80kg	90kg
Speed	Asphalt				
15 km/h	3,74	3,26	5,85	6,11	12,22
20 km/h	6,54	13,33	13,39	24,18	11,19
Speed	Thermoplastic (bikeway)				
15 km/h	4,54	7,05	5,02	6,70	5,47
20 km/h	12,48	13,13	19,54	27,30	10,45
Speed	Concrete plates				
15 km/h	5,50	3,63	8,26	9,73	3,78
20 km/h	18,60	10,36	14,52	28,15	11,09
Speed	Concrete bricks				
15 km/h	5,31	2,82	9,58	4,81	6,41
20 km/h	15,32	5,82	19,10	24,95	12,82

In Table 2, we present the results of the bicyclists' braking distance according to their weight, pavement type and speed. The 50kg bicyclist, biking with a speed of 15km/hr presented the minimum braking distance on asphalt (3.74m) and the maximum braking distance on concrete plates (5.50m). Biking with a speed of 20km/hr presented the minimum braking distance again on asphalt (6.54m) and the maximum braking distance on concrete plates (18.60m).

The 60kg bicyclist, biking with a speed of 15km/hr presented the minimum braking distance on concrete bricks (2.82m) and the maximum braking distance on thermoplastic (7.05m). Biking with a speed of 20km/hr presented the minimum braking distance on concrete bricks (5.82) and the maximum braking distance on asphalt (13.33m).

The 70kg bicyclist, biking with a speed of 15km/hr presented the minimum braking distance on thermoplastic (5.02m) and the maximum braking distance on concrete bricks (9.58m). Biking with a speed of 20km/hr presented the minimum braking distance on asphalt (13.39m) and the maximum braking distance on thermoplastic (19.54m).

The 80kg bicyclist, biking with a speed of 15km/hr presented the minimum braking distance on concrete bricks (4.81m) and the maximum braking distance on concrete plates (9.73m). Biking with a speed of 20km/hr presented the minimum braking distance on asphalt (24.18m) and the maximum braking distance on concrete plates (28.15m).

The 90kg bicyclist, biking with a speed of 15km/hr presented the minimum braking distance on concrete plates (3.78m) and the maximum braking distance on asphalt (12.22m). Biking with a speed of 20km/hr presented the minimum braking distance on thermoplastic (10.45m) and the maximum braking distance on concrete bricks (12.82m).

Bicyclists' braking time (sec)					
Weight	50kg	60kg	70kg	80kg	90kg
Speed	Asphalt				
15 km/h	1,65	1,50	3,05	3,05	5,65
20 km/h	2,25	3,90	4,20	6,00	3,60
Speed	Thermoplastic (bikeway)				
15 km/h	1,85	2,75	2,40	3,15	2,85
20 km/h	4,95	3,80	5,95	6,60	3,80
Speed	Concrete plates				
15 km/h	2,50	1,60	2,95	3,85	2,80
20 km/h	6,00	2,90	3,95	7,20	3,20
Speed	Concrete bricks				
15 km/h	2,90	1,35	3,45	2,60	2,60
20 km/h	3,75	2,05	5,40	6,30	4,10

Table 3: Bicyclists' braking time

In Table 3, we present the results of the bicyclists' braking time according to their weight, pavement type and speed. The 50kg bicyclist, biking with a speed of 15km/hr presented the minimum braking time on asphalt (1.65sec) and the maximum braking time on concrete plates (2.90sec). Biking with a speed of 20km/hr presented the minimum braking time again on asphalt (2.25sec) and the maximum braking time on concrete plates (6sec).

The 60kg bicyclist, biking with a speed of 15km/hr presented the minimum braking time on concrete bricks (1.35sec) and the maximum braking time on thermoplastic (3.80sec). Biking with a speed of 20km/hr presented the minimum braking time on concrete bricks (2.05sec) and the maximum braking time on asphalt (3.90sec).

The 70kg bicyclist, biking with a speed of 15km/hr presented the minimum braking time on thermoplastic (2.40sec) and the maximum braking time on concrete bricks (3.45sec). Biking with a speed of 20km/hr presented the minimum braking time on asphalt (4.20sec) and the maximum braking time on thermoplastic (5.95sec).

The 80kg bicyclist, biking with a speed of 15km/hr presented the minimum braking time on concrete bricks (2.60sec) and the maximum braking

time on concrete plates (3.85sec). Biking with a speed of 20km/hr presented the minimum braking time on asphalt (6sec) and the maximum braking time on concrete plates (7.20sec).

The 90kg bicyclist, biking with a speed of 15km/hr presented the minimum braking time on concrete plates (2.80sec) and the maximum braking time on asphalt (5.65sec). Biking with a speed of 20km/hr presented the minimum braking time on thermoplastic (3.80sec) and the maximum braking time on concrete bricks (4.10sec).

Table 4: Braking profile

Material	Asphalt	Bikeway	Concrete plates	Concrete bricks	Average
Speed	Average braking distance (m)				
15 km/h	6,23	5,78	6,18	5,75	5,98
20 km/h	13,72	16,58	16,54	15,60	15,61
Speed	Average braking time (sec)				
15 km/h	2,98	2,60	2,74	2,58	2,73
20 km/h	3,99	5,02	4,65	4,32	4,50

In Table 4, we present the bicyclists' braking profile according to the pavement type and speed. We present the average braking distance (Fig.11) and average braking time (Fig.12) from the five bicyclists for each pavement type. When the bicyclists rode the bike with a speed of 15km/hr the braking distance was similar in all pavement types. The maximum braking distance was noticed on asphalt (6.23m) and the minimum braking distance on concrete bricks, (5.75m). The average braking time was noticed on asphalt (2.98sec) and the minimum braking time on concrete bricks (2.58sec). The average braking time was 2.73sec.

When the bicyclists rode the bike with a speed of 20km/hr the braking distance presented wider scale between pavement types. The maximum braking distance was noticed on thermoplastic bikeway (16.54m) and the minimum braking distance on asphalt (13.72m). The average braking distance was 15.61m. The maximum braking time was noticed on thermoplastic bikeway (5.02sec) and the minimum braking time on asphalt (3.99sec). The average braking time was 4.50sec.

From the results of the braking profile (Table 4), we concluded that a 5km/hr faster bicyclists speed (from 15km/hr to 20km/hr), resulted to a 160% higher braking distance (from 6m to 15.6m) and a 65% higher braking time (from 2.73sec to 4.50sec).

In Fig.7, we present the biking profile as a diagram of speed-time in the case of the bikeway (thermoplastic material). The blue line describes the biking profile of a maximum speed of 15km/hr and the pink line the biking profile of a maximum speed of 20km/hr. The bicyclist after the acceleration time of 5-7sec reaches the maximum speed and keeps it as steady as possible watching the speedometer until he/she apply the brakes in order to completely stop.







In Fig.8, we present the biking profile as a diagram of speed-distance in the case of the bikeway route (thermoplastic material). The blue line describes the biking profile of a maximum speed of 15km/hr and the pink line the biking profile of a maximum speed of 20km/hr. The bicyclist after the acceleration distance of 10-15m reaches the maximum speed and keeps it as steady as possible watching the speedometer until he/she apply the brakes in order to completely stop. We conclude that they bicyclists quickly reached the desired speed and rode the bike properly, according to their orders.





Fig.8: Speed-Distance diagram (Bikeway)

In Fig.9, we present the biking profile as a diagram of time-distance in the case of the bikeway route (thermoplastic material). We notice the acceleration stage (0-5sec), the steady speed stage (5-25sec) and the deceleration stage (25-30sec). We also notice that the acceleration distance and time was similar but a little higher to the deceleration ones.

DISTANCE - TIME DIAGRAM: BIKEWAY



Fig.9: Time-Distance diagram (Bikeway)

In Fig.10, we present the biking profile as a diagram of acceleration-distance in the case of the bikeway route (thermoplastic material).



Fig.10: Acceleration-Distance diagram (Bikeway)

BRAKING DISTANCE (m)



Fig.11: Average braking distance (m)

BRAKING TIME (sec)



Fig.12: Average braking time (sec)

4 Conclusions

The conclusions of our study are the following:

- A 5km/hr faster bicyclists speed (from 15km/hr to 20km/hr), resulted to a 160% higher braking distance (from 6m to 15.6m) and a 65% higher braking time (from 2.73sec to 4.50sec).
- The acceleration distance and time was similar but higher to the deceleration ones.
- Higher bicyclists' speed relates to a much higher braking time and distance.
- Bicyclists should not bike faster than 15km/hr, unless they have adequate visibility of other road users.
- Asphalt presented the best friction rate from all the tested pavement materials.
- Asphalt is a material convenient for bicyclists used in the greater part of the urban road network.
- The major problems for bicyclists are the slippery surface of the pavement, the lack of maintenance and the presence of potholes.
- Road safety auditors should consider the bicyclists' needs of proper pavement maintenance during an urban road safety project.
- Proper design and maintenance of the bicycle infrastructure is necessary for the promotion of sustainable transportation.

More research is necessary to estimate the bicyclists' braking profile and biking behavior.

- Testing of speed cases: 10km/hr, 15km/hr, 20km/hr and 25km/hr
- Selection of one weight category typical for young men (75-80kg) and women (60-65km)
- Greater sample of bicyclists
- Examination of water slippery pavements

Finally, bicyclists driving behaviour and influence from the pavement conditions on their road safety should be under continuous research. In Greece, bicycle is a brand new transport mode in urban areas that has not yet being implemented into the urban transportation system. This study answered some of the problems that bicyclists face when they bike in the urban road network in the issue of braking profile according to the pavement type.

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