Abstract: Pedestrians are vulnerable road users and because of that it is necessary to analyse their behaviour in order to define quality measures to influence their behaviour. As behaviour of other road users, pedestrian behaviour should be safe, in order not to influence their own safety and safety of other road users. Many different researches indicate that pedestrian crossings while there is red light on the traffic light are very common. Research methodology for pedestrian behaviour at intersections regulated with traffic light is presented, but also obtained research results. Pedestrian behaviour was researched at three locations in Belgrade, in order to determine differences between locations and obtain more quality research results. Pedestrian behaviour has been analysed from many different aspects (number of pedestrian which respect and violate red light for pedestrians): pedestrian gender and age, group membership (pedestrian alone or in group), but in this paper waiting time has been analysed as most significant measure for traffic signals operation configuration.

Keywords: pedestrians, red light, behaviour, Belgrade

1. INTRODUCTION

Almost every road users is sometimes pedestrian, because we begin and end most trips on foot. Yet, due to lack of attention to the needs of pedestrians, and a tendency to favour motorized transport, pedestrians are at great risk of death, injury and disability. Of the total world road traffic fatalities (1.24 million fatalities), more than 270,000 are pedestrians (WHO, 2012). This constitutes 22% of all road deaths (WHO, 2012). Most pedestrian road accidents happen when pedestrian are crossing the road, rather than walking or standing alongside the road (WHO, 2012).

In order to identify unsafe junctions, where priority should be shifted to pedestrians it is necessary to understand the crossing behaviour of pedestrians as the effect of age, gender or some other circumstances (crossing with/without luggage or children, walking in group etc.).

During 2012, 3114 pedestrians died or got injured in traffic accidents, which makes 16.3% of all injured or dead pedestrian in traffic (RSTA, 2013). However, if we only analyse number of pedestrian fatalities, about 23.8% of all persons who died in traffic are pedestrians (RSTA, 2013) which indicated how vulnerable they are among other road users.

Illegal pedestrian behaviour is common and is reported as factor in many pedestrian crashes. Signalised junctions should be the safest one, because conflict flows of traffic (pedestrian and vehicle traffic flow in this case) are always separated. However, disrespect of
traffic signals may lead to traffic accident. Finally, unsafe behaviour is more dominant on a pedestrian side. It is important to understand pedestrian street-crossing behaviour because it is not only crucial for improving pedestrian safety but also helps to optimize vehicle flow.

Research methodology for pedestrian behaviour at signalized crossing is presented in this paper (database design and terrain research process), and also received results are presented. Research has been carried on a signalised pedestrian crossing in Karadjordjeva Street in Zemun, Belgrade. Violating behaviour of pedestrians is studied and relationship with dependent variables such as waiting time, gender, age, and group/single walking.

2. LITERATURE REVIEW

Different researches documented that most pedestrian road accidents occur when pedestrians are crossing a road. However accidents mostly happed away from crossing facilities compared with on a crossing (AA Foundation, 1994; Ghee et al, 1998). National statistics in Great Britann shows that more road accidents occur at mid-block signalised crossings compared with other types of pedestrian crossings (zebra crossing, signal-controlled junctions and crossings with human control) (DoT, 2004), which may be misleading because number of each crossing type in not taken into account.

Keegan et al. (2003) showed that 35% of pedestrians entered illegally at signalized crossing. On the other side in New South Wales and Victoria it has been proved that 32-44% of pedestrian crashes at signalizes crossing that pedestrian illegal movement featured (Ausroads, 2000). Knowledge of pedestrian rules is usually not a problem. However, pedestrian systematically refuse to respect law, and common engineering measures are usually with no significant result (overpassed, underpasses and pedestrian barriers).

King et al (2009) analysed illegal pedestrian crossing at signalised intersections, and compared pedestrian behaviour with accident data for 11-year period (1996-2006), between 8 a.m. and 6 p.m. on the walkways. Their analysis showed that 77 crashes (41.8%) which occurred when the pedestrian were crossing legally, 43 (23.4%) accidents occurred when pedestrian entered the crossing against the flashing or steady red man, and 64 (34.8%) accidents when pedestrian crossed within 20 m of the signalised crossing. The risk ratios in the same study showed that crossing against the lights and crossing close to the lights both exhibit a crash risk per crossing event approximately eight times that of legal crossing at signalised intersection. King et al (2009) also showed that almost 12.8% pedestrians crossed signalised crossing at flashing or steady red light, while 8.2% pedestrians cross away from signals, within 20 m.

Li (2013) analysed pedestrian intended waiting times for street crossing at signalized intersections, with the result that average waiting time is 43 s for male pedestrians, 54.7 s for female pedestrians, 44.3 s for young pedestrians, 47.5 s for middle-aged pedestrians and 57.1 s for elderly pedestrians. Pedestrian waiting time has U-shaped distribution. That means that there is a large proportion of pedestrians who cross the street immediately after arriving at the crossing point, and a large proportion of pedestrians who are willing to wait the entire red interval.

Koh et al (2014) showed that 22% of pedestrian fatal accidents in Singapore occurred at signalised pedestrian crossings. Of which, one in three such accidents occurred during the red-light phase. The average age of killed pedestrians is 52 years old. The chances that pedestrians become victims of road accidents would be reduces, if they obeyed traffic signals. During the same research 18% of pedestrian decided to cross the street while “red traffic light” for pedestrians (Koh et al, 2014). In general, Koh et al (2014) summarized that pedestrian violating behaviour could be influenced by personal characteristics (in a hurry or not, crowd behaviour), situational characteristics (vehicle volume, pedestrian volume), environmental conditions (crossing length, pedestrian crossing facilities, countdown timers, waiting duration).
Different studies have proven that men have a tendency to commit more violations than women. Also, young teenagers tend to violate a traffic light more often than other age groups (Moyano Diaz, 2002; Rosenbloom, 2009). Rosenbloom (2008) research shows that 13.5% of pedestrians cross the street during red-light phase among group of 20-40 years old pedestrians.

Wangs et al. (2011) found that about half of the pedestrians would not wait longer than 40 s. Teenagers, are most likely to violate traffic control in a larger group - so called social acceptance (Rosenbloom, 2009). Rosenbloom showed that 13.5% of the pedestrians arriving in the red-light phase crossed the street on a red light, and found that normal in comparison with general Israeli statistics (about 15% of pedestrians cross the street on red light). Period of year, and time of day influences proportion of violations, but that is often related to trip purpose (Wang et al., 2011). Also, research in Toronto shows that pedestrians are less likely to wait due to the cold, and during other weather conditions such as heavy rain (Li et al., 2010).

Lipovac et al. (2013a; 2013b) used before/after countdown display installation method in two different works (second one with more quality results in relation to previous work) to evaluate influence of pedestrian countdown display on pedestrian behaviour. The results of their study have shown that a countdown display reduces statistically significant the total number of violators, regardless of its location and traffic flow. Lipovac et al. (2013b) also concluded that statistically larger number of male pedestrians crossed the street during red light (23.9%), in relation to female pedestrians (16.3%). Also, a significantly larger number of male pedestrians crossed at red light before (25.1%) than after (24.4%) the installation of countdown display, which is also proven for female pedestrians where 18.8% female pedestrians crossed at red light before countdown display installation and 13.5% after countdown display installation (Lipovac et al., 2013).

3. RESEARCH METHODOLOGY

Research has been carried out at signalized pedestrian crossing in Karadordeva Street in Zemun, Belgrade during two days (30 and 31 March, 2014 – Saturday and Monday) from 1 p.m. to 3 p.m. Actually, researches recorded two hours of video material for each research day. Data collection is being done by later video material analysing in laboratory. Error and subjectivity of observer is at minimal level during this research, not only because of analysis based on late video material examination, but because of simple definition of pedestrian violator during research. Thus, pedestrians who do not obey traffic rules (cross street on red light for pedestrians) is a person which enter roadway while red light for pedestrian is still on, no matter when that person finish crossing.

Beside pedestrian behaviour characteristics, observers also measured traffic flow in both directions of vehicles. Also, research has been conducted in preferable weather conditions (no rain, snow, ice, fog or other weather conditions which influence pedestrian behaviour). On the other side, research has not been carried out during unusual environment conditions (road accident near research location or work on roads). In other words, all expected and proven influential factors are taken into account, as aim of the research is to measure pedestrian behaviour without influence of additional factors.

On a research location there is a road with four traffic lanes (two traffic lanes to centre of Zemun, and two to centre of Belgrade), and mid-block crossing controlled with traffic lights. Traffic signals at research location work in fixed timing mode. Red light for pedestrians lasts 65 seconds, and green light for pedestrians lasts 10 seconds. Vehicle traffic light timings are different for each direction. Actually vehicles which go to centre of Zemun have longer green light interval (48 s) than vehicles in opposite direction (32 s).
For each pedestrian in database, several variables have been analysed:

- Gender
- Age (Table 1)
- Direction
- Group
- Group number (Increasing consecutive number for each new pedestrian group - if pedestrian belongs to group)
- Number of pedestrian in group (if pedestrian belongs to group)
- Crossing interval
- Time of arrival (Time from video material when pedestrian arrived to pedestrian crossing – waiting space)
- Time of crossing (Time when pedestrian stepped at roadway)
- Waiting time (Time between time of arrival and time of crossing)
- Time after “red light” appearance (elapsed time since last pedestrian red light occurrence).

“Waiting time” and “Time after red light appearance” should be additionally explained, especially because of difference in comparison with Li (2013) research. “Time after red light appearance” is actually waiting time from Li (2013) research and that time represent when in the period of red light signal duration some pedestrian crossed the street. Because most pedestrians cross the street (proved in mentioned foreign research and will be presented later in this paper)
during first and last seconds of red light that curve looks like U letter. However, “time after red light appearance” does not present time which pedestrian spend until decision to cross the street, because pedestrian can come to waiting positions somewhere inside red light interval. That’s why “waiting time” has been introduced in this research as time which represents how many second pedestrian was in waiting position. “Time after red light appearance” is being captured only for pedestrian which cross pedestrian crossing during red light.

Finally, pedestrians in group are those who obviously come together to waiting area and crossing together and it is obvious that they are in a group (communicating, holding hands). All measured variables are being same for every group member (time of arrival and time of crossing).

4. RESEARCH RESULTS

Totally 563 pedestrians crossed the pedestrian crossing at the research location (256–45.5% males, 260–46.2% females and 47–8.3% children). Most pedestrians were alone while crossing the pedestrian crossing (351 pedestrians – 62.4%). When analysing direction of pedestrian movement, most pedestrian were crossing in direction “from camera to Danube” (288 pedestrians – 51.1%), in comparison with those going in opposite direction (274 pedestrians – 48.9%). Age structure of pedestrians is showed in Table 1.

<table>
<thead>
<tr>
<th>Age</th>
<th>≤12</th>
<th>13-16</th>
<th>17-19</th>
<th>20-24</th>
<th>25-34</th>
<th>35-45</th>
<th>45-55</th>
<th>55-65</th>
<th>≥65</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>47</td>
<td>10</td>
<td>11</td>
<td>87</td>
<td>89</td>
<td>96</td>
<td>72</td>
<td>122</td>
<td>29</td>
</tr>
</tbody>
</table>

Analysis shows that most pedestrians obey traffic signals. Actually, 81 pedestrian was crossing the street during red light interval (14.4%), which is lower than in most of presented previous researches.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Red Light</th>
<th>Green Light</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n  %</td>
<td>n  %</td>
</tr>
<tr>
<td>Male</td>
<td>51 19.9</td>
<td>205 80.1</td>
</tr>
<tr>
<td>Female</td>
<td>28 10.9</td>
<td>232 89.1</td>
</tr>
<tr>
<td>Children*</td>
<td>2 4.2</td>
<td>45 95.8</td>
</tr>
</tbody>
</table>

* up to 12 years old which crosses the street alone

Most pedestrian violators are among males (19.9%), and least violations among children (4.3%). However, those results are expected, as males traffic participants have been identified as more prone to risk. Results from Pearson’s $\chi^2$ test show that there is a great difference in number of violators between different gender groups ($\chi^2 = 13.047 > \chi^2_{0.05} = 5.991$). If only male and female groups are compared same difference is proven ($\chi^2 = 7.643 > \chi^2_{0.05} = 3.841$).

Comparison of pedestrian violation per pedestrian direction (Table 3) shows no significant difference which is proved statistically ($\chi^2 < 0.001 < \chi^2_{0.05} = 3.841$). However, as this result has no significance from scientific aspect it can be used to prove that camera monitoring of pedestrian behaviour did not influenced their behaviour during our research. Pedestrian behaviour differences will not be further examined in this paper.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Red Light</th>
<th>Green Light</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n  %</td>
<td>n  %</td>
</tr>
<tr>
<td>To Danube</td>
<td>39 14.2</td>
<td>236 85.8</td>
</tr>
<tr>
<td>From Danube</td>
<td>42 14.6</td>
<td>246 85.4</td>
</tr>
</tbody>
</table>
Unexpected results are received while comparing pedestrians in group and pedestrians which are crossing alone. Actually, more violations are recorded for “alone” pedestrians - 17.7% which is opposite to presented previous studies and our expectations, while only 9% pedestrians in group crossed the street during red-light phase. Differences are proven with Pearson’s $\chi^2$ test ($\chi^2 = 7.766 > \chi^2_{0.05} = 5.991$).

<table>
<thead>
<tr>
<th>Pedestrian Company</th>
<th>Red Light</th>
<th>Green Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>19</td>
<td>9.0</td>
</tr>
<tr>
<td>Alone</td>
<td>62</td>
<td>17.7</td>
</tr>
</tbody>
</table>

Differences between pedestrian violation per research day show that more violations happened during Monday (16.7%), in comparison with Sunday (11.3% pedestrian crossed street during red-light interval), but those differences are not statistically significant ($\chi^2 = 2.951 < \chi^2_{0.05} = 3.841$). However, a bit larger percent of pedestrian violations during Monday can be explained with different travel purposes (recreation purposes may de dominant during Saturday). It is also noticeable that during Monday totally 7934 vehicles passed through over pedestrian crossing, and 2544 vehicles during Saturday, which mean that vehicle flow didn’t influenced pedestrian behaviour as expected (more vehicles and more violations during Monday).

<table>
<thead>
<tr>
<th>Pedestrian Company</th>
<th>Red Light</th>
<th>Green Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday</td>
<td>33</td>
<td>11.3</td>
</tr>
<tr>
<td>Monday</td>
<td>48</td>
<td>16.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age</th>
<th>Red Light</th>
<th>Green Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;12</td>
<td>2</td>
<td>4.2</td>
</tr>
<tr>
<td>13-16</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>17-19</td>
<td>3</td>
<td>27.2</td>
</tr>
<tr>
<td>20-24</td>
<td>11</td>
<td>12.6</td>
</tr>
<tr>
<td>25-34</td>
<td>14</td>
<td>15.7</td>
</tr>
<tr>
<td>35-44</td>
<td>10</td>
<td>10.4</td>
</tr>
<tr>
<td>45-54</td>
<td>12</td>
<td>16.6</td>
</tr>
<tr>
<td>55-65</td>
<td>25</td>
<td>20.4</td>
</tr>
<tr>
<td>&gt;65</td>
<td>4</td>
<td>13.7</td>
</tr>
</tbody>
</table>

Finally, comparison between different age groups of pedestrians shows that most violations are in group of 17-19 years old pedestrians (27.2%). After that group, most violations can be expected in group of 55-65 years old pedestrians (20.4%). However, as number of pedestrians in each group present a small sample for adequate statistical analysis, and those results can be misleading. That’s why comparison should be done with two larger groups (17-34 years old pedestrians – 15% crosses while red light and 35-65 years old pedestrians – 16.2% crosses during red-light). However, differences between two dominant groups (17-34 years and 35-65 years) is not proven ($\chi^2 = 0.0541 < \chi^2_{0.05} = 3.841$). Such results are opposite from previous researches, and show that research sample must be much larger and also skills of fields
researcher for recognizing specific age group. Finally, comparison of three of four age group will make their research easier, lower the error probability and also give better results.

4.1. Waiting time

Totally 148 (26.8\%) pedestrian arrived at pedestrian crossing while green light was on, so those pedestrian crossed the street without waiting. Those pedestrians are not being taken into calculation while analysing average waiting time, because those pedestrians waited 0 s. Average waiting time for male pedestrians is 26 s, and average waiting time of female pedestrians is 29 s. As waiting time has no normal distribution, a non-parametric test – Man-Whitney Test has been used for testing differences in waiting time. Differences in waiting time of male and female pedestrians is confirmed by Man-Whitney Test ($U = 15438, Z = -1.147, p = 0.148$).

Average waiting time of pedestrian in group is 28 s, while average waiting time of pedestrians who were alone is 27 s. At first glance those differences are not significant, while it is noticeable that waiting time of alone pedestrians is lower than waiting time for pedestrians in group, which is expected in comparison with previously showed result where more violation are being done by alone pedestrians. However, Mann-Whitney U test show a significant difference in waiting time between pedestrians in group and alone pedestrians ($U = 19969, Z = -0.304, p = 0.761$).

Finally, average waiting time for pedestrian who are 17-34 years old is 26 s, while average time of pedestrians who are 35-64 years old is 28 s. Despite more violations in older group of pedestrians (35-64 years old), it is obvious that those pedestrian wait much longer at pedestrian crossing. However, that can be result of their positive attitudes or experience, but also coincidence in which those pedestrians come earlier to pedestrian crossing and wait much longer which will be examined later. Mann-Whitney U test show a significant difference in waiting time between two pedestrian age groups ($U = 13342, Z = -0.448, p = 0.654$).

In previous analysis of waiting time, waiting time of those pedestrians who waited until green-light phase has also been taken into calculation. However, it is more significant to analyse waiting time only for those pedestrians who were impatient and crossed the street on red light. That waiting time shows how long actually they are willing to wait (if all other circumstances are being rejected). Waiting time for those who crossed pedestrian crossing at red-light phase is:

- For male pedestrians - 21 s, and for female pedestrians - 26 s (difference between males and females is even more dominant compared to all pedestrians waiting times – pedestrians which crossed during red light and green light phase)
- For pedestrians in group 20 s, and for alone pedestrians 23 s (It is obvious that those waiting times are lower than waiting time for all pedestrians waiting times – pedestrians which crossed during red light and green light phase).
- For pedestrians 17-34 years old - 23 s, and for pedestrians 35-64 years old - 22 s (Despite waiting time for whole sample, waiting time for 35-64 years old pedestrians who crossed during red-light phase compared to all pedestrians waiting times – pedestrians which crossed during red light and green light phase).

There is two main factors that influences pedestrian waiting time: moment of arrival and moment of crossing. For instance: If all male pedestrians came at pedestrian crossing in last second of red-light phase, they will not wait too much – not because their willingness, but because the traffic light is soon going to be changes. Other possibility is that those pedestrians
who came earlier at traffic red-light phase have stronger wish to cross earlier, than those pedestrians which know that red-light phase will soon expire and decide to wait until change.

Spearman’s correlation coefficient for waiting time and arrival time (inside red-light phase interval) shows very high negative correlation between those variables \( r = -0.853 \)\(^1\). The regression is negative, because those pedestrians who came later, have less time to wait and their waiting time is lower. So, with the increase of arrival time, waiting time decreases. However, those results are not describing anything special in terms of pedestrian behaviour. That’s why only pedestrians which crossed the street during red-light phase should be analysed. However correlation between arrival time and waiting time (only for those pedestrians who crossed the street during red light phase) shows similar results, with strong negative correlation \( r = -0.809 \)\(^2\), which means that as time of arrival is increasing, pedestrians will wait less to cross at red light.

Those results can be explained in following way: At a beginning of red light phase, vehicles flow start (green light for vehicles), and those pedestrians can’t cross the street. That’s why they wait longer, until vehicles flow is empty. Finally, it is obvious from Fig. 1 that there are pedestrian with no waiting time (without waiting) who crossed the street at red-light phase (28 pedestrians). Also, it is noticeable that in first six seconds (safe time after vehicles are still stopping) of pedestrian red light almost 19 pedestrians crosses street without waiting time.

### 4.2. Time after red light appearance

According to our expectations and presented previous research results, distribution of time when pedestrian decide to cross street inside red-light phase has U letter nature. Actually, most pedestrians cross at red light in the first 4 seconds (20.5%), ant almost at the end of red-light phase interval at 55-59 seconds (19.2%) and 60-65 s (16.7%). It is interesting that after 35 s, percent of pedestrians who cross the street at red light significantly increases. Also, it is interesting that during 30-34 s of red light no one crosses the pedestrian crossing (last seconds of green light for vehicles going in direction towards centre of Belgrade, and if there is no vehicle in opposite direction pedestrians start to cross pedestrian crossing).

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\(^1\) Interpretation of Spearman’s correlation coefficient values range is taken from SPSS: Survival Manual by Jullie Pallant.

\(^2\) For calculation of Spearman’s correlation coefficient those who have 0 s waiting time are not being taken into calculation.
Female pedestrians are more likely to cross the street at the starting seconds of red light (0.4 s – 25.9%), while male pedestrians are more likely to cross red light during last seconds of red light phase (55-59 s – 26%). Finally, unsafe behaviour of pedestrians in group is visible when analysing time when they cross the street during red-light phase. Most pedestrian in group cross the street in first seconds of red light appearance (41.2%). All other pedestrians in group crossed street as soon as 35th second passed (23.5% in 35-39 s and 23.5% in 40-44 s).

Mann-Whitney Test actually shows that there is difference between genders when analysing “time after red light”, but that difference is very close to be rejected ($U = 488.2 = -1.885$, $p = 0.059$). However, hypothesis about difference of “times after red light” for alone pedestrians and pedestrians in group should be rejected – there is no difference ($U = 171.2 = -4.540$, $p < 0.001$). Finally, those result should be taken with care, because of small sample which can influence quality of given results (19 pedestrians in group who crossed street during red light an 62 alone pedestrian who crossed street during red light).

5. CONCLUSION AND PROPOSED MEASURES

As pedestrians, in general, want to cross where it is convenient (not safe) in order to get to destination with as little delay as possible it is very difficult to project measures to stop that unsafe behaviour. On the other side, 14.39% of pedestrians cross the street during red light interval, or 81 pedestrian in this research, which means 81 potential conflict situation which can end with traffic accidents. Male pedestrian are characterized by more risky behaviour. However, significant differences between alone pedestrians and pedestrians in a group could not be found.

Generally, pedestrian education campaigns have not been successful, and it has become axiomatic in several areas of road safety that public education is most effective when it signals
or supports a change in environment, such as enforcement campaign (Schonfeld et al., 2003). However, pedestrian fines are usually the lowest one, which makes no significant effect on their behaviour.

Effective deterrence of illegal behaviour requires a high perceived risk of detection, combined with a high perceived severity of the consequences, and swiftness and certainty in the application of those consequences.

Risky behaviour of pedestrian is not always cause of an accident, but it significantly increases their risk. The best way to access pedestrian safety is trough intensive campaign (which includes education and intensive enforcement) trough whole territory (not only one location). Before proceeding with campaign every pedestrian crossing location should be deeply analysed. Actually, there is possibility that inadequately set signal plan influences driver and pedestrian behaviour (small flow of vehicles in comparison with pedestrian flow, makes pedestrian cross street much more). Finally, there should be investigated option for countdown display installation, as some studies have proven their positive effect on pedestrian behaviour (Lipovac et al., 2013b).

6. LITERATURE