

1 **Analysis of Road User Behavior and Safety during New York City's**
2 **Summer Streets Program**

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1 **Abstract**

2 Automated computer vision video analysis techniques were used to analyze
3 video data during the operation of New York City’s Summer Streets Program at a
4 major signalized intersection. The main objectives of this study were to:
5 1) diagnose pedestrian and cyclist safety issues during the “shared space”
6 operation and 2) demonstrate the feasibility of the automatic extraction of road
7 user (e.g. pedestrian, runner, rollerblader, or cyclist) data required for
8 microscopic behavior analysis. Road users’ speeds and pedestrian gait
9 parameters (step frequency and step length) were automatically extracted and
10 analyzed. The results show that pedestrian walking speed was highest during the
11 Summer Street operation (1.49 ± 0.54 m/s) as they had more street space to use
12 and slowest during normal operations (1.30 ± 0.22 m/s). Bike speeds were low
13 during the Summer Streets event (3.62 ± 0.97 m/s), likely because of interaction
14 with pedestrians, but increased during normal traffic operations. Pedestrians
15 and cyclists moving in groups tended to be slower, confirming results found in
16 previous studies. The safety analysis was conducted using traffic conflict
17 techniques (TCT). It was observed that the lowest rate of conflicts between
18 pedestrians and cyclists and between cyclists was found to be during Summer
19 Streets operations. In addition, an analysis of spatial violations show that some
20 road users were not observing traffic rules in the transition period after Summer
21 Streets ceased to operate.

22 **Introduction**

23 Encouraging sustainable modes of transportation and exercise—such as walking,
24 rollerblading, jogging and cycling—is important to build healthy and livable
25 communities. Policies promoting non-motorized modes of travel and events
26 encouraging active lifestyles help motivating users to shift from motorized
27 transportation modes to other sustainable modes. Active transportation is a
28 simple way to increase the physical activity level of the population, contributing
29 to improvements to overall public health. However, transportation safety
30 problems are a serious concern for vulnerable road users. Vulnerable road users,
31 such as pedestrians and cyclists, are subject to higher safety risks and usually
32 represent the highest share of fatal road collisions [1]. They have higher per-mile
33 casualty rate than car travel, yet pose minimal risk to other road users. Overall,
34 traffic casualty rates are found to decline as walking and cycling increase in a
35 community because drivers are more cautious [2]. Safety experts study
36 pedestrian and cyclist behaviors and develop appropriate techniques to diagnose
37 pedestrian safety issues and recommend pedestrian safety improvements. To
38 enhance the safety of vulnerable road users, it is necessary to develop an
39 understanding of this behavior through developing better tools to study
40 vulnerable road user behavior.

41 In August 2008, New York City initiated the Summer Streets program. This event
42 opened Park Avenue from Brooklyn Bridge to Central Park (approximately 7
43 miles/11 km) to pedestrians, cyclists, rollerbladers, and joggers, and created
44 vehicle-free streets on three consecutive Saturdays from 7AM to 1PM to promote
45 sustainable forms of transportation. This annual event was modeled after other

1 car-free events from around the world, including Ciclovía in Bogotá, Colombia.
2 All activities at Summer Streets were provided free of charge and designed for
3 people of all ages and ability to share the streets respectfully [3], creating a
4 “shared space.”

5 In this study, video data was collected at a busy signalized intersection in New
6 York City (Park Avenue South and East 29th Street) on August 2nd, 2014 during
7 three operating periods: the Summer Streets event, the transition period from
8 Summer Streets to normal operation and the normal operation. The purpose of
9 this data collection is to demonstrate an automated methodology to diagnose
10 safety issues of non-motorized road users during a busy car-free “shared space”
11 environment. The potential for automatic extraction of non-motorized road
12 users’ data required to understand their behavior was also examined. In the past
13 few years, video data collection has been gaining wider acceptance as an
14 effective and practical data collection method that avoids problems associated
15 with manual data collection. Video sensors are effective in capturing and
16 analyzing vehicular, pedestrian, and bicycle traffic information. Due to the
17 significant advances in the computer vision field, it is possible to automatically
18 and accurately detect and track road users. This automatically collected and
19 analyzed data is more accurate than manually collected and analyzed data [4].

20 The main objectives of this study are:

- 21 1. Diagnose non-motorized road users’ safety issues during Summer Streets’
22 transition period and normal operation. Assess the road user safety issues
23 at the location and identify factors contributing to them. Traditionally,
24 road safety analysis has been dependent on statistical analysis of
25 aggregated collision data. The limitations of this approach are
26 summarized in [5]. To overcome these shortcomings, alternative
27 approaches to road safety have been developed, such as the use of the
28 traffic conflict technique (TCT) [[5], [6]]. In this study, the TCT was
29 applied to assess vulnerable road user’s safety during the three phases of
30 operation at the study location. The analysis was conducted using an
31 automated road safety analysis system [[7], [8], and [9]]. This system can
32 detect, track and classify road users as well as measure the severity of
33 conflicts for complex interaction.
- 34 2. Extract data of non-motorized road users, including pedestrians, joggers,
35 cyclists and other users (such as rollerbladers). Traditionally, pedestrian
36 and cyclist walking speed measurement and volume counts have been
37 considered the most important data for behavior analysis. With the
38 advancement of computer vision technology, studying the behavior of
39 vulnerable road users becomes more efficient. The automated video-
40 based system was used successfully in previous studies to automatically
41 collect pedestrian crossing speeds and volume data [[10], [11]] and
42 cyclist speeds and volume data [[12], [13]]. This study is unique in its
43 analysis as it demonstrates the applicability of the system to collect
44 pedestrian, rollerblader, joggers and cyclist data during a complex shared
45 space urban environment. Furthermore, pedestrian gait parameters, such

1 as step frequency and step length, were automatically extracted, which
2 can be used to provide better understanding of pedestrian behavior.

3 **Previous Work**

4 **Pedestrian and Cyclist Tracking**

5 The detection and tracking of different road users is a significant application in
6 computer vision technology. Compared to tracking vehicular traffic, tracking
7 smaller road users (such as pedestrians) is more difficult because of various user
8 sizes and their complex movements. Pedestrians, for example, are difficult to
9 track due to their frequent change in direction and other road users can easily
10 occlude them. Common problems with tracking cyclists and pedestrians also
11 include global illumination variations, shadow handling, and multiple object
12 tracking [14]. Different technologies are combined to increase the accuracy of
13 pedestrian and cyclist tracking [15], [16]. Enzweiler et al. [17] and Bertozzi et
14 al. [18] provide detailed reviews of different methods used to track and detect
15 pedestrians. A detailed methodology for detecting, tracking and classifying
16 bicycles from video scenes can also be found in [19] and [20]. A typical road user
17 detection and tracking sequence starts with object detection, hypothesis
18 generation, classification, and tracking.

19 **Conflict Analysis**

20 Recently, the TCT has been advocated as a promising approach of evaluating the
21 safety of road users from a broader perspective than relying on collision data,
22 which requires observing collisions for long periods of time. A traffic conflict is
23 defined as “an observable situation in which two or more road users approach
24 each other in space and time to such an extent that there is a risk of collision if
25 their movements remain unchanged” [21]. The objective of the TCT is to observe
26 and analyze the frequent traffic interactions and near misses between road
27 users. The validity of using traffic conflicts in safety studies has been established
28 through the investigating the relationship between conflicts and collisions in
29 recent studies [22], [23], and [24]]. There are a number of conflict indicators
30 proposed to measure the severity of a traffic conflict. In this study, the Time-To-
31 Collision (TTC) indicator was used, defined as “the time that remains until a
32 collision between two road users would have occurred if the collision course and
33 speed difference are maintained” [25].

34 **Speed and Gait Parameters**

35 Pedestrian and cyclist speed is considered an important parameter in
36 understanding road user behavior. For pedestrians, previous studies focused on
37 estimating pedestrian speeds to investigate the behavior of pedestrians in
38 different walking environments [e.g., [26]]. In addition, the effect of different
39 pedestrian attributes on walking speed (such as age, gender, and group size,
40 among others) has been investigated in several studies. For example, it was
41 found that single pedestrians have faster crossing speeds compared to
42 pedestrians walking in groups [26], [27]]. More recently, automated methods
43 using computer vision techniques calculate speed to study pedestrian behavior
44 [4]. There are gaps in the literature analyzing jogger and rollerblader speed,

1 mainly due to the lack of data of these road users. For cyclists, speed and
2 behavior analysis has been an active research topic recently, with cyclist speed
3 being studied within different route configurations. To overcome shortcomings
4 in manual methods, automated video analysis has become increasingly common.
5 One study using computer vision to analyze cyclist speed behavior found that
6 group size, travel path, lane position and helmet usage affect the cycling mean
7 speed [12].

8 Gait analysis has recently emerged as an important approach to understanding
9 pedestrian behavior, analyzing pedestrian step length and frequency. Hediye et
10 al. [4] conducted a study using computer vision techniques to collect pedestrian
11 gait parameters and speed data. Results of the study showed that the step
12 frequency and step length are influenced by factors such as crosswalk grade,
13 pedestrian gender, age, and group size. Hussein et al. [11] used computer vision
14 techniques to conduct a gait analysis showing that walking speed for a single
15 pedestrian is faster than those who walk in groups, males walk faster than
16 females with a longer step length and violators have higher walking speed, which
17 was dependent on step length, not step frequency.

18 Shared Space

19 Encouraging the mixing of slower speed pedestrians and cyclists with higher
20 speed vehicles in a “shared space” is a novel concept following previous
21 objectives of separating vulnerable road users from vehicles. A “shared space”
22 typically achieves this safely and efficiently by designing the road to reduce the
23 dominance of vehicular traffic by promoting pedestrian and cycling activity
24 while viewing the road as a “place,” in addition to its transportation mobility and
25 accessibility purpose. The theory of “shared space” requires multi-disciplinary
26 professions to collaborate in the development of transportation corridors, which
27 has been argued by many authors [e.g. [28], [29]]. There are gaps in the
28 literature with regards to safety studies of “shared spaces.” Kaparias et al. [30]
29 used a behavior analysis technique instead of a conflict analysis technique to
30 analyze the conduct of pedestrians and vehicles in “shared space,” and found an
31 increased confidence of pedestrians but an unchanged behavior in drivers.

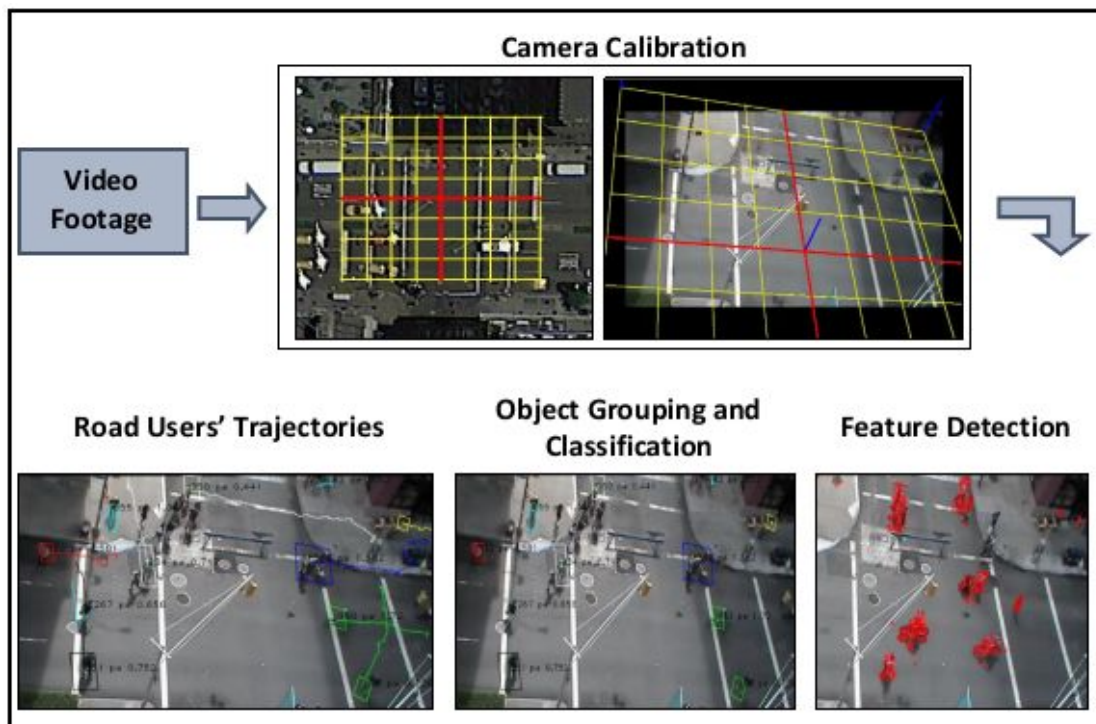
32 Ciclovía or Open Streets events have also become popular festivals, taking place
33 in “shared space” streets around the world. More than 80 North American cities
34 share their streets by offering regularly scheduled events drawing pedestrians
35 and cyclists to enjoy car-free streets [31]. Studies have documented the positive
36 effects of these events on physical activity, environment, social cohesion and
37 businesses in the area [e.g., [32], [33]], and are an ideal testing ground for what
38 can be implemented for future streets [34].

39 Methodology

40 This section describes the methodology used in this paper to analyze pedestrian
41 and cyclist safety and extract pedestrian speed and gait parameters. The three
42 issues discussed below are road user trajectory extraction, conflict analysis and
43 the estimation of road user speed and pedestrian gait analysis.

1 Road Users' Trajectory Extraction

2 The detection of road users from a video and the extraction of their trajectories
3 is achieved through an automated video processing system developed at the
4 University of British Columbia. As shown in Figure 1, the procedure starts with
5 the feature tracking step, in which discrete points (features) are tracked on
6 moving objects in the video scene. The system relies on the Kanade-Lucas-
7 Tomasi Feature Tracker algorithm to track moving features. The details of the
8 feature tracking process could be found in [35]. Next, features are grouped [29]
9 [9] [3] on their speeds, proximity and movement patterns to create one object.
10 The position of each object is tracked frame by frame to produce the road user
11 trajectory. These objects are classified into different road users, depending on
12 the classification methodology as described in [36]. However, a vital component
13 of the system is to relate the tracked trajectories in the video image coordinates
14 to their actual positions in the real world. This is done by creating a mapping
15 between the real world coordinated and the image space (camera calibration).
16 The camera calibration process is described fully in [37].



17
18 **Figure 1. Trajectory Extraction Process**

19 Conflict Analysis

20 The conflicts between road users in this study were extracted by predicting the
21 future positions of each pair of road user trajectories and examining the
22 probability of these predicted future positions to collide, in space and time, into
23 one another. Predicting the future positions of road users involve preparing a set
24 of prototypical trajectories from previously learnt motion patterns of road users.
25 Road user trajectories are then matched to these prototypes using the longest
26 common sub-sequence algorithm (LCSS) to provide a set of predicted future
27 positions with relative probabilities [8]. Details of the procedure are found in [7].

1 Typically, conflict indicators are used to measure the severity of the detected
2 conflicts. This study used the TTC indicator as a measure of conflict severity.
3 Only traffic conflicts with TTC less than 1.5 seconds was considered. TTC is
4 calculated for each frame between conflicting road users until they are no longer
5 on a collision course, and each conflict is associated with a set of TTC values. The
6 minimum TTC is then used to represent the overall severity of the conflict. TTC is
7 used for in this study for demonstration only. Other conflict indicators, such as
8 Post Encroachment Time (PET), could also be used. This procedure of conflict
9 analysis has previously been validated in [38].

10 Road Users' Speed and Pedestrian Gait Parameters Analysis

11 After a road user trajectory is extracted from the video scene, the road user
12 speed profile can be easily produced. The average speed of any road user is
13 estimated directly from the speed profile as the average speed through the
14 lifetime of the trajectory. For the automatic extraction of pedestrian gait
15 parameters, step frequency can be computed automatically by analyzing the
16 speed profile of each pedestrian [39]. It was observed that a pedestrian speed
17 profile typically shows cyclic fluctuations repeated continuously over time.
18 Hediye, et al. [39] determined that each fluctuation in a given speed profile
19 corresponds to a new step taken by the pedestrian. Based on these observations,
20 the pedestrian speed profile can be seen as a time-series. Identifying the step
21 frequency involves evaluating the power spectral density (PSD) [[1], [39]] of the
22 speed signal to detect the dominant periodicity in the speed profile. Once the
23 step frequency and walking speed of a pedestrian is determined, the average
24 step length can be calculated from the fundamental linear relationship:

$$25 \text{ Walking Speed} = \text{Step Frequency} \times \text{Step Length} \quad (1)$$

26 Data Collection and Study Location

27 Video data was collected from the intersection of Park Avenue South and East
28 29th Street in New York City. The analyzed date could be classified into three
29 phases: First, 30 minutes of data covering the Summer Streets operations where
30 both intersecting streets were closed for motorized vehicles. The second phase
31 covers the transition period starting from the moment the streets are reopen for
32 traffic until road users adapt to the regular operation The transition period was
33 estimated to be 15 minutes based on the observed road users' behavior in the
34 video scene. Finally, the third phase covers 30 minutes of data of the regular
35 operations of the intersection. During regular operations, Park Avenue South is a
36 two-way north-south roadway with two moving lanes, a raised median, and a
37 parking lane in each direction (total roadway width = 69 feet or 21.0 meters).
38 East 29th Street carries one-way westbound traffic (total roadway width
39 approaching Park Avenue South North Bound = 30 feet or 9.1 meters). The
40 intersection is controlled by a pre-timed signal (cycle length = 90 seconds). Data
41 used in this study was collected on August 2nd, 2014, from 11:45 AM to 2:30 PM.

1 **Summary of Findings**

2 **Road Users Count**

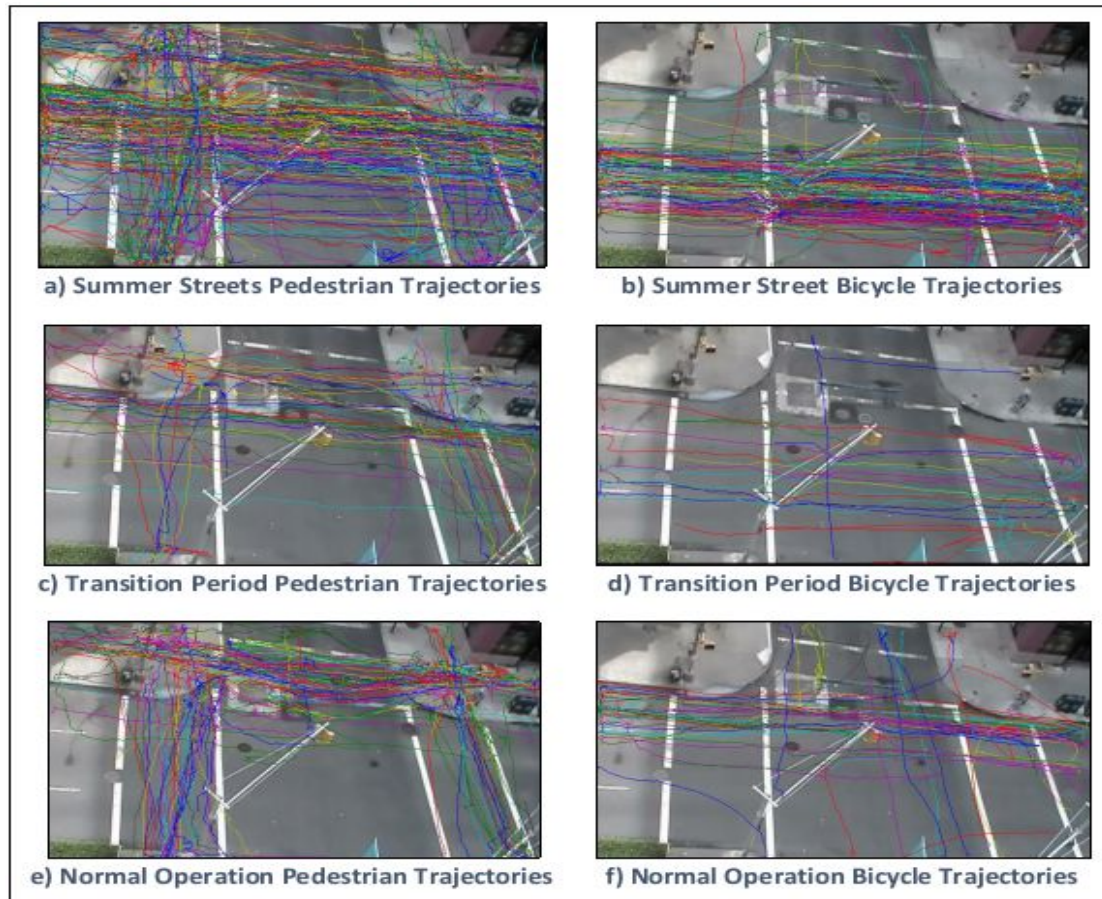
3 Table 1 summarizes the count of different road users during each of the three
4 phases considered for the analysis. Counts are reported per 15 minutes for
5 consistency as the transition period was only 15 minutes.

1 **Table 1: Road users count for each period**

Road user	Count (Per 15 minutes)		
	Summer Streets	Transition period	Normal operation
Pedestrians	560	398	384
Bikes	230	83	29
Vehicles	0	161	236
Child, bike	10	0	0
Baby carriage	6	0	0
Rollerblade	6	1	0
Jogger	49	4	2

2 **Road User Trajectories**

3 Road user trajectories were extracted according to the methodology described
 4 earlier. Figure 2 shows the spatial distribution of the pedestrian and bicycle
 5 trajectories for each of the three time periods considered. As shown in the figure,
 6 pedestrians use the full width of Park Avenue during the summer street
 7 operation (Figure 2-a). After the summer street operation was terminated,
 8 pedestrians start to shift towards the crosswalks during the transition period
 9 until the spatial distribution of their trajectories get back to normal operation
 10 configuration (Figure 2-e). However, during the transition phase (Figure 2-c),
 11 many trajectories were observed in the middle of Park Avenue, which can be
 12 considered as a violation event. This indicates that the transition period
 13 represents a hazard to pedestrians as they are not fully aware that the summer
 14 street operation has ended, which may lead to serious conflicts with other
 15 motorized road users using the roadway. Similar situations were noticed for
 16 bikes despite the absence of bike infrastructure at the intersection. Cyclists ride
 17 their bikes along Park Avenue during Summer Street operation (Figure 2-b),
 18 then move to the right side of the road when the event is over (Figure 2-f). The
 19 problem again appears during the transition period, when many bikes are still
 20 using the full width of Park Avenue despite the presence of vehicles in the street.
 21 These observations show that the transition period is a time where vulnerable
 22 road users have a higher risk of being involved in serious conflicts with
 23 motorized road users due to their non-compliance to traffic regulations.

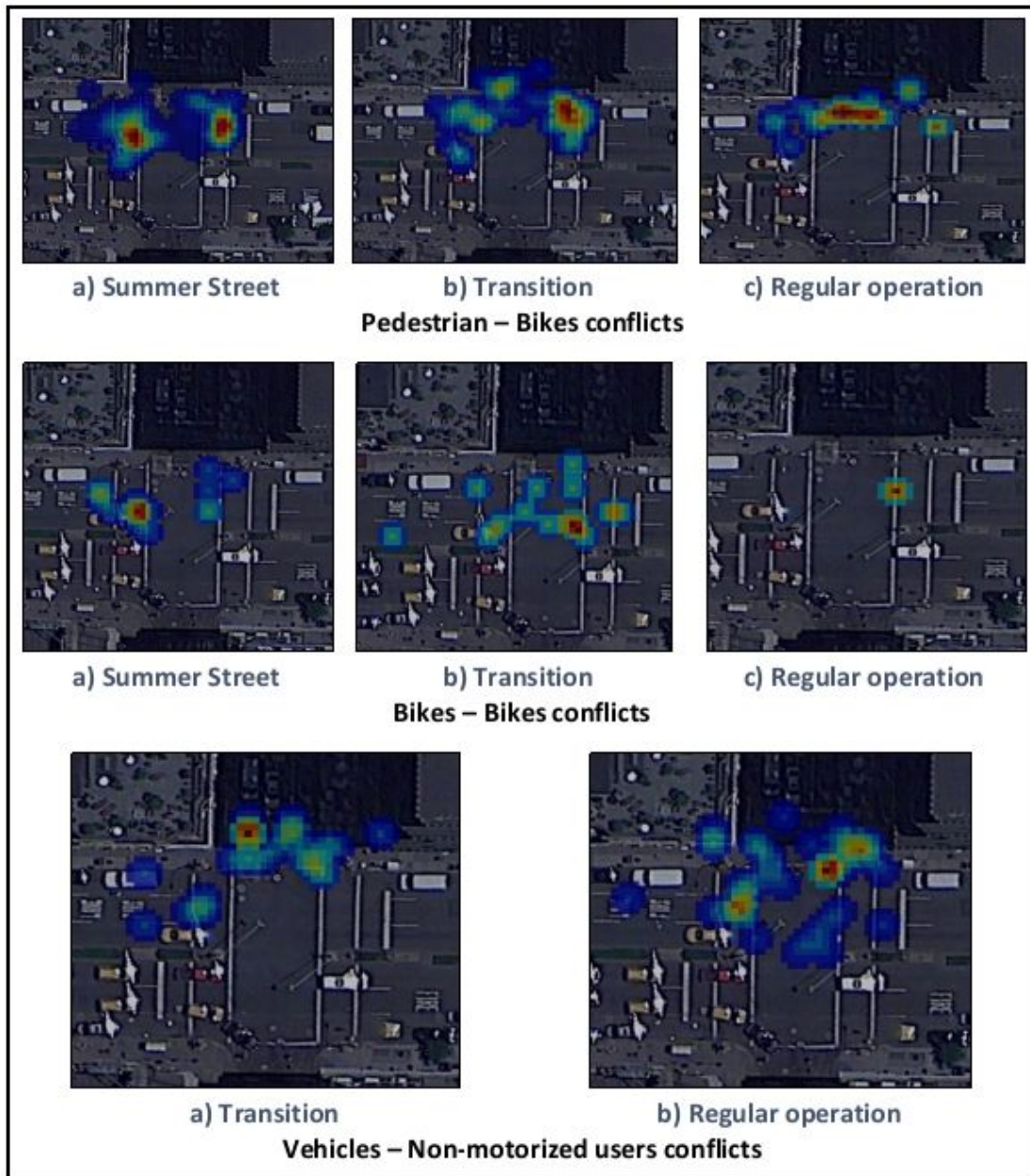


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Figure 2. Spatial Distribution of Road Users' Trajectories

3 **Traffic Conflicts**

4 TCT was applied to investigate the severity and frequency of interactions
 5 between different road users. Three conflict classes were extracted: conflict
 6 between bikes and pedestrians, conflicts between bikes and other bikes, and
 7 conflicts between motorized vehicles and all non-motorized road users.
 8 Extracted conflicts were classified among the three operational periods: Summer
 9 Street, transition period, and normal operation. Figure 3 shows the heat maps of
 10 automatically identified conflicts of the three classes considered while Table 2
 11 summarizes the number of conflicts for each period and collision type.



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Figure 3. Heat Map of Road Users' Conflicts

3 **Table 2: Number of TTC events for each period and collision type**

Class	TTC events (Per 15 minutes)		
	Summer Street	Transition period	Normal operation
Pedestrian - Bike	127	59	26
Bike - Bike	16	14	1
Motorized Vehicle - Non motorized	4	24	43

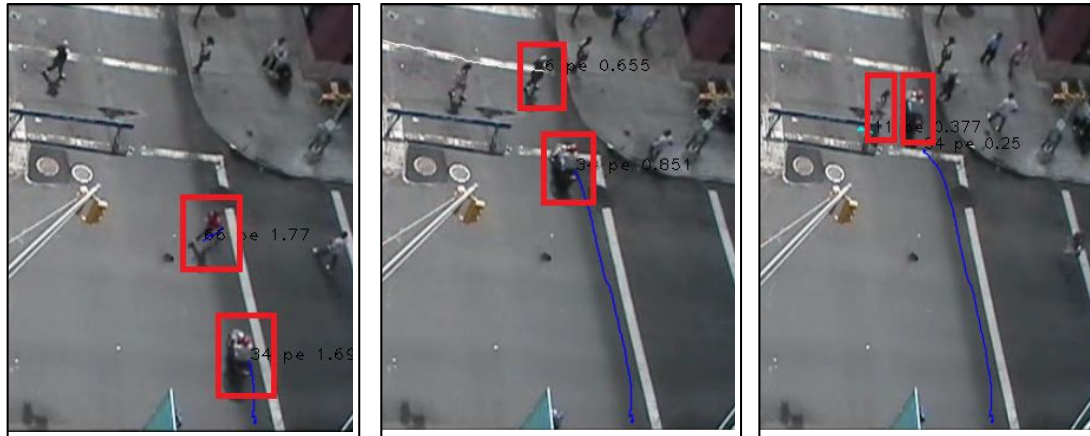
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5 The results show a large number of conflicts between pedestrians and bikes
 6 during the Summer Street period (127 conflicts/15 minutes) and these conflicts
 7 are spread almost over the whole study area as shown in Figure 3 (top left
 8 image) a. This large number of conflicts is difficult to compare since there are no

1 published studies examining pedestrian–bicycle conflicts in a shared space
2 environment. However, this large number of conflicts was expected because the
3 Summer Streets event drew a large number of pedestrians that used the full
4 width of Park Avenue to walk. In addition, bikes have to navigate through the
5 crowds creating many conflicts with pedestrians. The number of pedestrian–
6 bicycle conflicts was reduced significantly in the transition period and the
7 normal operation period afterwards. As well, conflicts began to concentrate
8 around the crosswalks instead of the whole space, as it appears in Figure 3 (top
9 right image). However, the relatively large number of conflicts in the transition
10 period (59 conflicts in 15 minutes) and their spatial distribution (conflicts
11 spread throughout the study space) suggests that the transition between
12 Summer Streets and normal operation represent a hazardous period to road
13 users as they are not yet complying to the traffic rules. This was the reason
14 behind the presence of traffic police officers and traffic control agents to help
15 direct traffic during the transition.

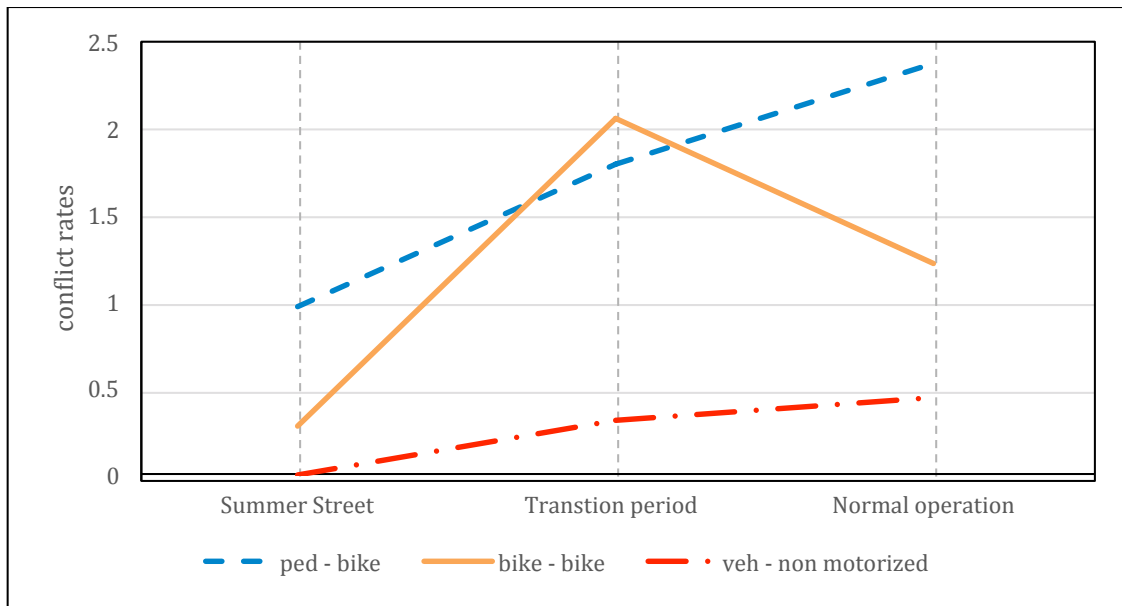
16 Conflicts between bikes were almost constant during the Summer Streets and
17 transition periods despite the fact that the number of bikes during the transition
18 period was significantly lower compared to during Summer Streets, as shown in
19 Table 1. This suggests that the transition period reveals many road users’ non-
20 compliance to traffic rules, which lead to higher rates of conflict. This also shows
21 that when organizing “shared space” events, the transition period should be
22 carefully planned. The conflicts between bikes were not notable during normal
23 operation, due to the fact that a smaller number of bikes use the intersection
24 during that period.

25 Conflicts between vehicles and non-motorized users were not expected during
26 the Summer Streets period. However, a violation was observed during the
27 Summer Streets event where a motorcycle passed through East 29th Street
28 causing four conflicts with non-motorized road users (Figure 4). During the
29 transition period, conflicts between motorized and non-motorized users mainly
30 occurred at the east crosswalk (crossing East 29th Street), as shown in Figure 3
31 (the bottom left image). This is mainly because vehicles were allowed to move
32 along East 29th Street for some time before Park Avenue was open for traffic. As
33 such, many transitional period conflicts occur between the westbound traffic on
34 East 29th Street and pedestrians and bikes on Park Avenue. The number of
35 conflicts rises to 43 conflicts per 15 minutes during the normal operation phase,
36 which is very high and agrees with reported results [11] that intersections in
37 New York City have high conflict rates between vehicles and non-motorized
38 users.



1 **Figure 4. Motorbike Violation Event during Summer Streets and Associated**
 2 **Conflicts**

3 Furthermore, as the number of road users varied significantly among the three
 4 periods analyzed, it is important to investigate the conflict rates in addition to
 5 the conflict frequencies discussed above. Figure 5 presents the different
 6 observed conflicts normalized by the number of conflicting road users of each
 7 category. Although the number of “pedestrian–bicycle” and “bicycle–bicycle”
 8 conflicts during the Summer Street period were significantly higher than the
 9 other two periods, the conflict rates were significantly lower. This indicates that
 10 the Summer Street period is the safest period for road users in terms of serious
 11 conflicts with other road users. Despite many interactions observed during
 12 Summer Streets, road users make use of the larger space available during
 13 Summer Streets where they can navigate freely and avoid serious conflicts,
 14 especially as their speed are slower during this period as will discussed in details
 15 later in the paper. The “bicycle–bicycle” conflict rate recorded its peak during the
 16 transition period, which serves as confirmation of safety issues during the
 17 transition period and that it requires special focus when planning such events. As
 18 well, although the conflict rates for “vehicle–non-motorized users” and
 19 “pedestrian–bicycle” conflicts were higher during the normal operation phase,
 20 the rates observed during the transition phase were still high and very close to
 21 those observed during the normal operation. The difference in observed rates
 22 between the two periods was about 24% and 28% for “pedestrian–bicycle” and
 23 “vehicle–non-motorized users” conflicts, respectively, despite the presence of a
 24 police officer to regulate traffic during the transition period.



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Figure 5. Conflict rates

3 Road Users' Speed and Pedestrian Gait Analysis

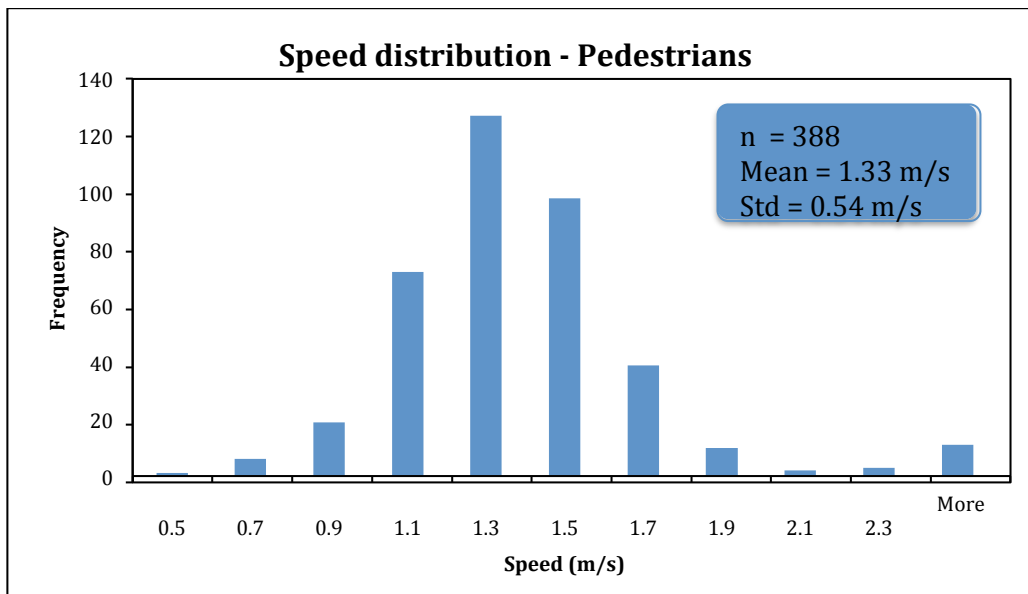
4 Pedestrians and Joggers' Speed

5 Speeds of non-motorized road users (pedestrians, cyclists, joggers, and
6 rollerbladers) were automatically extracted following the methodology
7 described earlier. The distribution of both pedestrians' and joggers' speed is
8 presented in figure 6. The mean and standard deviation for pedestrian and
9 jogger speed was found to be $(1.33 \pm 0.54 \text{ m/s})$ and $(2.81 \pm 0.54 \text{ m/s})$,
10 respectively. The variation of pedestrian speed during the three time periods of
11 the festival was investigated. As shown in Table 3, pedestrians walked faster
12 during the Summer Streets event and their speed reduced during the following
13 periods. One hypothesis that can explain this is that they may be taking
14 advantage of the "shared space" to move freely all over the width of the
15 intersecting streets, while during the normal operation phase pedestrians have
16 limited space (the sidewalks and crosswalks), which limit their speed, especially
17 with the high density of pedestrians in the study location. Table 3 also shows the
18 variation of pedestrian speed with group size. As shown in the table, the walking
19 speed decreases as the group size increases which agrees with results reported
20 in several previous studies [e.g., [11], [39], and [40]]. Unfortunately, the
21 investigation of jogger's speed variation during different phases and with group
22 size was not possible, as joggers were only present during the Summer Street
23 event and only ran individually.

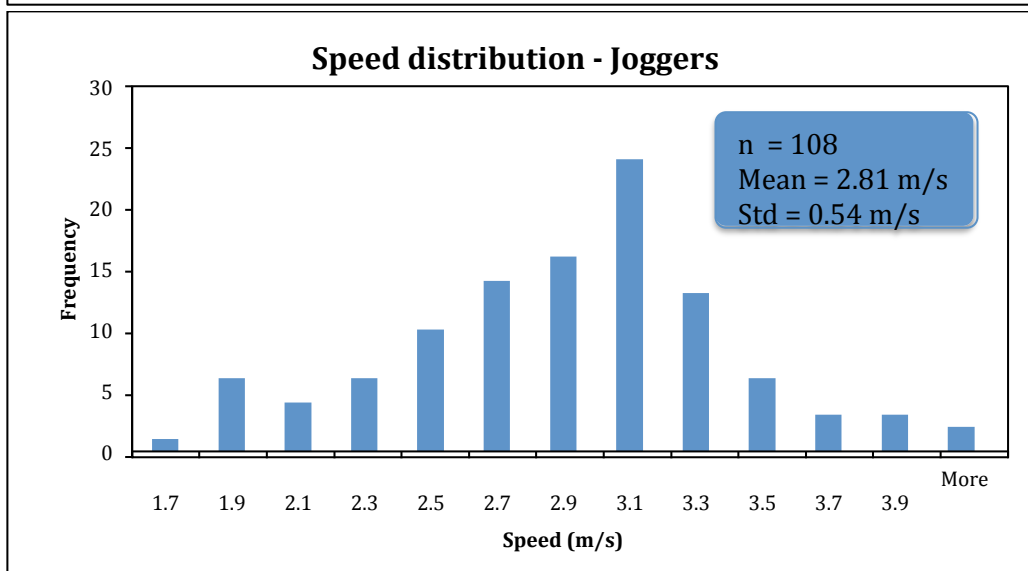
1 **Table 3: Summary of Pedestrian Speed**

	Group Size			Analysis time			Total
	Single	Size = 2	Size = 3 +	Summer Streets	transition period	normal operations	
Count	148	174	66	220	58	92	388
Average speed (m/s)	1.38	1.33 (0.21)	1.24 (0.10)*	1.49	1.39 (0.17)	1.30 (0.21)	1.33
Standard deviation (m/s)	0.58	0.54	0.42	0.74	0.73	0.47	0.54

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Figure 6. Speed distribution of pedestrian and joggers

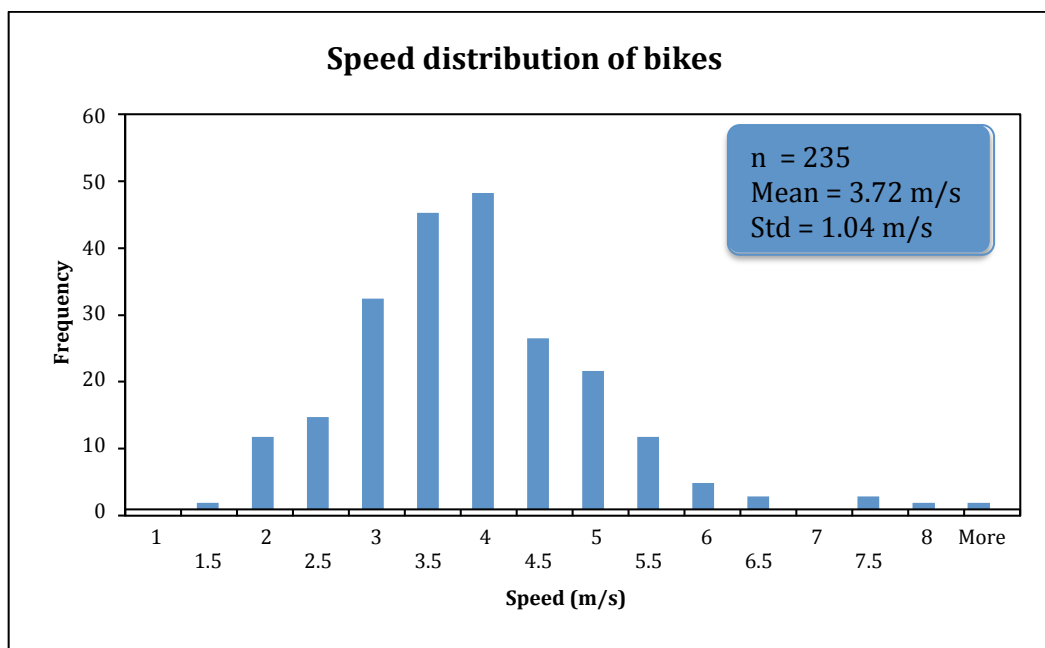
1 Cyclists' Speed

2 The distribution of both cyclists' speed is presented in figure 7. The mean and
 3 standard deviation for cyclists' speed was found to be $(3.72 \pm 1.04 \text{ m/s})$ with a
 4 minimum speed of 1.09 m/s and maximum speed of 8.30 m/s. The variation of
 5 cyclists' speed during the three time periods of the festival were investigated. As
 6 shown in Table 4, bike speeds were very low during the Summer Streets event
 7 and increased during normal traffic operations. These findings were expected
 8 because the "shared space" of Summer Streets allowed cyclists to relax and cycle
 9 slowly, as oppose to normal operations when cyclists were traveling adjacent to
 10 fast car traffic. In addition, the presence of pedestrians in the street during the
 11 summer street event forces bikes to slow down to avoid collision with
 12 pedestrians and to navigate through the crowds. The effect of group size on
 13 biking speeds was also investigated. As was expected, when the cyclists' bike in
 14 groups, their speed on average becomes slower. Groups of cyclists were
 15 observed only during the Summer Streets operations, when the "shared space"
 16 allowed them to take the road and cycle at slower speeds in larger groups. Group
 17 cycling is common in bicycle-friendly cities where larger proportions of cyclists
 18 and separated bicycle infrastructure allow cyclists to feel safe and relaxed
 19 cycling in groups. This was the first study to automatically investigate speeds of
 20 groups of cyclists.

21 **Table 4: Summary of Cyclist Speeds**

	Group Size		Analysis time			Total
	Single Bike	Size = 2+	Summer Streets	Transitio n Period	Normal Operations	
Count	101	134	150	34	28	235
Average speed (m/s)	3.93	3.56 ** (.01)	3.62	3.86 (0.13)	4.17 (0.2)	3.72
Standard deviation (m/s)	1.43	0.79	0.97	1.17	1.57	1.04

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Figure 7. Speed distribution of bikes

Rollerbladers' Speed

The concept of Summer Streets encourages alternative road users, such as rollerbladers, to utilize and share the road. Although only 13 rollerbladers were observed during the analyzed data, we think it is worth reporting the values obtained as a reference. Further analysis on a larger data set is highly recommended. The mean speed, standard deviation, and minimum and maximum speed of rollerbladers are summarized in Table 5.

Table 5: Summary of Speed Distribution for Rollerbladers

Count	13
Average speed (m/s)	3.13
Standard deviation (m/s)	0.69
Max (m/s)	4.39
Min (m/s)	2.48

Road users' speed compared to FHWA study

The speed of different road users during summer street operation were compared to the Federal Highway Administration's *Shared Use Path Level of Service Calculator* [41], presented in Table 6. It was observed that the average speeds for road users during Summer Streets operations are slower than the typical speeds for road users on shared paths. This is most likely because the festival encourages a larger group of people to enjoy "shared spaces" and road users may be slowing down to enjoy the Summer Streets.

Table 6: Comparison of road users' speed during Summer Street and values extracted from shared use path LOS calculator

Road User	Summer Streets average Speed (m/s)	Shared Use Path LOS Calculator average Speed (m/s)
Pedestrians	1.38	2.91
Bikes	3.93	5.72
Rollerbladers	3.13	4.52

Pedestrian Gait parameters

Pedestrian gait parameters (mainly, step frequency and step length) were automatically extracted and compared to the findings reported from the pedestrian gait analysis studied at Park Avenue South and East 28th Street during typical New York City street operations in [11]. The frequency and length parameters were found to follow the normal distribution with 95% confidence, as confirmed by the χ^2 test. Step frequency and step length were found to be $(1.8 \pm 0.17 \text{ Hz})$ and $(0.7 \pm 0.116 \text{ m})$, respectively. Both the step frequency and lengths were smaller compared to values extracted from typical New York City street operations reported in [11] (reported step frequency in this study was $1.96 \pm$

1 0.17 Hz and step length was 0.75 ± 0.14 m). These differences are due to the fact
2 that Summer Street data is collected on pedestrians in a “shared space”
3 environment, while the New York City data is collected during peak hour normal
4 operations. The “shared space” creating a sense of place on the street and the
5 recreational nature of the festival is hypothesized as the reason for smaller
6 pedestrian gait parameters during Summer Streets.

7 **Conclusions and Future Research**

8 Seventy-five minutes of video data were collected at a signalized intersection of
9 Park Avenue South and East 29th Street in New York City during three different
10 periods of operations: Summer Streets “shared space” operations, the transition
11 period, and normal operations. Analysis was conducted on video data by means
12 of computer vision techniques using an automated system developed at the
13 University of British Columbia. The main purposes of the analysis are: 1) to
14 assess pedestrian and cyclist safety issues at the intersection during the “shared
15 space”, transition, and normal operations and to identify factors that contribute
16 to the safety issues; 2) to demonstrate the utility of the automatic extraction of
17 pedestrian, cyclist, rollerblader, and runner data to better understand road user
18 behavior, speed, and pedestrian gait parameters (step length and step
19 frequency) during the “shared space,” transition, and normal operations periods.

20 TCT were adopted to diagnose road user safety at the intersection during the
21 three periods. The study identified pedestrian–bicycle, bicycle–bicycle, and
22 vehicle–non-motorized conflicts during the Summer Streets operation, transition
23 period, and normal operation time periods. Trajectories of pedestrians and
24 cyclists show that the road users were not observing traffic rules in the
25 transition period and normal operations, as they were spatially distributed
26 through the street. The lowest rate of conflicts between pedestrians and cyclists
27 and between cyclists was found to be during Summer Streets “share space”
28 operations. It is hypothesized that this is due to cyclists slowing down because
29 they do not need to compete with vehicle traffic, as well as the street being used
30 recreationally during the festival. It is recommended that North American cities
31 take the opportunity to implement “shared spaces” to create safer streets for
32 vulnerable road users. Many European cities have examples of place-making and
33 improving safety through implementing “shared spaces.” In the meantime, open
34 street festivals that close roads to vehicular traffic encourage sharing space,
35 active lifestyles, and sustainable living.

36 Relatively large number of pedestrian–bicycle conflicts were observed in the
37 transition period (59 conflicts in 15 minutes) and bicycle–bicycle conflicts (14
38 conflicts in 15 minutes) and their spatial distribution (conflicts spread
39 throughout the study space) suggests that the transition between Summer
40 Streets and normal operation represent a hazardous period to road users as they
41 are not yet complying to the traffic rules. This shows that when organizing
42 “shared space” events, the transition period should be given more thought.

43 In addition to conflict analysis, road user (pedestrian, runner, cyclist, and
44 rollerblader) speeds and pedestrian step frequency and step length were
45 automatically extracted. The parameters were found to follow the normal

1 distribution with 95% confidence, as confirmed by the χ^2 test. Comparing
2 Summer Streets operations to typical New York City street operations, both the
3 pedestrian step frequency and lengths were smaller. The “shared space” creates
4 a sense of place on the street and recreational nature of the festival is
5 hypothesized as the reason for smaller pedestrian gait parameters during
6 Summer Streets. Results show that pedestrians were fastest during Summer
7 Street operations (1.49 ± 0.54 m/s) and slowest during normal operations (1.30
8 ± 0.22 m/s). These results show that pedestrians may be taking advantage of the
9 “shared space” festival to get exercise. The results for different pedestrian group
10 sizes of singles, two pedestrians and three pedestrians were found to be ($1.38 \pm$
11 0.34 m/s), (1.32 ± 0.30 m/s) and (1.24 ± 0.18 m/s), respectively, show that as
12 group sizes become larger, pedestrians walk more slowly. This study was the
13 first to automatically extract rollerblader speed and found it to be (3.12 ± 0.69
14 m/s), however due to small sample size ($n=13$), further analysis is
15 recommended.

16 For cyclists, the results show that the “shared space” allowed them to cycle
17 slower at speeds of (3.62 ± 0.95 m/s) than normal operations where cyclists
18 traveled adjacent to vehicle traffic at speeds of (4.17 ± 2.46 m/s). The results also
19 showed that as cyclist group sizes became larger, the cyclists on average were
20 slower. Group cycling is common in bicycle-friendly cities with separate bicycle
21 infrastructure, and it is a good indicator of a positive safety environment. This
22 was the first study to automatically extract groups of cyclists, and further study
23 on this topic is recommended.

24 Future work includes analyzing additional video data of “shared space” road user
25 behavior and conflict analysis, calculating other conflict indicators (Post
26 Encroachment Time, etc.), recommending specific safety countermeasures to
27 design the optimal “shared space” and potentially conducting a before and after
28 safety evaluation of the implemented “shared space.” More data is required to
29 come to any conclusions about the speed and behavior of rollerbladers, groups of
30 pedestrians, and groups of cyclists. To better understand the safety and road
31 user behavior of “shared spaces” it is important to analyze other similar
32 environments—such as pedestrian-only streets, multi-use pathways, and Open
33 Street events.

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