THE USE OF CELLULAR TMSI/BLUETOOTH TECHNOLOGY FOR TRACKING PEDESTRIAN MOVEMENT AT A MASS EVENT: A PILOT-STUDY UNDERTAKEN AT THE CAPE TOWN STADIUM

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ABSTRACT

In this paper, proximity-based Temporary Mobile Subscriber Identity (TMSI) tagging and Bluetooth tracking is postulated as an efficient and effective methodology for analyzing the routing dynamics of spectator movements around the Cape Town stadium both before and after a mass participation event. A case pilot-study of the "Coldplay" music concert event undertaken by Path Intelligence Ltd (a UK-based company) on 5 October 2011 (with 60,000 spectators attending the concert) is described in detail. The results of this study will give an indication of the added value of the methodology for the various stakeholders hosting and managing the event and provides valuable input towards the feasibility study for provision of a proposed new pedestrian bridge across the Western Boulevard at Portswood Road.

By covering seven locations within the stadium study area with receiver units with a further two units located at the BRT and rail station in the Cape Town CBD, the study was able to extract individual pathway trajectories generated by detected spectators. Apart from generating clear statistics such as pedestrian routing, the analysis revealed other valuable outputs such as pedestrian counts, travel times, fan-walk versus BRT modal split etc.

The paper concludes that TMSI/Bluetooth tracking offers significant advantages for tracking pedestrians at mass participation events and outlines some shortcomings and remaining deficiencies identified during the pilot-project experience.

1. INTRODUCTION

The tracking and analysis of large volumes of pedestrian movements has become a major topic of interest triggered by the widespread adoption of location-aware devices and associated technologies. To date, video surveillance, on the basis of closed circuit television (CCTV), has been the customary approach to capture human motion in crowded environments. Technological advances in the last decade has, however, led to a large number of distinct research topics related to video surveillance, including crowd density estimation, crowd behaviour monitoring and face recognition. However, despite substantial progress made in recent years, the use of video data to track individual movements within crowds remains a challenging task, particularly in terms of counting and distinguishing between individuals in a crowd, due to occlusion (Teknomo et al. 2001). Other tracking methods involve Bluetooth as the only tracking method (Versichele et al. 2011) but sample sizes are dependent on tracked devices being enabled (typically less than 10% of the population being tracked). Active cell-phone tracking by means of sending blind SMS's (Short Message Service) or "pinging" users has been tested at an event by Schmitz and Cooper (2011), but the system requires user consent and has accuracy issues in areas of congestion.

In response to these issues, and given the ubiquity of mobile phones, passive TMSI tagging, together with Bluetooth tracking, is proposed as a simple and low-cost alternative for identifying spatial movement of crowds. The devices are tracked by reconstructing their TMSI addresses that gets broadcasted in the discovery process. Because the TMSI address is not fixed (i.e. TMSI addresses changes with time), it cannot be linked to any personal information, such as names or a cell number. Since tracked individuals remain anonymous, potential privacy infringements are avoided. Also, because TMSI/bluetooth tracking allows for non-participatory, unannounced and simultaneous tracking of a large number of individuals, it is particularly useful to study pedestrian flows at mass events. Despite its potential, only permanent indoor commercial applications within shopping malls using this technology.

The case study experiment was carried out at the Coldplay concert hosted at the Greenpoint stadium on 5 October 2011, attracted approximately 60,000 spectators, which was challenging in terms of crowd size and spatial extent of the study area. The aim of this case study was to explore the routing dynamics of arriving and departing spectators prior and after the event respectively, specifically with reference to the routes selected for journeys, in order to assess the feasibility of providing a pedestrian bridge across the Western Boulevard at Portswood Road.

This paper aims to expose this tracking technology by reporting on the event using TMSI and bluetooth as a tracking technology. The remainder of the paper is organised as follows: Chapter 2 gives a brief description of TMSI/bluetooth as a tracking technology. Chapter 3 describes the background and experimental design of the case study and in Chapter 4 the results of the study are presented. Finally, the results are contextualised and an argument is presented why TMSI/bluetooth tracking has the potential to become a valuable methodology for studying the dynamics associated with mass events and some of the shortcomings of the technique is outlined in Chapter 5.

2. TMSI/BLUETOOTH AS A TRACKING TECHNOLOGY

2.1 Working Principle

The system passively tracks GSM (Global System for Mobile Communications) and Bluetooth-enabled mobile phone signals using new technology and enables the anonymous movement of specific individuals to be followed throughout the target area.

The TMSI is the identity most commonly sent between the cell phone and the GSM network. It is a randomly allocated number, which is given to the cell phone every time the cell phone does a location update procedure. The network can also force the mobile to accept a new TMSI at any time. These procedures make it difficult to trace cell phones, except for brief periods.

2.2 Equipment

Figure 1 shows the hardware components used in this pilot project. The standard enclosure for the antennas is shown below (although other enclosures, such as a domes can be utilized depending on the environment). The equipment can either be installed as a permanent solution where it is affixed to walls or ceilings of existing sites, or alternatively as a temporary setup. For the purposes of the Coldplay concert, the equipment was temporarily mounted high up on lamp posts, which provided added security and necessary electrical power.

(a.) Antenna Box enclosure

(b.) Data Receiver enclosure

Figure 1: Permanently installed hardware

The smaller antenna box shown in Figure 1(*a*), with dimensions 310 mm x 200 mm x 80 mm, is usually deployed in passenger areas where the antennas can freely monitor the radio frequency signals in that area. This enclosure does not require power but needs to be cabled to the receiver enclosure (with a maximum cable run of up to 10 m) and can be mounted on any suitable wall.

The receiver enclosure, shown in Figure 1(*b*), with dimensions 393 mm x 342 mm x 195 mm, is cabled to the antenna box but is placed out of sight of pedestrians or the general public, usually in service corridors or above false ceilings. This enclosure nevertheless requires power and cannot be located in a completely sealed area as it requires a degree of ventilation.

2.3 Privacy

The tracking system detects transmissions from cell phones and locates those cell phones in 3D space. At no time is any personal information intercepted including cell phone numbers. The information collected does not allow for the identification of individuals. The surveillance procedure, therefore, does not contravene the South African "*Access to Information and Protection of Privacy Act*", Act 5/2002 (amended Act 5/2003), since "personal information is not collected" (Government Notice 2003).

3. BACKGROUND AND EXPERIMENTAL DESIGN

3.1 Description of the Event and Study Area

The Coldplay music concert took place at the Cape Town (Greenpoint) Stadium on 5 October 2011 between 20:00 and 22:00. Whilst the main concert started at 20:00, several curtain raiser performances were scheduled starting at 18:00. Whilst determining spectator numbers is relatively simple from ticket sales, a study to determine how the spectators arrive and depart from the stadium, including routing was the primary objective. The resulting lack of quantitative routing data was a major shortcoming towards the identification of spectator movement dynamics. Other than stadium ticket sales and the use of video technology by the Metro police and Disaster Management Departments for crowd and disaster management control purposes, little is known about the general movement patterns of the spectators within and to the stadium precinct. The tracking study proposed to highlight the potential of TMSI/bluetooth tracking for understanding such crowd dynamics and thereby, significantly improve the quantitative OD-routing data.

Because of the large size of the stadium precinct, mobility issues regarding the movement of visitors to and from the event are important. Consequently, the precinct study area also focused on the BRT station and the local pub/restaurants along Portswood Road. A general overview of the study area is depicted in Figure 2. A summary of the different locations that were covered with the scanners is also shown in the figure and explained in the next section.

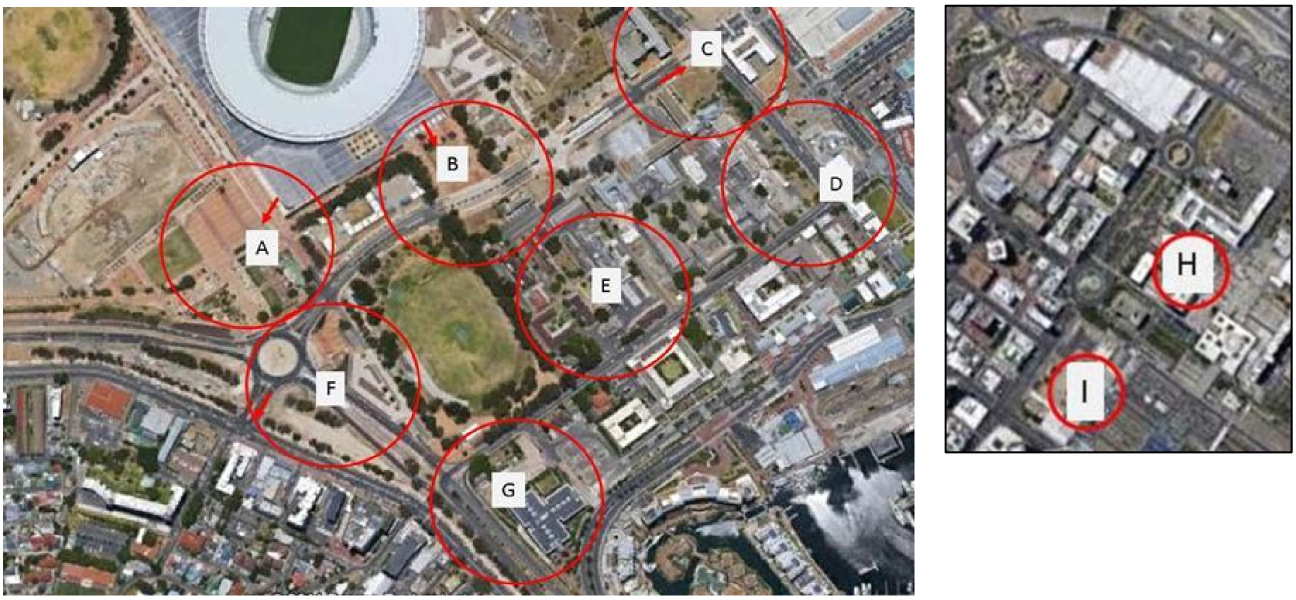


Figure 2: Overview of the precinct study area and location of TMSI scanners

3.2 Selection of Scanner Sites

Given the limited 100 m radius range of the TMSI scanners and the size of the precinct area, a full coverage of the entire study area was impossible from a practical point of view. Instead, a careful selection of strategic coverage sites was made after consultation with City stakeholders with the purpose of collecting as many significant individual movements as possible. This is particularly important as data tracking is recorded in terms of the scanner ID (i.e. proximity based) and not the co-ordinate trajectory of the individual. The spatial distribution of the selected locations is depicted in Figure 2 showing the nine strategic locations covered. In order to capture movements entering/exiting the stations, scanners were located at the stadium access gates (scanners A and B, refer to Figure 3(*a*) and (*b*) respectively).

To cover routes to and from the Waterfront, scanners were located at location C (viz corner of Granger Bay Blvd and Somerset Road, see Figure 3(*c*)), D (Somerset Road) and

E (Fort Wynyard Road, see Figure 3(*d*)). To identify spectators using the BRT service, scanner F was located within the station facility. Scanner G (see Figure 3(e)) was located on the corner of Portswood and Western Boulevard Drive to specifically identify spectators using the fan walk or frequenting the local restaurants/pubs.

All scanners were operational for the entire duration of the event from 16:00 to 01:00 and were equipped with 3G GSM data transmission cards that continually transmitted real time data to recording devices in the UK. A backup hard drive was also located on each of the TMSI devices as a secondary backup.

(a.) Scanner A

(b.) Scanner B

(c.) Scanner C

(d.) Scanner E

(e.) Scanner G

(f.) Scanner H

(g.) Scanner F

(h.) Scanner I

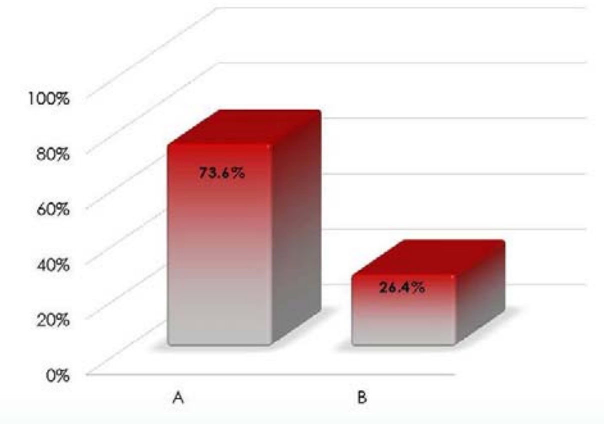
In order to identify rail, BRT users, additional scanners where placed at location H at the Civic Centre and location F at the stadium (see Figure 3(*f*) and 3(*g*) respectively) and location I at the station (see Figure 3(*h*)).

4. TRACKING RESULTS

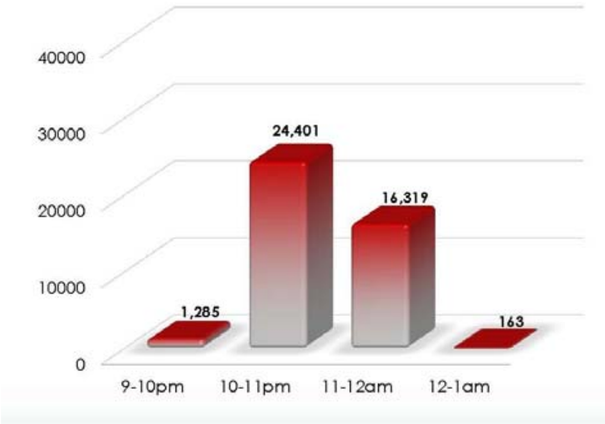
In the remainder of this chapter, some of the analytical possibilities of TMSI/bluetooth tracking in the context of mass spectator events will be highlighted by showing a selection of case study results from the Coldplay concert. In accordance with strict privacy policies instituted by Path Intelligence Ltd, raw data is not distributed to clients, but the equipment essentially records the random TMSI ID#, time and station for each tracked cell phone. A total of 42,000 phone ID's were tracked during the time from 21:00 to 01:00 for the post-event scenario, constituting a representative 70% sample of the approximate 60,000 spectator population that attended the concert.

4.1 Total number of Visitors tracked at the Event

Of the 42,000 phone ID's tracked during the post-event scenario, 74% of spectators were first tracked at location A as shown in Figure 4(*a*). After the event finished at around 22:30, 67% of spectators used the Fan walk (locations F and G) and 24% went to the Waterfront (locations C and D). Figure 4(*b*) shows the time distribution of all the 42,000 tracked ID's at locations A or B from 21:00 to 01:00.



(a.)Stadium Gate use



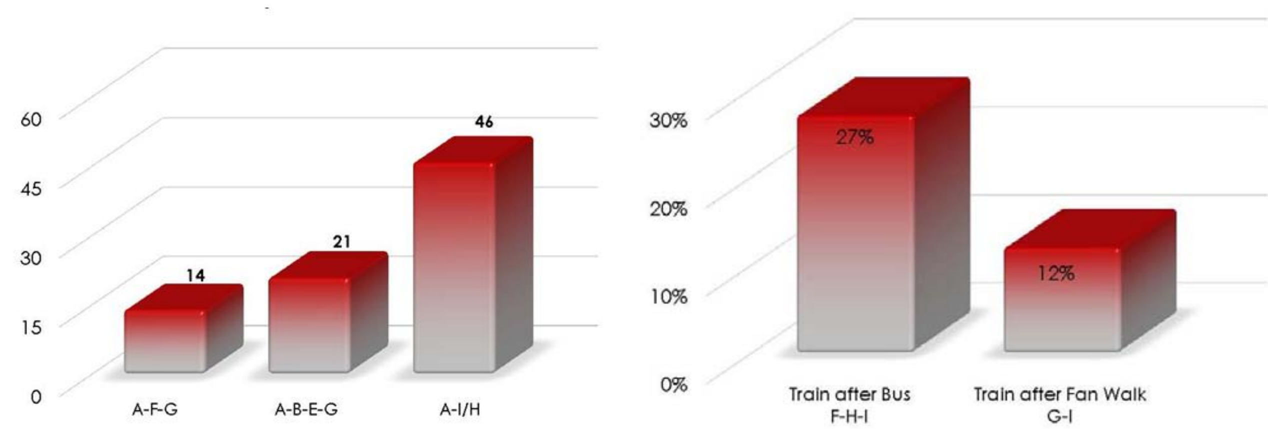
(b.)Time distribution of tracked spectators

Figure 4: Stadium gate exit use (Post-event only)

4.2 Transportation Mode and Travel Time

The TMSI/bluetooth tracking data could offer additionally useful data concerning transportation mode by careful selection of the sites covered with scanners: train users can be distinguished in a train station, car users in a parking lot, patrons in a restaurant etc. In this case study, train users were detected by a single scanner placed in the Station concourse (refer to Figure 3(*h*), BRT users at the stadium and at the civic centre were detected by scanners located within those facilities (refer to Figure 3(*g*) and 3(*f*) respectively).

Figure 5(*a*) shows an average 14 min walking time from locations A to G and 46 min from locations A to I or H. Figure 6(*b*) shows that BRT users are more likely to use Rail transport (i.e. 27% of those observed at locations on the F to H route were also observed or continued on to location I).

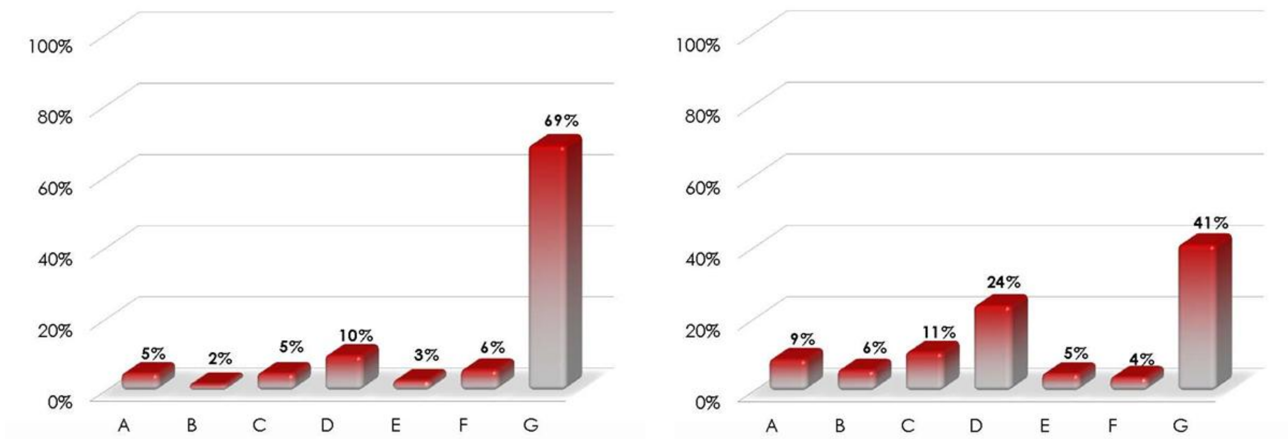


(a.)Average Travel Times *(b.)From Exit B*

Figure 5: Final tracked destination from Stadium Exits

4.3 <u>Stadium Exit: Final Tracked Destination</u>

Figure 6(*a*) shows of those that exited gate A, 70% were last tracked at G (i.e. used the fan walk underpass) and 15% were last tracked at locations C and D (Waterfront). Figure 5(*b*) shows of those that exited gate B (ie. the Fort Wynyard gate), 41% were last tracked at G (i.e. used the fan walk underpass) and 35% were last tracked at C and D (i.e. Waterfront destinations).

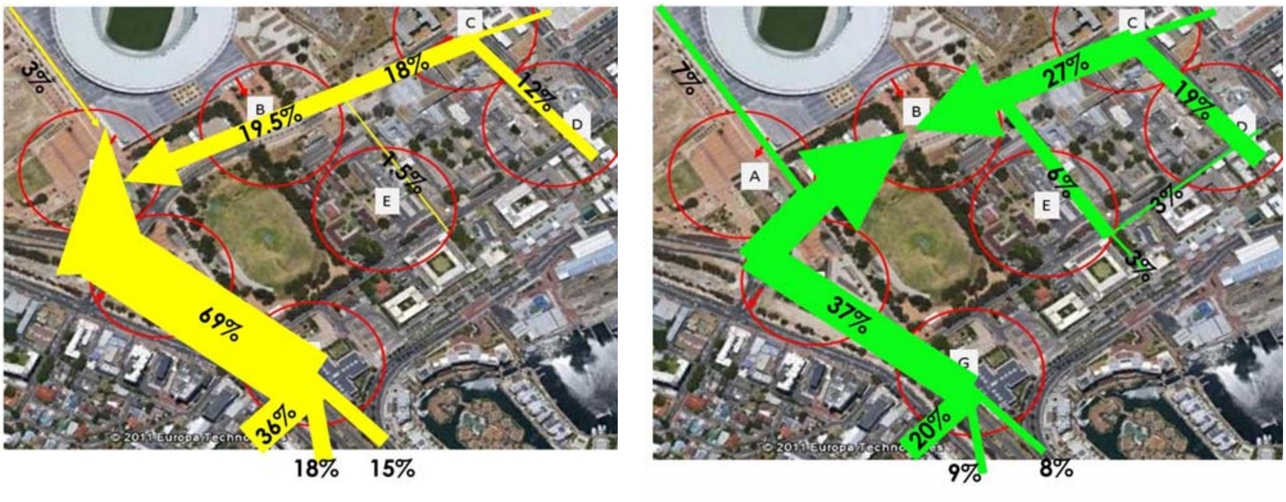


(a.) From Exit A *(b.) From Exit B*

Figure 6: Final tracked destination from respective Stadium Exits

4.4 <u>Pre-event routing results</u>

Figure 7(*a*) shows that of the 31,645 spectators tracked entering at gate A, (21,661) 69% arrived using the underpass, with (11,285) 36% walking using the fan walk only, (5,670) 18% walking from the rail station and (2,353) 15% using the BRT bus.



(a.)Routes to location A *(b.)Routes to location B*

Figure 7: Pre-event spectator routing

Figure 7(*a*) also shows a further 6,053 spectators (19.5%) were observed to originate from the Waterfront using, predominantly, Granger Bay Boulevard. A small 1.5% (472) of pedestrians used the Fort Wynyard Road as a routing option.

Figure 7(*b*) shows that of the 15,812 spectators tracked entering at gate B, (5,620) 37% arrived using the underpass, (3,081) 20% walking, (1,352) 9% walking from the rail station and (1,187) 8% using the BRT bus. A further 5,229 spectators (33%) were observed to originate from the Waterfront using predominantly Granger Bay Boulevard (4,356) 27% and 6% (873) of pedestrians using the Fort Wynyard Road route.

4.5 Post-event routing results

Figure 8(*a*) shows the tracking routing of 30,244 spectators exiting from gate A. A total of 20,983 (69%) spectators used the underpass of which 5,367 (17%) were last tracked at the rail station and 2,777 (10%) used the BRT service. A total of 12,839 (42%) spectators were tracked to walk on the fan walk. A total of (7,273) 23% of spectators had destinations in Waterfront, of whom most (19%) using Granger Bay Boulevard.

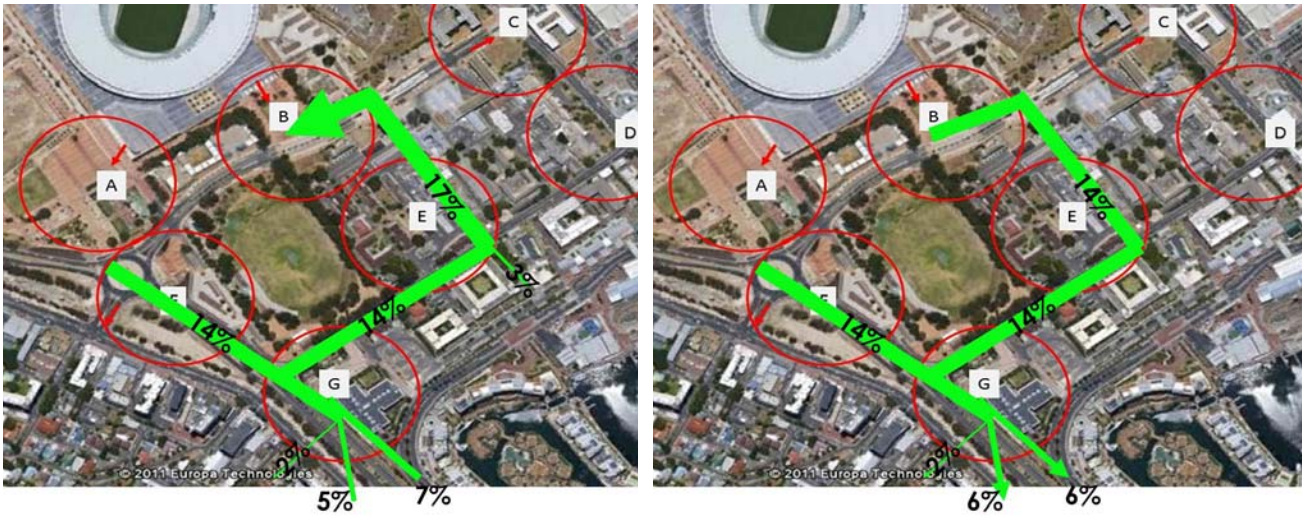
(a.)Routes from location A *(b.)Routes from location B*

Figure 8: Post-event spectator routing

Figure 8(*b*) shows the tracking routing of 11,528 spectators exiting from gate B. A total of 3,598 (32%) spectators used the underpass of which 750 (7%) were last tracked at the rail station and 712 (6%) used the BRT service. A total of 2,136 (19%) spectators were tracked to walk on the fan walk alone. A total of (3,910) 34% of spectators had destinations in Waterfront, most of whom (28%) used Granger Bay Boulevard with a small contingent (6%) using Portswood Road.

4.6 Results of Pre- and Post-event routing via Portswood Road

Figure 9(*a*) shows the pre-event routing profile to gate B specifically isolated to highlight the Portswood Road-Wynyard Road routing from the fan walk and BRT Station. This routing was specifically extracted to provide an indication of the pedestrian crossing activity across the Western Boulevard at the Porstwood Road intersection. Over and above the proportions indicated in Figures 7 and 8, a total of (2,584) 17% and (1,613) 14% of Gate B spectators were tracked utilizing the Portswood Road-Wynyard Road routing both for the Pre-event (Figure 9(*a*)) and Post-event (Figure 9(*b*)) situation respectively.



(a.)Pre-event routing to Gate B *(b.)Post-event routing to Gate B*

Figure 9: Pre-& Post-event spectator routing from the fan walk via Portswood Road

The observation of almost a similar proportion of spectators selecting their post-event routing as the pre-event routing, particularly along Wynyard Drive, prompted the professional team to close off Wynyard Road early in the day for a follow-up "Kings of Leon" concert in order to alert spectators of road closure. This road closure, together with metro policing, effectively eliminated the problem of pedestrians crossing the Western Boulevard during the post-event scenario and contributed towards the decision not to provide a pedestrian bridge across this roadway.

5. DISCUSSION AND CONCLUSION

The discussion is organized as follows. First, the added value of TMSI/bluetooth tracking in the context of mass events is discussed by reviewing the results generated from the Coldplay concert. Next, the potential of TMSI/bluetooth a tracking technology in this specific niche of case applications is described. The paper concludes by highlighting some remaining issues and weaknesses concerning the methodology and make suggestions for further research.

5.1 The Added Value of TMSI/Bluetooth Tracking at Mass Events

This experiment was able to generate a large dataset of movement trajectories with a limited number of scanners. As indicated earlier, a total of 42,000 cell phone devices were detected in 4 hours. Comparing the total number of detections in the raw data with the number of scanners, it was observed that each of the 9 scanners on average detected 4,670 cell phone devices. This is a good indication that the employed technology and recording system is able to manage a large flow of information generated by tracking spectators.

5.2 The TMSI/Bluetooth niche

If a tracking technology is to be suitable for studying trajectory dynamics of crowds at mass events, it needs to comply with certain requirements. This section explains why TMSI/Bluetooth tracking can potentially fill this niche, by comparing the technology with GPS (Global Positioning System) mobile technology.

Firstly, it has been demonstrated that TMSI/Bluetooth tracking offers the ability to track a very large number of individuals discreetly in an easy and relatively inexpensive way. A large population sample is often necessary to understand the complex dynamics involving crowd movements at mass events.

Other tracking technologies, such as GPS only reach a small subset of individuals, because of the low penetration rate in the general audience. Additionally, they involve the tracked individual in a direct way (e.g. by distributing and later recollecting logging units). This renders the tracking process labour-intensive and makes it prone to possible bias, since individuals might behave differently when they know they are being tracked (ie. the Hawthorne effect (Brocklehurst, 2005)) or because certain population segments might be more inclined to cooperate with such experiments and, hence, be over-represented in the resulting dataset.

TMSI and Bluetooth tracking both have a clear advantage over other technologies because of its ubiquitous applicability in indoor, as well as outdoor environments.

5.3 Remaining Issues and Suggestions for Future Research

Although the tracking system has a proven track record in indoor applications such as shopping malls and retailers, it is demonstrated in this paper that TMSI/Bluetooth tracking is also effective for tracking mass individuals in an outdoor setting. There are however some remaining issues to be addressed, including the possibility that there is an over representation of certain segments of the population.

For example, adolescents with a higher education may own more 3GSM/Bluetooth enabled cell phones than say elderly people, whilst young children will probably not be detected. Due to this uncertainty, a more systematic way of calculating the cell phone user profile will be necessary for reliable data extrapolation in the future. It may be beneficial in future studies to combine the measurement of pedestrian traffic via TMSI/Bluetooth sensors with market research surveys of attendees to identify whether there are demographic biases in the dataset. Although, of course, the benefit of such additional research will depend on the event being measured – for example, the Coldplay concert would presumably be demographically biased towards younger and more affluent attendees.

Additionally, the influence of time and space on detection ratio needs to be further investigated, since it is possible for an individual to pass through a detection zone undetected, due to the nature of the passive TMSI pinging tracking process.

Because of the difficulty of directly correlating the TMSI detection with the distance between the sensor and the detected device, the proximity principle to generate the trajectories from the detection data has been used. Triangulation of the signal strengths registered on different sensors to calculate an accurate location seems unrealistic, due to the need for numerous overlapping sensors, but a rough triangulation might be possible under certain circumstances. In this way, a continuous crowd density over a public area might be calculated which is not possible using the proximity method.

6. ACKNOWLEDGEMENT

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