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MULTI-MODAL DATA FUSION FOR BIG EVENTS

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ABSTRACT

Many of the transportation problems that are prevalent in urban areas culminate in large-scale events. Such events generate large multi-modal flows that arrive and depart within short time intervals to constrained areas. Monitoring and managing big events pose a challenge for transport planners, operators, event organizers and city officials. In this study, data concerning multi-modal flows was collected and analyzed for a so-called triple event in Amsterdam, the Netherlands, where more than 60,000 people visited the Amsterdam ArenA area. The collection and fusion of large and diverse datasets provided this study a unique opportunity to reconstruct from incomplete data, the crowds' arrival and departure times and estimate their modal split patterns. Considerably different arrival and departure time patterns are observed for car and public transport users. Visitors that arrive by public transport arrive approximately 45 minutes prior to the event start times compared with 75 minutes for car users. The lag between event end time and the departure time of public transport users is approximately 20-50 minutes whereas a lag of 20-80 minutes can be observed for departing cars. The factors that possibly underlie these differences are discussed along with the limitations of our analysis. The results of this study can support decisions concerning the allocation of parking lots and the scheduling of public transport services.

Keywords: Data fusion, Big events, Pedestrian flows, Multi-modal transport

1 INTRODUCTION

Amsterdam, like many other metropolitan areas, faces a number of serious transportation related challenges. These range from severe congestion problems on the freeway and city road network; overloading of the train stations during peak hours; limited accessibility for goods distribution; parking regulation; massive (and sometimes high-risk) pedestrian flows during events; poor connectivity of public transport services; the high demand on cycling infrastructure; and the fact that different transport modes compete over the same, scarcely available space. Specific situations in which many of these problems coincide are large scale events such as concerts, soccer matches and city-wide festivities. These events generate huge crowds which visit specific sites and arrive by many different modalities. Examples in Amsterdam are Kings' day, SAIL, and days in which multiple large public events take place simultaneously in specific areas. The first step to address these challenges and unravel the underlying traffic and travel processes is to collect and archive all relevant multi-modal transportation data.

To this end the AMS Urban Mobility Lab (UML) project *(1)* was set up in the fall of 2014. The proposition of UML is to develop a data and information platform that brings together data from different transport modes, of different semantics and varying spatial and temporal scale. The long-term objective is to have a common (distributed) database on top of which a range of analysis tools are built and which in turn can be exploited for both research projects and commercial services (FIGURE 1 right). In 2015 the aim is to develop a number of proofs of concept that demonstrate the application potential of combining and fusing multi-modal mobility data from a wide range of data sources. In this paper we present the results of one such proof of concept study that involved monitoring and analyzing multi-modal traffic flows to and from a large (so-called triple) event in the south-east of the Amsterdam region (FIGURE 1 left—the event site will be described in in more detail in section 3). The collection and fusion of large and diverse datasets provided this study a unique opportunity to reconstruct from incomplete data the crowds' arrival and departure times and estimate their modal split patterns.

[FIGURE 1 placed here]

Recent history shows that monitoring and management of large events is critically important to secure efficient operations and to guarantee the safety of visitors *(2,3,4,5)* One of the recommendations of a detailed account of the Love parade disaster in Duisburg in 2010 is that "[such] events must be planned on the basis of the number of expected people, not on the basis of capacity" *(3)*. Key to planning and managing large events thus is to monitor and anticipate arrival and departure patterns of events' visitors. However, comprehensive monitoring of all multi modal (i.e. car, train, metro, pedestrian) traffic flows to and from an event may be technically and/or economically infeasible. For example, in the Amsterdam case discussed in this paper no detailed arrival counts by public transport were available.

The research question addressed in this paper is whether it is possible to infer the public transport arrival and departure distributions and the approximate modal split for all visitors to the event by combining and fusing the available data which include pedestrian counts and parking data. In the literature a number of multi modal traffic information platforms are described, in most cases these accounts focus on the sensor and ICT architecture involved such as in Gan *(6)* and Kanhere *(7),* or on the information disseminated through these platforms, for example the performance monitoring as in Zaiat et al. *(8)*. To the best of our knowledge, no applications of fusing multi-modal data to reconstruct unobserved (multi-modal) flows or other variables have been reported yet.

The objective of this paper is hence to estimate the modal split and the multi-modal arrival and departure time patterns of visitors to a large-scale event by combining and fusing a selection of different data sources collected and archived in the urban mobility lab. The contribution of this paper is a structured framework to do so and a series of lessons learned and recommendations for follow up case-studies.

This paper is organized as follows. Section 2 first outlines the analysis framework used to arrive at these results. Section 3 describes the test site and the data collected after which section 4 discusses the analyses done and the results obtained. The paper closes with a discussion of the results and outlook to further research in section 5.

2 ANALYSIS APPROACH

Our objectives are to infer the number of people visiting the events by mode (modal split) and origin and their arrival and departure patterns given the absence of complete information on multi-modal flows. To this end, we deploy a multi-step process where information from multiple data sources is integrated. We represent the event site as a walking network where incoming and outgoing visitor flows are superimposed on the network. Missing information such as car occupancy rate and train passenger flows can then be inferred by solving a set of flow-conservation equations.

Figure 2 illustrates the overall analysis framework based on the data available for the case study investigated in this paper. The first step involves the collection, integration and fusion of multiple data sources. Datasets often refer to counts such as traffic, parking, pedestrian, public transport passengers and visitors counts available from cameras, loop detectors, vending machines, gate or smartcard transactions and barcode records (cylinders in Figure 2). A sequence of data fusion and estimation modules then follows (rectangles). By representing the event site area as a network, flow relations between transport facilities such as public transport stations and car parking facilities to event entering and exiting gates can be established. Pedestrian flows are then superimposed on this network and enable the estimation or inference of intermediate metrics such as the average occupancy rate of car users that park in the event site, incoming and outgoing train passenger flows and event entrance and exit distribution. Finally, performance metrics (parallelogram) - such as visitors' modal split and its temporal distribution (e.g. different events may be characterized by different modal splits) as well as the temporal and spatial distribution of visitors in the event site - can be estimated. The combination of these outputs will ultimately allow estimating the charging and discharging rates of visitors and whether these varies for different event types and travel modes.

[FIGURE 2 placed here]

A schematic network representation can be then used to construct a directed graph $G(V, L)$, where the node set V represents physical locations and the link set $L \subseteq V \times V$ represents direct walking connections between physical locations. The set of nodes consists of three types of nodes: transport nodes (A), event nodes (E) and walking intersections (N), these sets are mutually exclusive and collectively exhaustive ($V = A \cup E \cup N$). Transport nodes may correspond to parking facilities or public transport stations. Event nodes are entrance and exit gates to and from the event venues. Visitors traverse walking links and nodes when travelling between transport and event nodes or vice-versa.

Transport and event nodes constitute the generation and attraction nodes in the network. Let $q_a(\tau)$ and $q_e(\tau)$ denote the number of travellers generated or attracted to node $a \in A$ and $e \in E$ during time period τ. The modal split of travel mode u in a certain time period, $p_u(\tau)$, can be then attained from the share of mode-specific incoming flows out of the respective flows for all transport modes as follows:

$$p_u(\tau) = \frac{\sum_{a \in A^u} q_a(\tau)}{\sum_{a \in A} q_a(\tau)} \qquad (1)$$

where, A^u is the set of transport nodes associated with travel mode t and $A = \bigcup_{u \in U} A^u$ where U is the set of relevant transport modes. Alternatively, $q_a(\tau)$ can be substituted by $q_e(\tau)$ in Eq. 1 to obtain the modal split for outgoing flows.

In the hours preceding the event start time, transport nodes are generators and event nodes are the attractors ($q_e(\tau) = 0\ \forall e \in E, \forall \tau < \tau_1; q_a(\tau) = 0\ \forall a \in A, \forall \tau < \tau_1$) and vice-versa in the hours following the event end time ($q_a(\tau) = 0\ \forall a \in A, \forall \tau > \tau_2; q_e(\tau) = 0\ \forall e \in E, \forall \tau > \tau_2$), where τ_1 and τ_2 are the event start and end time, respectively. In the case that multiple events take place in the same site but start and end at different times, transport and node events may simultaneously serve as generators and attractors.

Visitors are generated in the transport nodes and are loaded into the event area network, travelling to event nodes. Visitors demand can be represented as an origin-destination matrix where each origin-destination pair is denoted by $q_{a,e}$. While origin-destination flows are not directly observable, each pedestrian count $m \in M$ provides information on a certain link $l \in L$ on which it is positioned. For each walking intersection node $n \in N$, a flow conservation equation of the following form can be formulated:

$$\sum_{l \in L_n^-} q_l = \sum_{l \in L_n^+} q_l \quad \forall n \in N \qquad (2)$$

where, L_n^- and L_n^+ are the sets of incoming and outgoing links from node n, respectively. The underlying origin-destination flows are not estimated in this study.

3 EXPERIMENT

This chapter describes the test site, followed by details on the data collection procedure and obtained datasets.

3.1 Test Site Description

Three large-scale event venues are located in an area of less than 1 km^2 in the south-east of Amsterdam, the Netherlands (FIGURE 1). The event venues include the soccer stadium Amsterdam ArenA (AA; capacity of 53,490 seats for soccer matches) and the concert halls Ziggo Dome (ZD; capacity of 17,000 people) and Heineken Music Hall (HMH; capacity of 6,200 people). The area also houses offices, shops and restaurants. The pedestrian area leading to and from these venues (the area within the orange dashed line in Figure 3), is denominated the event area.

The event area is in within the range of three public transport stations. The Amsterdam Bijlmer ArenA station is the main station that serves the event area (shown in Figure 3). It is within 0.5-1km distance from the event area. The station is served by intercity, commuter and metro trains as well as an adjacent bus terminal. Two additional stations are located north to the event area. The Standvliet metro station is located within approximately the same distance as the Bijlmer ArenA station. Finally, the Duivendrecht metro and train station lies 1.5-2km from the event area.

Occasionally, an event may take place in the three venues simultaneously, leading to high multi-modal traffic flows in and out of the area. We made observations on such a triple event, on March 28, 2015, when an international qualifier match was played in the AA and concerts were held in ZD and HMH. The gate opening times and the time during which each event took place are indicated at the bottom of Figure 3. The arrival period, τ_1, is defined in this study as 17:30-21:00. The departure period, τ_2, lasts from 22:30-00:00. Note that both arrival and departure periods refer to the events in ZD and AA and do not apply for the smaller event in HMH since the event at HMH started later. Thus, flows towards and from HMH did not co-exist with flows towards or from AA and ZD.

[FIGURE 3 placed here]

3.1 Data Collection

We define the event site as shown in Figure 3 and counted arriving and departing pedestrians using six cameras positioned close to the event area boundaries (red dots). Note that no camera was positioned at the northernmost area entry point because of a blockage in the northern area of the ArenA: visitors from metro stations to the north of the event area, had to pass through the position where camera 1 was positioned.

The camera details are shown in Table 1. Reliability of counts based on the camera images in dusk and crowded circumstances was verified in separate experiments beforehand comparing automatic and manual analyses of video images. During the events, it was cloudy and there were light rain showers (< 5 mm/hr) throughout the evening; temperature was 10°C and there was a moderate breeze (≤ 8 ms). Sunset was at 19.06 h.

[TABLE 1 placed here]

The latest recording start time of the cameras described above, except for camera 4, was at 17:30. All cameras stopped recording at approximately midnight generating a video stream of 7.5 hours per camera. It should be mentioned that due to technical issues, pedestrian count 4 was available only from 22:00 onwards which means that data for this entry are not available when visitors arrived. Pedestrian counts were collected on measurement lines which are depicted in Figure 3 as solid red lines. The final dataset of pedestrian counts consisted of counts in 30-sec intervals.

In addition to pedestrian data, car parking utilization data for eight parking lots were retrieved from sources available on the web. Parking utilization data included the short-term and long-term residual and total capacity of each lot in 1-min intervals. It should be noted that the area of the event is serviced by a total of 14 parking lots. The amount of parking lots with available data should be considered sufficient provided that the parking lots for which data are not available do not differ much from the available parking lots. As it will be seen later in this paper, if parking lots –for which data are not available– are of the same company (which relates primarily to pricing and filling policy) and in a maximum 2-block proximity from a parking lot with available data, then the utilization rate for the latter parking lot is assumed to apply to the former. The temporal span of the data ranges from 1:00 of the day of the event (28th of March) to 1:00 on the following day (29th of March). Finally, the counts of arena spectators that entered the ArenA through each of the gates were also available for this study.

4 ANALYSIS AND RESULTS

In order to attain the final goal of inferring the number of visitors arriving and departing from the event site by travel mode and origin, we deployed data fusion techniques to integrate the available data sources. To this end, the sequence of steps outlined in Figure 2 was performed.

4.1 Network Representation

The area surrounding the event area was divided into zones I-VII (Figure 4, left) that generated trips towards the event area for the time interval before the start of events and attracted trips after the end of events (see Figure 3 for the timeline). The characteristics of these zones and the criteria for creating them are the same as Traffic Analysis Zones described in *(9)* with some exceptions of zones that are entirely the size of a building. Each zone contains one or more parking lot or train stations. The pedestrian network that surrounds the event area is represented as a graph. All possible walking links within the event area were represented using GIS. Entrances and exits to and from the event area were then identified. In the link network representation, the event area is the sequence of links that allow people to traverse the area around the AA and in front the ZD. The event area's entrances are the links that connect the surrounding zones to the event area and the exits are the entrances to the venues for the time when people arrive to the events and vice versa when leaving the events. The link network is shown in FIGURE 1-right. The network contains transport nodes ($a1 \dots a10$), event entrance and exit nodes ($e1 \dots e6$) and walking nodes ($n1 \dots n15$). The nodes are connected by walking links which are represented in sufficient level of detail to account for pedestrian choices (e.g. diverging in the presence of an obstable).

[FIGURE 1 placed here]

The network in FIGURE 1 is made for the time interval 17:30-21:00 which is when people arrived at the event site. During that time interval, the link between nodes n_2 and n_3 was blocked and allowed only one directional traffic. All other links enable bi-directional pedestrian traffic. Additionally, pedestrian count m_4 which is available only after 22:00 is not illustrated in the network. The links indexed as a_i for $i = 1,2, \dots ,11$ are the entrance links from the surrounding zones to the event area while e_j for $j = 1,2, \dots ,6$ are the venue entrance gates. The set of entrance links A to the event area has been added to the network with the principle that they correspond to at least one parking lot (or train station) based on the available infrastructure in the zones surrounding the event sites. This supports the direct correspondence of parking lot utilization rate and pedestrian flows. For example, link a_3 connects several parking lots in zone I to the event area. However, the shortest path leading from all of these parking lots to the event area goes through the Bijlmer ArenA station. All other possible paths are more than twice as long and have no amenities (e.g., restaurants, shops).

4.2 Estimating Total Flow by Travel Mode

Vehicle Occupancy Rate

The parking lot occupancy data available in this study do not provide direct inspection of the number of visitors arriving in the event area by car. However, by matching parking data with pedestrian counts from the corresponding entrance link, the average car parking occupancy rate can be estimated. To match parking data with pedestrian flows, one has to look into the number of incoming (outgoing) vehicles that arrive (leave) the parking lot and not the total number of occupied parking spots since the latter may include vehicles of persons that are in the event area for other reasons than the examined events.

Furthermore, to correlate the number of vehicles' arrivals to people, the person-to-vehicle ratio needs to be calculated. This can be achieved for a location where the parking lot is the sole incoming flow and there is a direct measurement of pedestrian flows. If the camera is located far away from the parking lot then variations in walking speed will hinder the temporal linkage of the two measurements *(10)*. Following these considerations, we selected a parking lot located next to entrance a_8 and pedestrian count m_2. Furthermore, the selected parking lot is located in a building; pedestrians do not spend much time inside the building and are likely to come out fast and using one single entrance/exit. By comparing the increase of parking lot utilization and the respective pedestrian counts, a people-to-vehicle ratio of 3.49 was obtained. In subsequent analyses, it is assumed that this vehicle occupancy rate can be applied uniformly to all parking lots since it is inherent to the travelers of the event.

Public Transport Outgoing Flows

As described in Section 3.1, Bijlmer ArenA Amsterdam station is the main station located in the event area while there are two additional stations in proximity to the event area. Entrance link a_4 connects the Bijlmer ArenA station with the event area. It is assumed that all the pedestrians traversing this link are public transport users that either access or egress the event area, after controlling for pedestrian flows destined to parking lots located further away. Similarly, people arriving from zone II are public transport users that use Standvliet or Duivendrecht stations. These people may either use link a_1 or a_2 to enter the event area network (FIGURE 1). Therefore, the summation of pedestrian counts on a_1, a_2 and a_4 during time interval τ_1 corresponds to the number of people that used public transport to reach the event area.

Unfortunately, counts on a_4 during τ_1 are not available due to a technical problem with m_4 (see Section 3.1). However, counts are available for the time interval when visitors were leaving the event area, τ_2, 22:30-00:00. To connect the counts with the interval τ_1, we make two assumptions: first, that the number of people leaving the event area with public transport is equal to the number of people that arrived to the area using public transport and second, that the number of people that board a train at each station is equal to the number of people that alight a train at each station.

The flow on a_4 can then be determined by exploiting the conservation of flow equations for nodes n_5 and n_7 as follows:

$$q_{n_5 \to a_3} = q_{n_6 \to n_5} + q_{n_7 \to n_5} \tag{3}$$

$$q_{n_6 \to n_7} = q_{n_7 \to a_4} + q_{n_7 \to a_{11}} + q_{n_7 \to n_5} \tag{4}$$

where, all of the flows refer to period τ_2: $q_{n_5 \to a_3}$ are $q_{n_7 \to a_{11}}$correspond to entrance links from parking lots and were estimated using the parking utilization data and the estimated vehicle occupancy rate.

Flow value $q_{n_7 \to a_{11}}$ connects to a single measured parking lot whereas $q_{n_5 \to a_3}$ leads to seven parking lots, of which only four have parking utilization data available. It was observed that the capacity utilization rate was similar across the parking lots for which data was available. It was therefore assumed that that their capacity utilization rate at the remaining parking lots is similar to those parking lots for which data was available. The joint temporal pedestrian flow on $q_{n_5 \to a_3}$ was constructed based on these assumptions. Flow values $q_{n_6 \to n_5}$ and $q_{n_6 \to n_7}$ are available from camera measurements. This procedure resulted with an estimated number of visitors leaving from Bijlmer ArenA Amsterdam station and thus traversing link $q_{n_7 \to a_4}$of 13,249.

4.3 Arrival and Departure Patterns by Travel Mode

The analysis hitherto considered the traveler flows by car and public transport. Other modes, such as bicycle are considered to contribute insignificantly to the arrival of visitors since the area is for a large extent primarily for businesses and shopping with very few houses. The temporal distributions of visitors' arrival and departure by travel mode can also be constructed. The temporal distribution of arrivals of the lion share of public transport users can be retrieved from count m_5 which is in front of the Bijlmer Arena station. The corresponding number of arrivals by car is retrieved from the summation of all incoming and outgoing parking flows, which include most parking lots surrounding the event area.

[FIGURE 5 placed here]

Figure 5 illustrates the normalized estimated temporal distributions for the arrival (above) and departure (below) periods, τ_1 and τ_2, respectively. Since both public transport and car estimates are based on a large albeit incomplete dataset, Figure 5 is normalized with respect to the respective maximum value and is interpreted in terms of the prevailing temporal patterns rather than the absolute total number. It is evident that the arrival of public transport users manifests distinct peaks arguably reflecting the arrivals and departures of intercity and subway trains. The arrival of visitors coming by public transport peaks between 19:15-20:15, approximately 45 minutes prior to the event start times (20:00 in ZD and 20:45 in AA).

The departure time distribution (Figure 5, below) exhibits two humps following the event ending times, albeit with clearly distinguished patterns for car vs. public transport users. Both groups depart in increasing numbers from 22:30, when the event in AA ended. The departure time is widely spread over the examined interval due to the discharging rate from distinct event venue exit gates and variations in walking time between these gates and parking lots and Bijlmer ArenA station. The second hump exercises less variations since the ZD has a single venue exit but this is located further away from Bijlmer ArenA station, resulting with a longer lag between event end time and outgoing public transport flows. Moreover, when the event of ZD ended, the pedestrian links leading from the venue to the station were already crowded with the visitors of the AA event (FIGURE 1). The increase of flow could cause formation of bottlenecks and other pedestrian flow related instances that reduced the flow towards the Bijlmer ArenA station and the parking lots that require traversing these links.

The lag between event end time and the departure time of public transport users is approximately 20-50 minutes whereas a lag of 20-80 minutes can be observed for departing cars. The larger variation among car users is presumably attributed to the large spatial spread of parking lots in proximity to the event area as well as congestion effects that decrease the discharging rates from parking lots (parking counts are recorded at the gate through ticket validation machines).

Visitors that arrive by car arrive earlier than public transport users with the arrival rate peaking between 18:45-19:45, approximately 75 minutes prior to event starting times. The larger buffer time as compared with public transport users could be attributed to three reasons: (a) greater travel time variability; (b) uncertainty associated with parking search and queuing; (c) longer walking distances from the parking lots. Figure 6 presents the utilization rate measured as the ratio between the total number of parking cars and the total parking capacity of all of the parking lots considered in this study. The number of occupied parking spots increases almost linearly between 17:30-20:00, operating almost at capacity around 20:20.

[FIGURE 6 placed here]

4.4 Estimating Visitor Flow per Generator and Attractor Node

By extracting the pedestrian counts from parking utilization data and using a series of flow conservation equations, the number of visitors entering the event area from each transport node and accessing the event at each event node can be estimated. In other words, the flow per generator and attractor at period τ_1, prior to the event, will be assessed. The results of the data fusion of the three datasets – parking flows, pedestrian counts, event entrance gates – are summarized in Table 2. With the exception of e_6 of the ZD, other attractors are known from the event venue gates. The number of visitors to the ZD was set to 15.000 visitors based on media reports. By specifying these values in the flow conservation equations all trip generators could be determined.

[TABLE 2 placed here]

4.5 Modal Split

In addition to the flows reported in Table 2, both AA and ZD have parking lots with direct access to the event venues that are not accounted for hitherto. Assuming that these parking lots are fully utilized given their centrality and the vehicle occupancy rate, an additional number of 1,920 and 8,376 visitors park in ZD and AA respectively.

The total number of visitors to all events is approximately 61.5 thousand based on the counts of spectators that entered the ArenA and the number of ZD visitors. Since the total number of visitors that arrived to the events in ZD and AA using public transport is 16,178, then the market share of public transport for visitors arriving in the event area is 26% whilst car market share is 74%. Other modes are expected to account for a negligible market share given the event size location.

5 DISCUSSION AND OUTLOOK

Big events attract large flows of visitors that travel into and within the event area. Such events pose a challenge to the design of infrastructure and the allocation of resources to accommodate the large volumes of visitors within short time periods. As this study demonstrates, fusion of multi-modal data sources can shed light on the travel patterns that characterize such events. By combining data and measurements of parking, public transport, pedestrian and event venue flows and capacities and deploying a set of assumptions, the temporal and spatial distributions of visitors' arrival and departure flows by mode were estimated.

The final result of this exercise, a 26% public transport share is certainly plausible given the nature of the events. The two concerts and soccer match of the Dutch national team are typically events which attract visitors from all over the country. Although the ArenA Boulevard is easily accessible by public transport, car accessibility is also good, particularly around 7 PM when the largest peak in incoming car flow was observed. Two other arguments may explain the rather low share of public transport in this case study. First, when traveling in larger groups (we estimated average car occupancy of 3.5 persons), long-distance car travel is significantly cheaper than public transport and second, efficient door-to-door public transport options when departing after 11PM for visitors outside the Amsterdam region are limited. On the other hand, an average of 3.5 persons per car seems rather high and may well be the result of assumptions made in this analysis. The assumption of the people-to-vehicle ratio can better be tackled on future applications through surveys conducted directly in the parking lots.

The pedestrian measurement campaign on the 28th of March has led to a lively discussion between the Urban Mobility Lab research team and a number of public and private stakeholders around the Amsterdam ArenA Boulevard, in which the possibilities for a more permanent multi modal monitoring system is discussed that may (a) support better mobility and crowd management of triple events; (b) provide visitors with comprehensive personalized travel information; and (c) help commercial operations maximize their businesses around and in the venues. For example, the location of parking lots and the scheduling and allocation of public transport services could be determined based on the expected arrival and departure rates. Providing visitors with pre-event travel information concerning recommended public transport stations and parking lots which are most accessible to the relevant entrance gate might help in decreasing congestion within and when travelling to and from the event area. Instead of waiting in queues visitors may be offered rebates on drinks or food in one of the many small and large restaurants and bars around the ArenA.

Such an extended monitoring system will not just support real time management and information provision but also off line analyses that will result in valuable new insights in the dynamics of multi modal traffic flows. At the end of 2015, the urban mobility lab will contain live feeds of all motorway traffic sensors (speeds, flows) in the Amsterdam region and feeds to a selection of the urban sensor network (intersection data and route travel times) around the ArenA. We are also collaborating with the public transport authorities in the region to provide feeds of (aggregated) chipcard/smart-card data from and to the event site. To unravel pedestrian movements on the ArenA Boulevard itself, a wide range of research opportunities arise. One exciting research avenue is to combine observations from (low-end) Placemeter camera's and for example Bluetooth and Wi-Fi detectors with advanced analytical pedestrian models *(10)* and Bayesian estimation methods analogously to successful car traffic state estimation and data fusion approaches (e.g. *(11,12)*). This may result in comprehensive and scalable pedestrian traffic state estimation methods.

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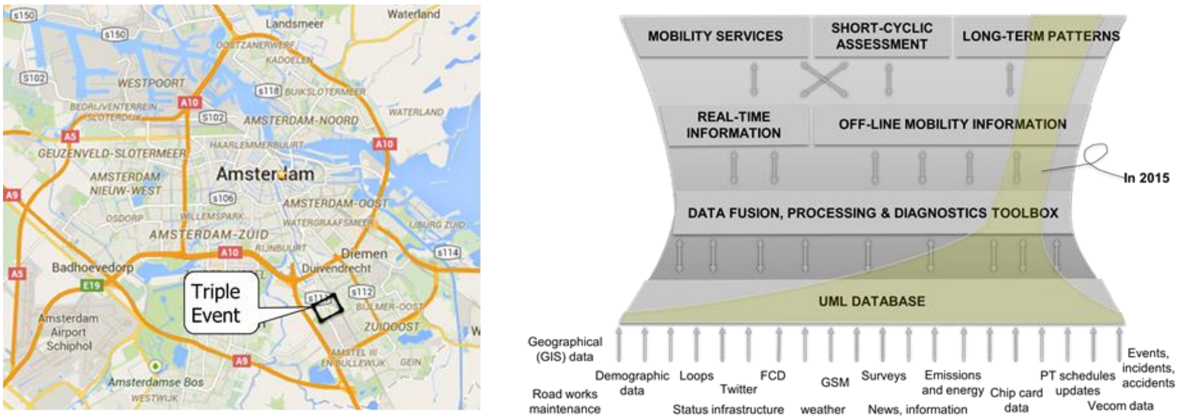


FIGURE 1 Map of the Amsterdam metropolitan area and location of the Amsterdam ArenA Boulevard (left); schematic representation of the Urban Mobility Lab (right)

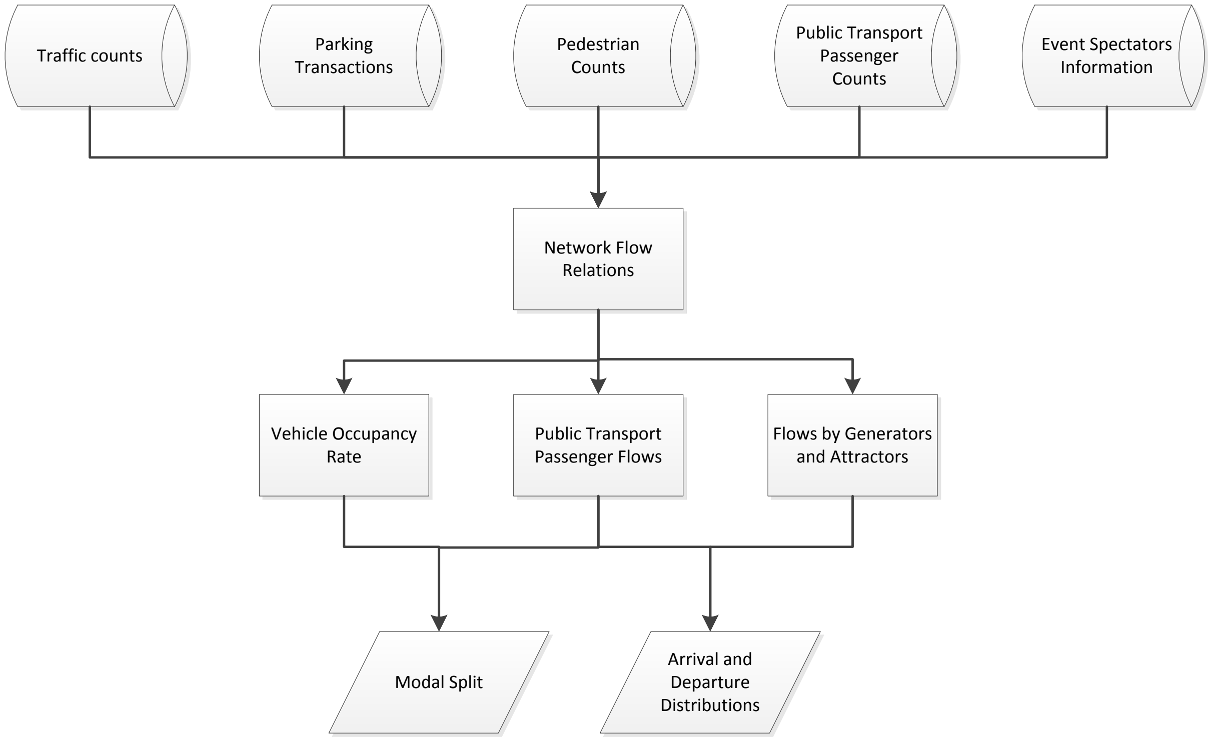


FIGURE 2 Analysis framework

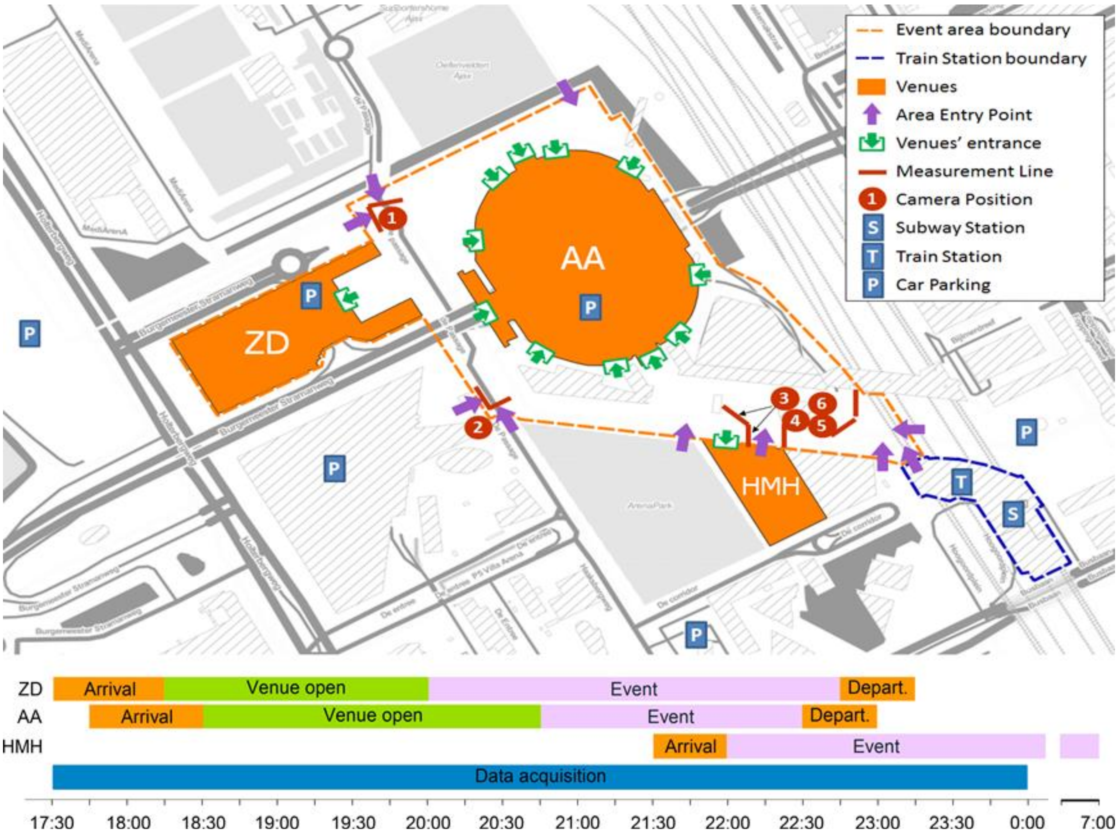


FIGURE 3 Event site and time schedule

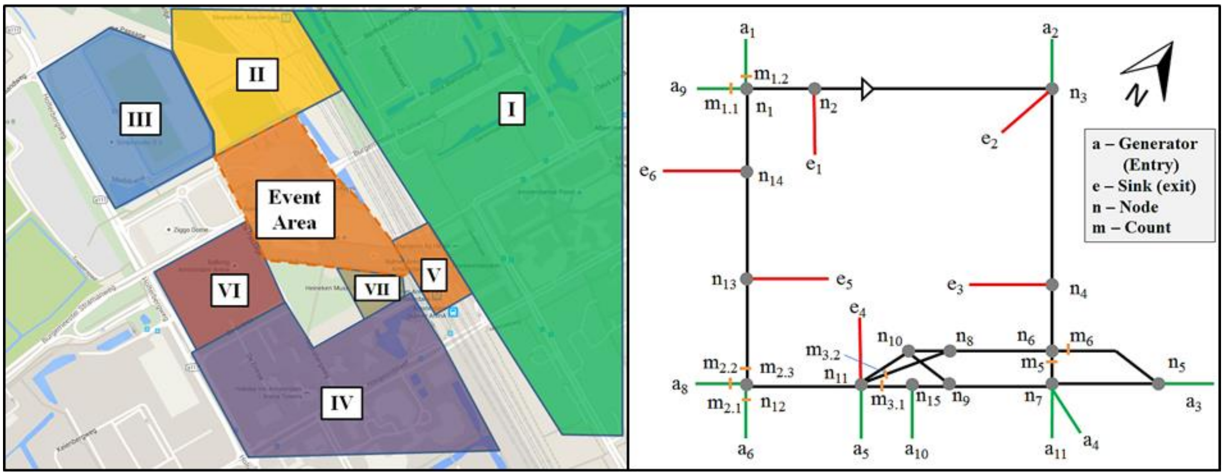
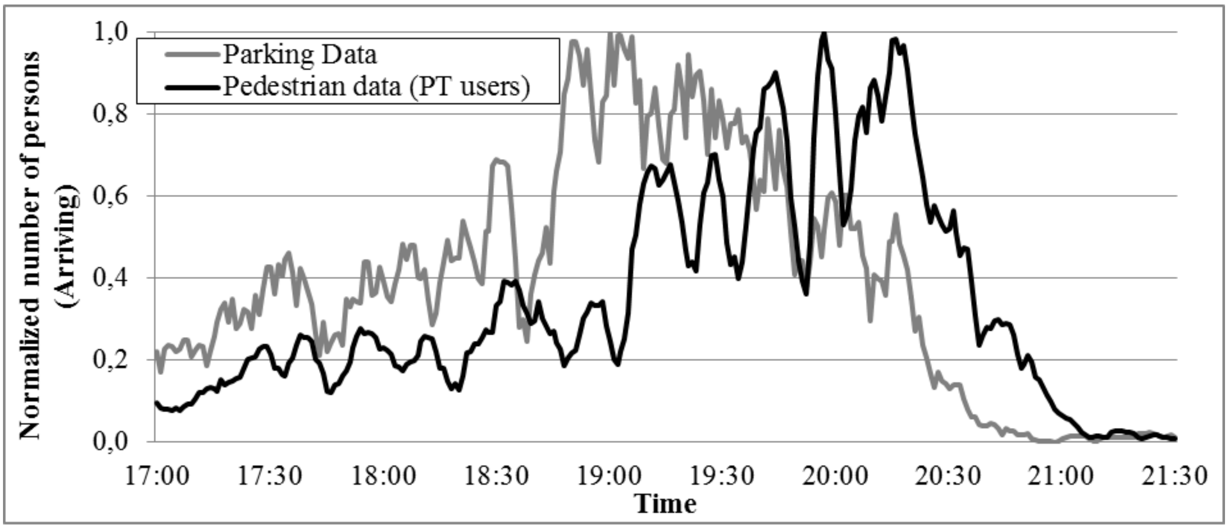


FIGURE 4 The origin and destination zones of pedestrians for the events (Left) and the network representation of the event area for 17:30-21:00 (Right)



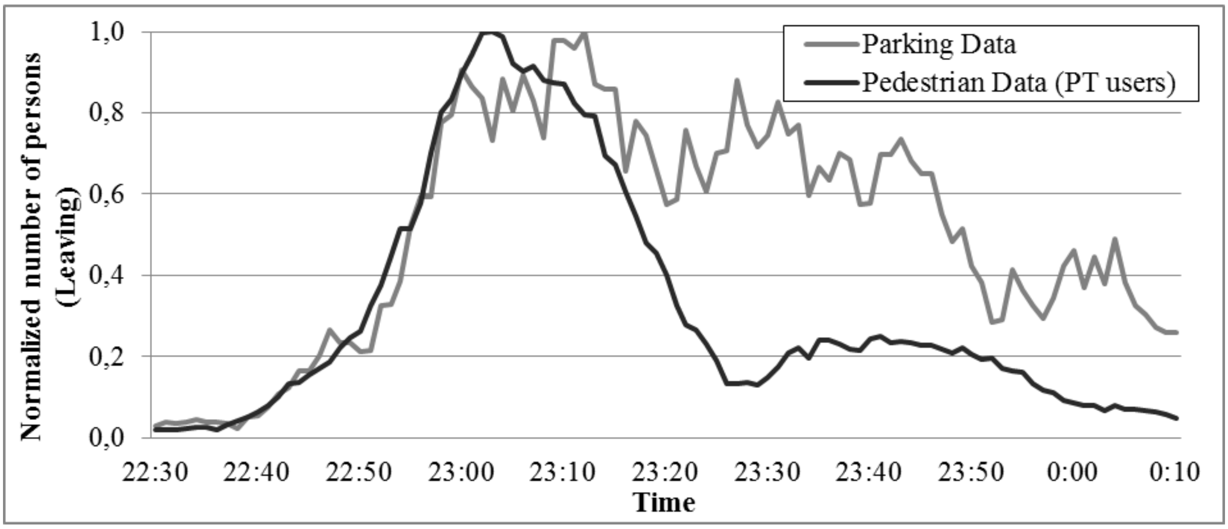


FIGURE 5 Arrival (above) and departure (below) distribution of visitors using private car and public transport

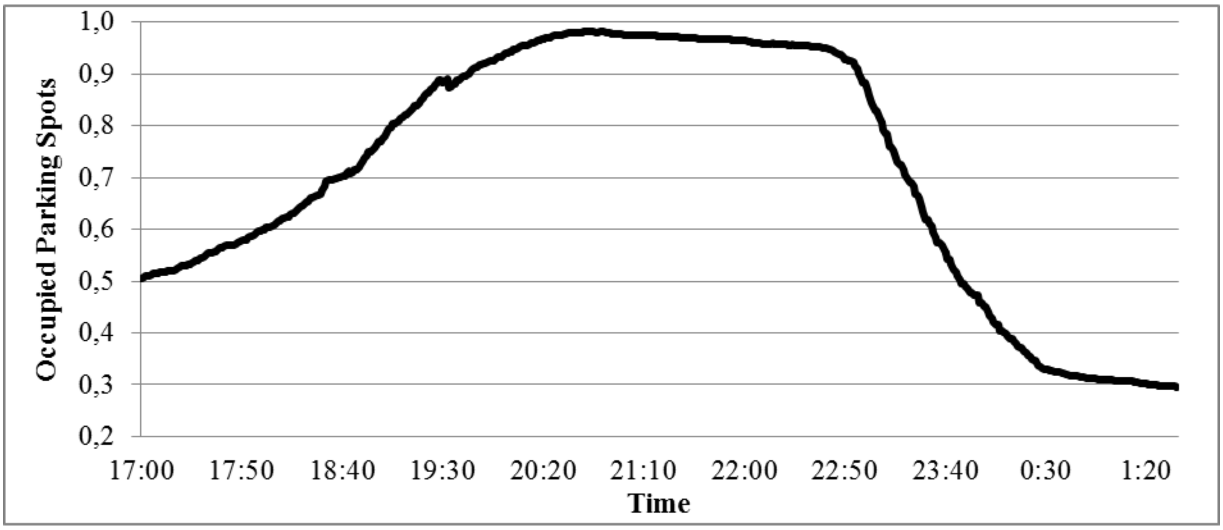


FIGURE 6 The change of parking utilization over time

TABLE 1 Camera Details

	Generic video camera	Webcams (C920 and C930)
Camera numbers (Figure 3)	1	2, 3, 4, 5, 6
Camera position (height, m)	7	10*
Horizontal field of view	35-70°	71°
Vertical field of view	-	40°
Diagonal field of view	-	78°
Resolution (pixels)	720 × 576	1920 × 1080
Frame rate (fps)	8	8

*Camera 2 was positioned at a height of 5m

TABLE 2 Total Passenger Flow for Each Origin (Transport) and Destination (Event) Node in the Period Leading up to the Event

Zone	Generators	Outgoing flow	Event venue	Attractors	Incoming flow
I	a_3	6,103	AA	e_1	3,587
II	a_1, a_2	2,929		e_2	10,027
III	a_9	14,212		e_3	3,588
IV	a_5, a_6, a_{11}	6,997		e_4	17,478
V	a_4	13,249		e_5	3,397
VI	a_8	2,489	ZD	e_6	13,081
VII	a_{10}	5,180			
Total		51,159			51,158