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Abstract: Monitoring operations at freight intermodal terminals are useful for estimating their performance, while collecting traffic data allows them to properly manage and control truck flows. Nevertheless, the key role of observation can be in contrast with users' privacy. A valuable solution to obtain traffic information preserving players' anonymity may be provided by scanning radio signals emitted by commonly used on-board devices, which can be locally identified by their unique media access control address. In this solution, no personal, freight or vehicle information is collected. An uncommon application of bluetooth scanners for monitoring operation of truck flows inside terminals is presented, based on a simple methodology for data processing. The algorithm starts from the data collection and the selection of information at relevant points of the terminal, then the network observation is composed by matching the data recorded in connected points. Finally, key performance indicators are estimated, starting from vehicle trajectories, node by node, and their travel time. The method is applied with on-field tests in a large-size rail–road terminal, where the detected counting results are lower than the ground truth, being not all the users equipped with bluetooth devices; however, the pioneering application results replicable in other contexts related to logistics.

1 Introduction

The bluetooth (BT) and Wi-Fi communications are commonly used in many on-board devices, such as headsets, car navigation systems and smartphones. In particular, trucks are usually equipped with BT devices to better manage during journeys other tasks than driving and this is also confirmed in [1], which reports that their detection rate in the observed freeways is between 65 and 70%, about five times more than passenger cars. Therefore, scanning instruments able to detect radio signals emitted by those commonly used on-board devices may provide vehicle tracking and many data useful for logistics, without collecting any personal, freight or vehicle information. Indeed, vehicles can be locally identified only by their media access control (MAC) address.

Recently, the number of traffic monitoring applications based on the use of BT data as a complementary traffic data source has been increasing, ranging from origin–destination (OD) matrixes estimation [2] to travel time monitoring along arterials [3]. However, the installation on the field of the scanner devices should be adequately planned and performed. This has been confirmed by the authors who have investigated the positive and negative features of traffic detection with Bluetooth sensors thanks to experimental observations. The main aspects that could influence the measure are for example: the distance of the scanner and the vehicle speed or the characteristics of the sensor fusion techniques [4–8]; thanks to experimental observations. The installation also depends on the specific scenario that should be observed and intermodal terminals, which have specific features as detailed hereafter – both for the infrastructural side and for vehicles as well as handling equipment, with related logistics – are the object of the research presented in this paper. For example, how the type of antenna can affect the quality of data collection was investigated by Abedi *et al.* [9]. They also compared Wi-Fi and BT standards in terms of architecture, discovery time, the popularity of use and signal strength.

To estimate freight OD matrixes using multiple sources of captured data Ma *et al.* [2] developed an approach based on entropy maximisation and Bayesian networks. BT scanners are among the sensors proposed and they are used to approximately estimate the OD, in combination with loop detectors, video cameras for plate number identification and other traffic sensors installed along the motorways observed. As it emerges also from this study, it is difficult to estimate the truck flow only from BT, because not all vehicles have these devices on board, and they have no information for identifying the vehicle type. An estimation approach based on Kalman filtering of OD matrices for a motorway scenario is given by Barcelö *et al.* [10]. Also, the study used BT detection of mobile devices and assumptions of equipped vehicles rate at the entrance and exit points to predict time-sliced OD matrixes, as well as time-dependent travel time for congested traffic conditions. They applied the method in simulation on a ring road in Barcelona and then to a real data set collected in a motorway connecting the city to the French border. Chitturi *et al.* [11] used BT data to estimate the OD matrix for a complex interchange of a freeway, by merging traffic counts and time-lapse aerial photography.

Concerning traffic monitoring in urban roads, a procedure to extract trip information in extended networks from over 580 BT scanners for the reconstruction of vehicle trajectories is proposed by Michau *et al.* [12]. They integrate data gathered from sensors, after cleaning operations to reduce overlapping phenomena, shared IDs and missing detections with shortest path algorithms to assign feasible routes between detecting nodes.

To detect travel times data along with the manoeuvres of a signallised intersection, Shiravi *et al.* [3] combined Wi-Fi signals with BT and confirmed in that scenario estimates for 30 min intervals are not properly sampled using only BT data. However, the traffic in the urban scenario was composted only by passenger cars, which have on-board BT devices less than trucks.

The data recorded in two observation points distant ∼1.5 km along an arterial by Abbott-Jard *et al.* [13] also integrate both BT and Wi-Fi sensors to increase the sample size. In this classic road monitoring scenarios, the two sensor ranges are not overlapping, as may happen in more complex transport system situations. Their empirical approach to clean and filter data is similar to that presented in this paper, although we are interested to follow, usually in a low level of traffic, any individual vehicle, if it can be detected, and its travel times along the processes inside the terminal, instead of providing average travel time between points. For this reason, the algorithm here presented and applied to the experimental scenario is quite different, as shown in Section 4.

An experiment to calculate travel time using the BT and global positioning system (GPS) data elaboration is made by Araghi *et al.* [14]: data obtained by GPS logger are used to calculate actual travel time and to geo-code the BT detection events. Another data fusion is instead presented by Bhaskar *et al.* [15]; they fused BT scanners and loops data to define the trajectories of the BT vehicles. The trajectories are then utilised to estimate the travel time statistics between any two points along one motorway. The BT technology has the potential to provide fairly accurate travel time estimations across urban arterials also in India conditions (the vast heterogeneity in vehicle classes and the lack of lane discipline) [16].

The BT/Wi-Fi data are widely used as a complementary traffic data source, especially in motorway or highway scenarios, where high traffic volumes are expected to be detected. With respect to the literature examined, the low traffic volumes composed by trucks – which should follow some established paths inside the terminal, according to the process to be monitored in some established points – are relevant features in the study presented in this paper. Moreover, in standard monitoring scenarios, the same vehicle is rarely detected more than once at the same point of observation, as it is expected in monitoring processes for intermodal freight terminals, where trucks may use the infrastructures cyclically. Furthermore, the distance between some points to be monitored of the process can be, in some cases, low and this can create overlapping problems in data analysis. The BT scanners can here be used also not in combination with Wi-Fi to measure travel time parameters of equipped trucks because the BT scanned devices are, for these particular users, widely adopted and they can be considered always on board for the vehicles inside the terminal.

To better localise vehicles at detection points, also RSSI could be used. However, given the scenario to be observed, in our experiments, we have tried to design adequate sensor positions to limit the need for associating ambiguous vehicles to detection points, using also the topology information coming from the terminal and the internal process, which are quite well established. On the contrary, in road networks, these advanced techniques are possibly necessary, since vehicles have no established path to follow. The use of this technique could be taken into account in future research to support the observation in more complex scenarios.

In Section 2, BT and Wi-Fi scanner technologies are described, comparing the main advantages and disadvantages of automatic traffic collection. Section 3 details the problem examined, clarifying the traffic observation scenario at an intermodal freight terminal and the relevant points of the process where trucks should be monitored. The proposed methodology of data processing and operations monitoring is then reported in Section 4. The algorithm, after linking BT information at network nodes and performing consistency checking according to typical terminal operations, estimates the selected key performance indicators (KPIs). To conclude, the on-field test carried out in a large-size rail–road terminal in Italy is reported in the last section.

2 BT and Wi-Fi scanners for automatic traffic data collection

BT is an open wireless technology standard using the 2.4–2.485 GHz unlicensed spectrum for short-range communication with main characteristics of robustness, low power and low cost. The communication range between two BT devices depends on the power of the radio transmitter, the sensitivity of the receiver, and the absorption rate of the medium [7], typically up to 20–30 m.

The Wi-Fi is a family of radio technologies commonly used for wireless local area networking (WLAN) of devices. This technology uses radio waves to provide wireless high-speed internet and network connections with a range of up to 100 m outdoors.

The BT and Wi-Fi communication operate in the same radio-frequency band, although the discovery time for Wi-Fi is <1 s and for BT can be ∼10 s [9].

BT and Wi-Fi signals are constantly being emitted by smartphones, tablets, wearable technology, and vehicular embedded systems. These common on-board devices can be locally identified by the unique media access control (MAC) address, which allows their simultaneous tracking in a given area, without collecting any personal, freight or vehicle information. The MAC address is represented by a 48-bit code, which is normally written in a 6-byte 12-digit hexadecimal format.

A time-synchronised detector scans the zone to read and record the MAC address of the discoverable devices transiting in the zone and gives the direct observation of their local movements. The zone of the detection depends on the type of antenna: its polarisation (e.g. omnidirectional, directional) defines the communication coverage shape (horizontal and vertical), while the strength defines the size of the coverage shape. In fact, the choice and setting of the antennas can help to select or exclude portions of areas during the monitoring with BT and WF scanners.

Due to the uniqueness of MAC address, the sensors detecting such information can track the device at various points where they are installed over time, and consequently the individual (or vehicle in our application) who moves with that on-board device [17].

The main characteristics of these type of sensors to detect vehicles and collected traffic data, according to the literature review (Section 1) and real application, are the following:

- Wide use of BT and WF technologies in the common on-board devices.
- Lower costs of BT and WF scanners compared to other sensors.
- Technology accessibility, because there are different options for BT scanners, ranging from Apps running on the smartphone to professional sensors.
- Non-intrusive installation for temporary observations.
- MAC univocity which allows the tracking of the devices along a sequence of detection points to estimate vehicle trajectories.
- MAC address data allows unannounced and non-participatory tracking of devices.
- Anonymity of MAC address which avoids potential privacy infringements.
- No interference with the normal terminal activities during the monitoring process.

These specific features have justified the selection of this type of technology, because meet the needs required by the context to be observed and presented in this paper. In fact, in an intermodal freight terminal, any traffic data collection should be done without interference with normal activities, avoiding problems of privacy, both for operators and external users.

In previous experiments, we also used cameras to measure truck flows at selected points, but the quality of results was not as expected, given the difficulties to properly install the cameras. Besides, for privacy reasons, not all the technologies can be used for intermodal terminals. Privacy is one of the relevant requirements for selecting BT/Wi-Fi technology, which is also not intrusive and does not require fixed installations: these may interfere with terminal operations. Furthermore, in the case of the tests presented, also the lower costs and the simple installation of sensors were appreciated, considering the temporary observation. Although some terminals are equipped with other technologies (RFID, cameras with LPR or for ILU/BIC codes recognition), they are always operated by the terminal itself and thus data cannot be obtained easily. On the other hand, collecting data using an external system makes the observation and KPI estimation independent and usable for similar terminals without the need of relying and connecting on the data management system of the terminal.

KPIs are useful to monitor and manage the truck flow inside the intermodal terminal. Since truck trajectories, node by node, can be built knowing the recording time in the selected nodes, the time duration of the different sub-processes can be estimated, as the first set of KPIs. Moreover, the total travel time in the intermodal terminal, defined as turnaround time, which is the time spent by a truck inside the terminal between the check-in and check-out operations, is a well-known parameter and used as a global KPI.

Nevertheless, some negative (or potentially risky) aspects must be taken into consideration during the monitoring phase, such as:

- Distance between the scanners and the devices, which affects its detection and the capturing rate.
- The installation position (angle, height etc.) of the scanners could influence the quantity of devices detected.
- Vehicle speed, both for high values (not captured devices) and low values (multiple scanned of stationary vehicles).
- Physical obstacles may generate a loss of performance in scanning operations.
- Environmental conditions and their effect on the measurement, and more precisely on the signal power.

In detail, the BT and WF scanners used during the on-field tests shown in Fig. 1 are composed of the scanner in a sealed IP68 enclosure suitable for roadside operation, the external antenna and the battery to guarantee monitoring for approximately a week.

Fig. 1 *Photo of BT and WF scanners used during the on-field tests composed by the scanner, the battery and the antenna*

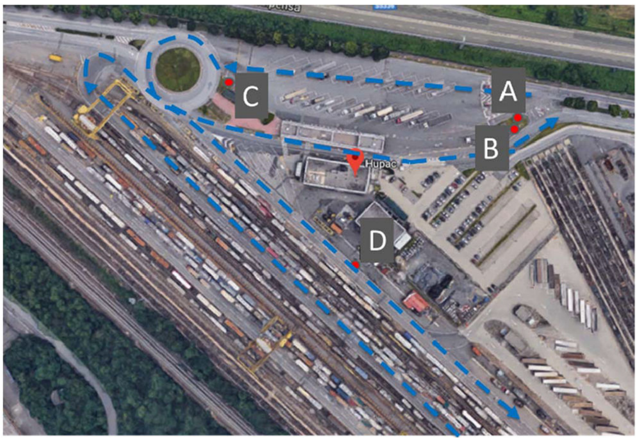

Fig. 2 *Example a large intermodal terminal layout and relevant detection points (source: elaboration on GoogleMaps)*

3 Traffic observation at intermodal terminals

Inland terminals are key elements in the combined transport chain as they must guarantee a fast, safe, and efficient transfer of intermodal loading units from one transport mode to another. Rail–road terminals are interchange hubs between rail and road traffic. They are fitted with all the equipment required to rapidly and efficiently handle and tranship loading units: gantries and mobile cranes, computer systems integrating tracks, storage areas, transhipment areas, and connections to roads and motorways [18].

In typical rail–road combined transport terminal the main elements of the process from the HDV point of view can be grouped as follows [19]:

- Check-in operations for the trucks incoming at the terminal, including the inspection procedures and the documents management for goods and drivers. These two operations can also be performed in two distinct phases and places.
- Loading or unloading operations with handling equipment, most frequently under cranes, from the truck to railway wagon or vice versa, or even in special areas in the case of technical stops or in parking lots for semitrailers.
- Check-out operations for the trucks leaving the terminal.

The selected rail–road terminal for on-field tests is a large-sized Italian terminal and specifically its southern part. As shown in Fig. 2, four relevant points are chosen as detection stations based on the terminal layout, operational processes location and the available number of sensors. Furthermore, the selected observation points, for their general features according to typical phases in the process, can be easily identified also in other intermodal terminals. This enables the transferability of the observation method and then the application replicability.

Thus, the four detection points where the BT and WF scanners are located and identified with letters A, B, C, D, as detailed in Fig. 2:

A. Gate in, the entering point of the terminal.
B. Gate out, the exit point of the terminal.
C. This point identifies the entering of the transhipment area after physical and document checks.
D. It is the detection point for the core terminal operations in an established sector and can be replicated in other sectors, according to the sub-processes to be observed or be adapted in relation to a different layout. In the tests reported in this paper, this point is defined to detect the traffic flow directed to the south part of the terminal.

The selected scenario presents some critical issues, such as the great number of containers managed inside the terminal: according to [9] metals are a severe obstruction in MAC ID scanning. This can be controlled through the careful location of the points on the map and the antenna attributes (e.g. strength and type of polarisation) set during the preparation activities of monitoring. Moreover, the distance between the detection points is in the range of some metres (10–100 m), whereas the distances in highway scenarios described in the literature overview are often >1 km. If on-board devices are detected almost simultaneously in close points, because the detection zones may overlap, this must be considered both during the antennas setting and the data processing. Finally, although the intermodal terminal is a quite closed environment, many external devices can be present and detected, such as those held by terminal operators or the equipment in the nearby offices. However, the MAC trajectories reconstruction helps to exclude the external devices, as will be shown in detail in Section 4.3.

In this study, we remark that vehicle tracing at relevant points is devoted to mapping the process inside the terminal, considering the consecutive phases and their duration, estimated by the travel time of the detected trucks, without considering intermediate events. The term 'trajectories' has been used not only to map with a high resolution rate the position of the trucks inside the terminal, which is out of the scope of the study, but also to clarify that we are interested to map travel time of individual vehicles along their relevant activities (service operations) and not only to average values of travel time on links connecting detection points.

The check of link direction and the expected travel time according to terminal operations (see Section 4.4) allow solving the problems related to devices on-board vehicles travelling on the external road infrastructure (as reported in Fig. 2) in the range of the detection points inside the terminal. This issue can also be managed, if possible, by installing the antennas considering their polarisation.

Date/Time	MAC	COD	Class Description	Direction	RSSI	Antenna
19/07/2019 00:09:52	F7 14 4E 00 C2 37			Exit	-92	2
19/07/2019 00:09:54	70 77 BC C0 84 A5	01 08 50	Toy	Entry	-94	2
19/07/2019 00:10:09	F7 18 4E 00 52 37	01 08 50	Toy	Entry	-94	2
19/07/2019 00:10:43	A1 27 DB CC 71 9A	03 00 00	Unknown	Entry	-91	2
19/07/2019 00:10:43	A1 27 DB CC 71 9A			Exit	-91	2
19/07/2019 00:10:46	DC 86 AF CE 59 A8	5A 02 0C	Smart Phone	Entry	-89	1

Fig. 3 *Example of data output from BT and WF scanners located in one detection point*

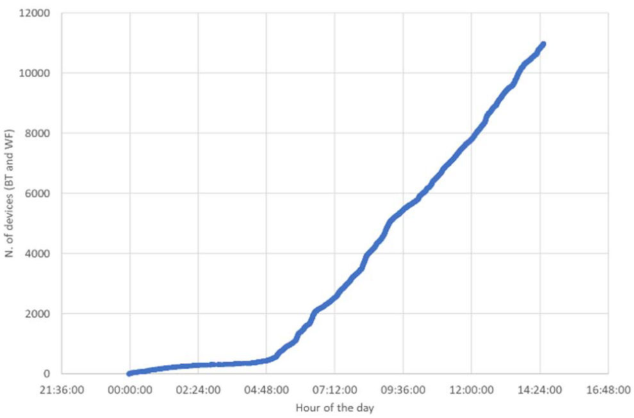

Fig. 4 *Example of cumulative plot obtained from BT and WF recording of one scanner (total amount: 12,000 devices in rush hours)*

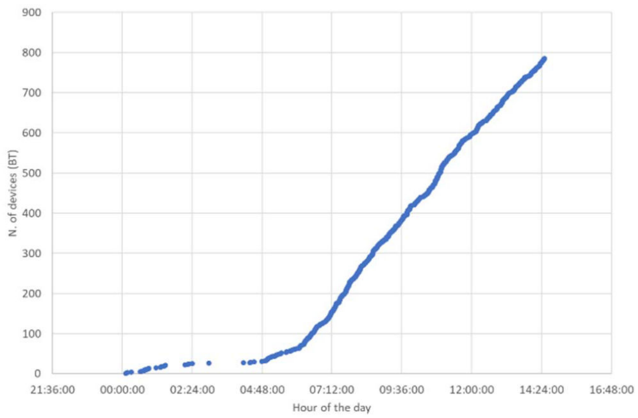

Fig. 5 *Example of cumulative plot obtained from BT recording of one scanner (total amount: 900 devices in rush hours)*

In conclusion, a preliminary analysis of the layout on the field is necessary to identify both the relevant points for the scanner location in relation to the position of the terminal's operational activities and the presence of possible critical aspects, such as obstacles to scanning.

4 Methodology of data processing for operations monitoring

The methodology for processing the collected data is proposed below to observe the heavy-duty vehicle flows inside the terminal, to detect their timing in sub-processes. This may enable the management and control of operations, thanks to the measurement of specific performance indicators.

Thus, the algorithm proposed is composed of some steps, described in detail in the following sections:

(1) Reading data from each detection node.
(2) Selection of useful information at nodes.
(3) Linking node information for network monitoring.
(4) Checking consistency of direction and travel time for links.
(5) KPI estimation.

4.1 Reading data from nodes

After positioning and setting the BT and WF scanners in the selected detection points and the time required for monitoring has elapsed, the outputs from each node can be analysed.

The information collected, as reported in Fig. 3, in each node, are:

- *date and time* are the time of MAC detection,
- *MAC* is the MAC address of the device,
- *class of device (COD)* defines the class of bluetooth device,
- *class description* is the decoded form of the COD,
- *direction*, the entry or exit direction status of the device,
- *RSSI*, the strength of the received signal of the detected device in DB,
- *antenna* displays the antenna from which the device was detected (BT or WF in our case).

The useful information for the method proposed is the time detection, the MAC code, the direction, and the antenna type.

4.2 Selection of useful information at nodes

In each data file collected from all the detection nodes, the antenna type is specified, because the MAC recordings come from both the BT and WF antennas (Fig. 3).

After the data analysis, the subset of records selected is only on MACs recorded by the BT antenna. There are two main reasons for this choice: to considerably reduce data noise (for example coming from external infrastructures), for the specific monitoring purpose, and easily link data to nodes thanks to antenna polarisation and the power of the signal; the Wi-Fi MAC randomisation phenomena that modify its identification code, precluding its tracking in different scanners. This is a privacy technique, emerging in this last period [20], whereby mobile devices rotate through random hardware addresses, especially when connecting for new networks.

Also, truck drivers detected inside the terminal are frequent users of BT devices and this guarantees a good number of observations. For example, in Fig. 4 the cumulative curve obtained from collected data in point A (see Fig. 2) from both BT and WF antennas during 5 h of monitoring is reported and the total amount of recording devices is considerably higher than the total detected MAC by BT antenna only (Fig. 5), which is more adequate for terminal observation.

Subsequently, the collected data are grouped by MAC address and the min and the max detection time are selected with reference to the 'entry' direction into the detection zone.

The output of these two starting steps is a single file containing the BT MAC addresses recorded in each point and their min and max detection time. The cumulative curve of recording data from a single scanner can be obtained.

4.3 Linking node information for network monitoring

The step explained in this section is possible, thanks to the type of automatic traffic data collection technology used, which reads the device ID, if its position is close to the scanner, and its time of detection, synchronised for all the scanners. In fact, starting from data individually collected in each point, matching the MAC ID is possible to map over the nodes of the network the routes covered by vehicles (Fig. 6). In this application, the MAC movements between nodes can be considered equal to the vehicle movements and no information is estimated for vehicles at intermediate points along with links.

To properly select those MAC devices, which actually can be part of the trucks flow is helpful to have the network topology because the knowledge of feasible paths allows us to exclude easily external devices. In Section 4.4, specific details on this selection process are reported.

The output of this phase is a merged file regarding the network (nodes and links), which includes the MAC addresses of the selected devices, their min and max detection time and the scanner ID from which the information is recorded.

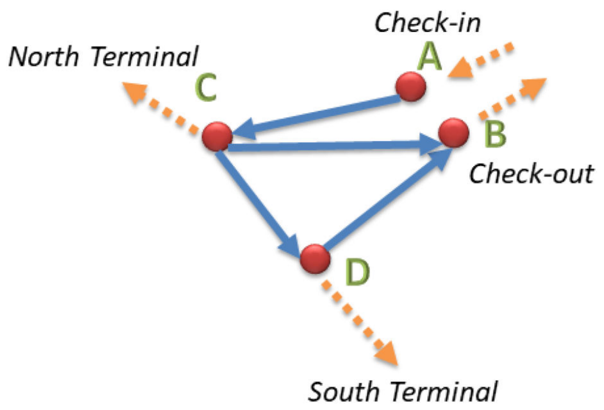

Fig. 6 *Example of a schematic representation of the network (analysed path in blue; external direction in orange)*

Fig. 7 *Schematic detection process description*

4.4 Checking consistency of direction and travel time for links

The fourth step of the proposed data processing method regards some quality check operations needed to be performed before calculating the possible traffic parameters (Section 4.5) and ensure data reliability.

The elements of procedure to filter out irrelevant records are similar to those that can be found in Michau *et al.* [12] and Abbott-Jard *et al.* [13] following an intuitive approach. However, the application studied presents some challenges that should be considered, such as the low traffic volume, the short distance between the points to be observed for entry and exit flows, disturbance in BT/Wi-Fi detection caused by high traffic level of a nearby highway.

The recording time used to select data and measure performance indicators is the first time when the device is registered at each point and some constrains are used to select data. According to the example shown in Fig. 7, the main conditions are the following (where C, A are the nodes of the same link; i, j are the MACs recorded):

$$t_C^i - t_A^i > 0 \quad (1)$$

$$t_C^i - t_A^i > T_{\min} \quad (2)$$

$$t_C^i - t_A^i < T_{\max} \quad (3)$$

$$t_C^i \cdot t_A^i \neq 0 \quad (4)$$

In particular, (1) checks if the one way for the link is respected; the feasible time difference between two nodes according to the specific terminal operation, namely knowing the typical minimum and maximum required time $T_{\min}$, $T_{\max}$ [see (2) and (3)] and the consecutive detection at both points [see (4)].

Moreover, as suggested by Margreiter *et al.* [1], one individual vehicle can carry several devices with activated BT interface simultaneously. To check and filter out these redundant devices, condition (5) is applied and, in case it is verified, probably if the two MACs are on the same vehicle then only one is considered:

$$t_A^j - t_A^i < T_x \quad \text{and} \quad t_C^j - t_C^i < T_x \quad (5)$$

4.5 KPI estimation

Here, the data collected from scanners are used to measure some performance indicators useful to monitor and manage the truck flow inside the intermodal terminal. They allow a rough estimation of the structure of the OD matrix, but the vehicle counting is difficult as not all vehicles have BT devices. In addition, the type of vehicle cannot be identified, as reported in the scientific literature (Section 1).

On the other hand, the truck's trajectories can be built, node by node, knowing the recording time in the selected node (scanner locations). In fact, the MAC movements can be considered equal to the vehicle movements, as aforementioned and the trajectories can be represented by a time–space diagram, where the space is discretised at node locations.

The individual travel time of each vehicle on a link (Fig. 6) can be calculated by the time difference between its records at two consecutive nodes [see (6)]:

$$\text{TT(MAC, pi, pf)} = t(M\text{AC, pf}) - t(\text{MAC, pi}) \quad (6)$$

where TT is the travel time, MAC is the single device, pi is the initial point and pf is the final point. In the case of the intermodal terminal, the trajectories describe the heavy-duty vehicle flow and the travel time of each link can be a measure of time required for the specific terminal operation on that link.

The total travel time in the intermodal terminal, defined as turnaround time, which is the time spent by a truck inside the terminal between the check-in and check-out operations, is a well-known performance parameter. According to Carboni and Deflorio [18] this performance indicators may represent the terminal productivity. It is affected by terminal procedure efficiency, terminal layout, and organisation, waiting time, and queue during the operations, presence of technologies, but other external elements can also influence the final value, as special customer requirements, drivers breaks, train delays, or, for vehicles, the number and the kind of operations that the driver has to do inside the terminal.

5 On-field tests and results discussion

The methodology proposed in this paper has been applied and tested in a large-sized Italian terminal, as introduced in Section 3. The scanners are four and located in key points, as shown in Fig. 2: check-in (A), after all, document check-in operations (C), at the entrance of the south sector of the terminal (D) and at check-out (B).

The results of the monitoring phase, which took place during a working day in July from 00:00 to 14:30, are reported in the following.

After applying the data selection described, the heavy-duty vehicle trajectories are traced node by node, distinguishing between the flow of vehicles that were detected or not in the node. In fact, both the routes are feasible: the first group includes the HDVs, which are served in the northern part of the terminal (class HDV flow 1) and the other includes vehicles served in the south or in both the areas (class HDV flow 2). The sequence of links for the two paths is

- A–C–B for class HDV flow 1.
- A–C–D–B for class HDV flow 2.

The time–space diagrams represented in Figs. 8 and 9 are the trajectories of the BT equipped trucks, with the recording time on the vertical axis, the detection nodes on the horizontal axis and the different lines are the various scanned MACs.

The observed data are verified by focusing on partial sub-process durations, which were measured also manually during several on-field data collection campaigns. Given the difficulties in comparing the traces obtained with the real ones, we have preferred to compare the time duration of the relevant sub-processes, which, however, are the final aim of the observation. The KPI obtainable from collected data is the travel time, associated with each link and disaggregated for the two classes of users, assigned at the two different sectors of the terminal, as well as their turnaround time, considering its importance for freight operators, as explained in Section 4.5.

According to (6) and the network scheme (Fig. 6), the total travel time for the nth MAC can be composed by different time elements, in detail:

$$\mathrm{TT}(n, A, B) = (t_C^n - t_A^n) + (t_D^n - t_C^n) + (t_B^n - t_D^n) \quad (7)$$

$$\mathrm{TT}(n, A, B) = (t_C^n - t_A^n) + (t_B^n - t_C^n) \quad (8)$$

Equation (8) is applicable to vehicle flow of class 1, whereas (7) is for heavy-duty vehicles of class 2.

The turnaround time composition and the detail of the duration of relevant operations are plotted in Figs. 10 and 11 for the selected MAC addresses. The time interval required for check-in operation, which includes both the UTI/vehicle inspections and paperwork operation, can be variable according to different aspects, such as the type of freight transported and documents, the number of operations or the number of terminal operators providing the service. The time share for 'terminal sud (south) entrance' (Fig. 10) is expected to be low (∼1 min), because the scanner points C and D

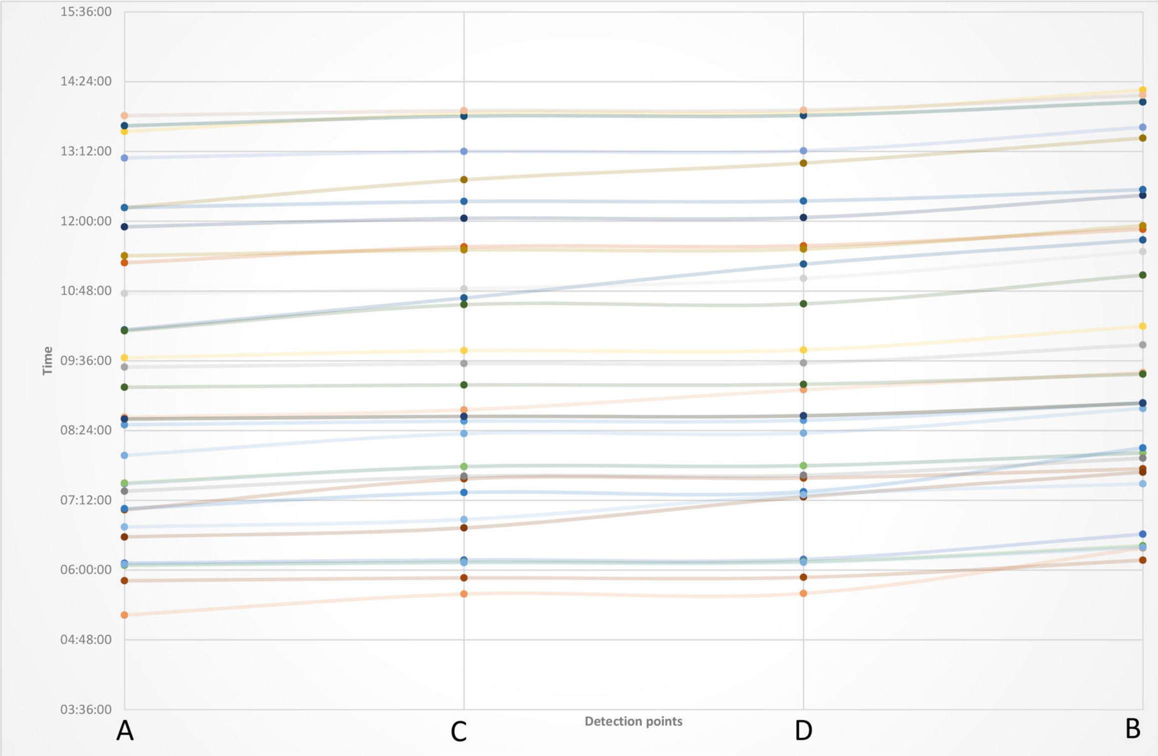

Fig. 8 *Vehicle (MAC) trajectories for HDV flow of class 2*

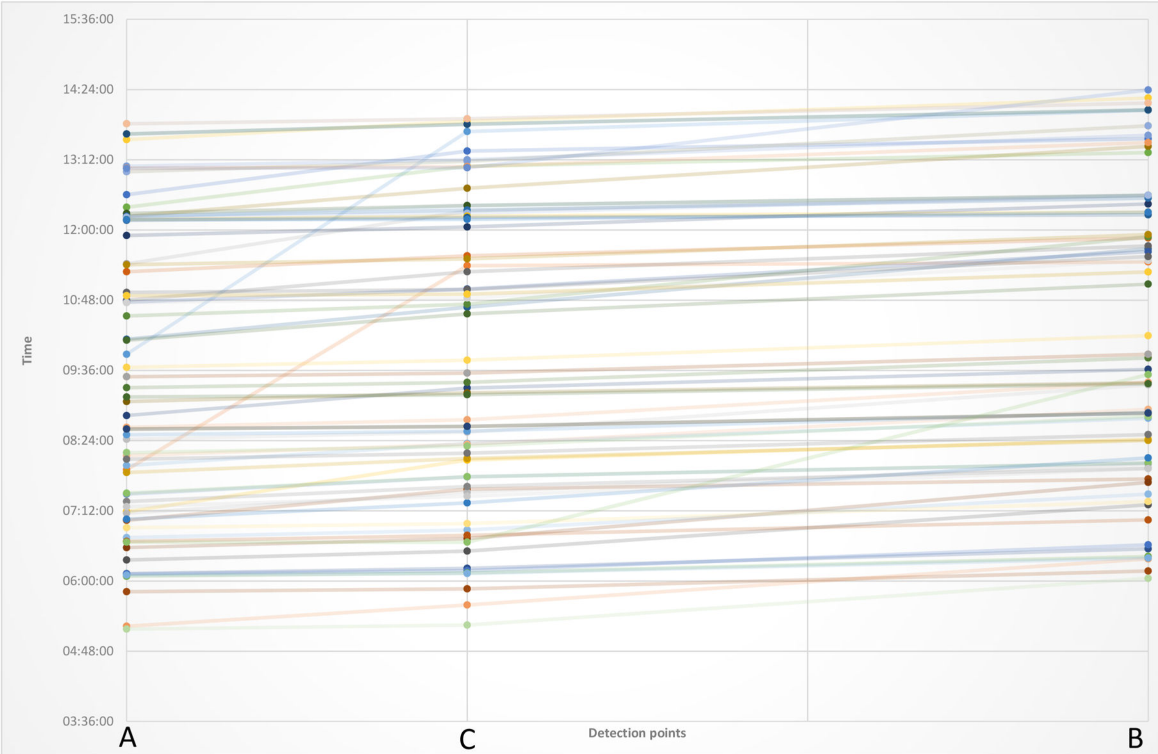

Fig. 9 *Vehicle (MAC) trajectories for HDV flow of class 1*

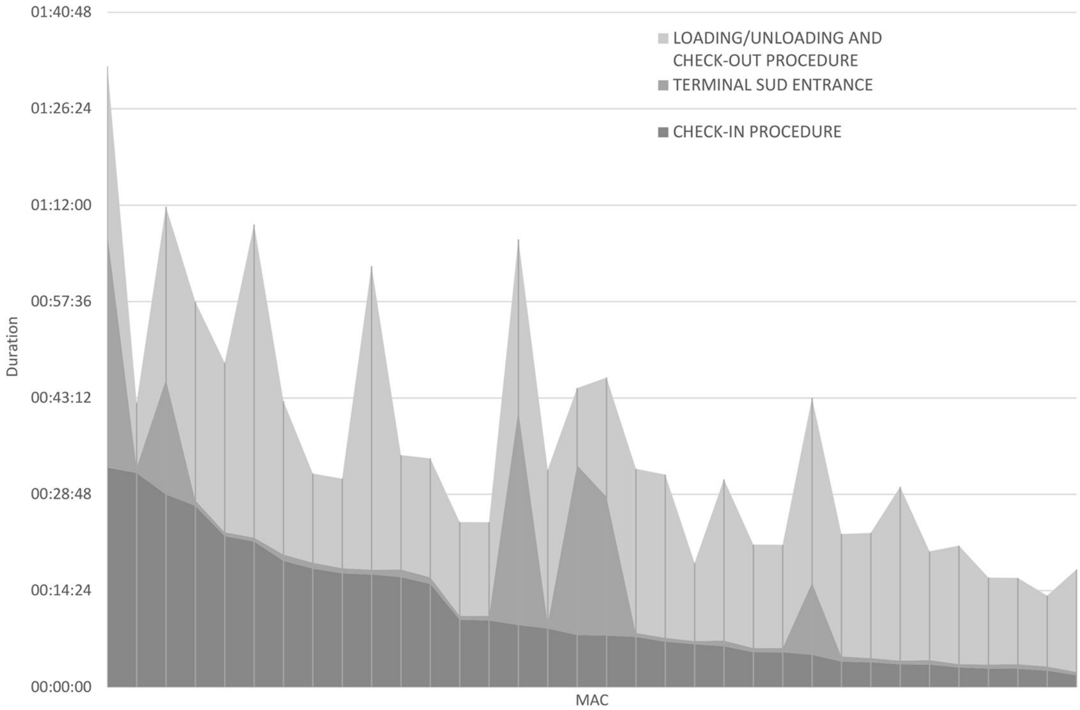

Fig. 10 *Turnaround time and duration of relevant operations for each HDV of class 2 identified by its MAC address*

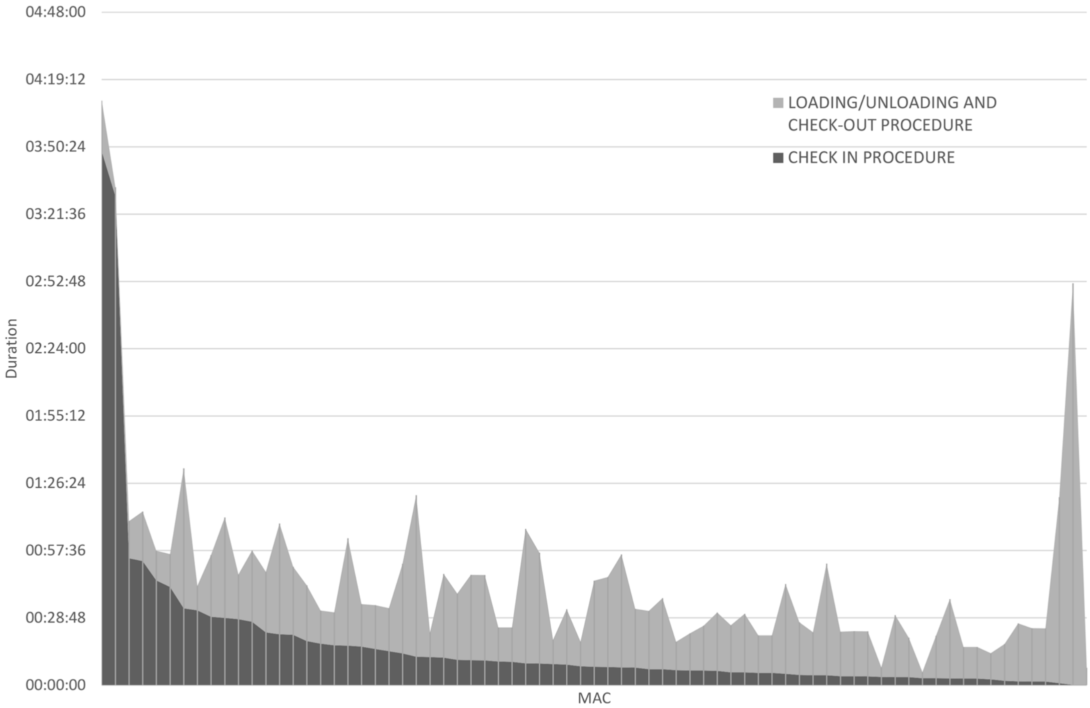

Fig. 11 *Turnaround time and duration of relevant operations for each HDV of class 1 identified by its MAC address*

are close and no delay should occur between these two nodes. However, some high values are observed, because they are referred to vehicles that first make operations at the north sector of the terminal and then to the south. The most relevant contribution of the process, in most of the cases, is the time for the transhipment and check-out operations. The values obtained are in the range of the time usually required for these operations, as expected by terminal operators interviewed and observed on the field during a series of on-field monitoring.

After the screening of the time spent by detected trucks inside the terminal at various sub-services and its distribution, to complete the picture and characterise the traffic flow, a view by time series is shown in Figs. 12 and 13. Focusing on the first operation, the time required for paperwork has been related in Fig. 12 to the time of arrival at the intermodal terminal to identify peak phenomena and analyse the time profile.

Most of the data observed using the described approach is consistent with the empirical time range of observed values (5–30 min) measured during manual on-field data collection. In the bar graph reported in Fig. 13, the average turnaround time values are related again to the time arrival at the intermodal terminal aggregated for hour bins. This chart shows that the peak hour, in terms of time required to perform the complete service, is at 10 am considering the arrival times, and the off-peak is not observed early in the morning, as observed in road traffic systems, but just 1 h before the peak (at 9 am) with a turnaround time of approximately one-third of the peak value.

Observation from BT is useful not only to measure the time variability during the day to be provided at tracked users as reliable

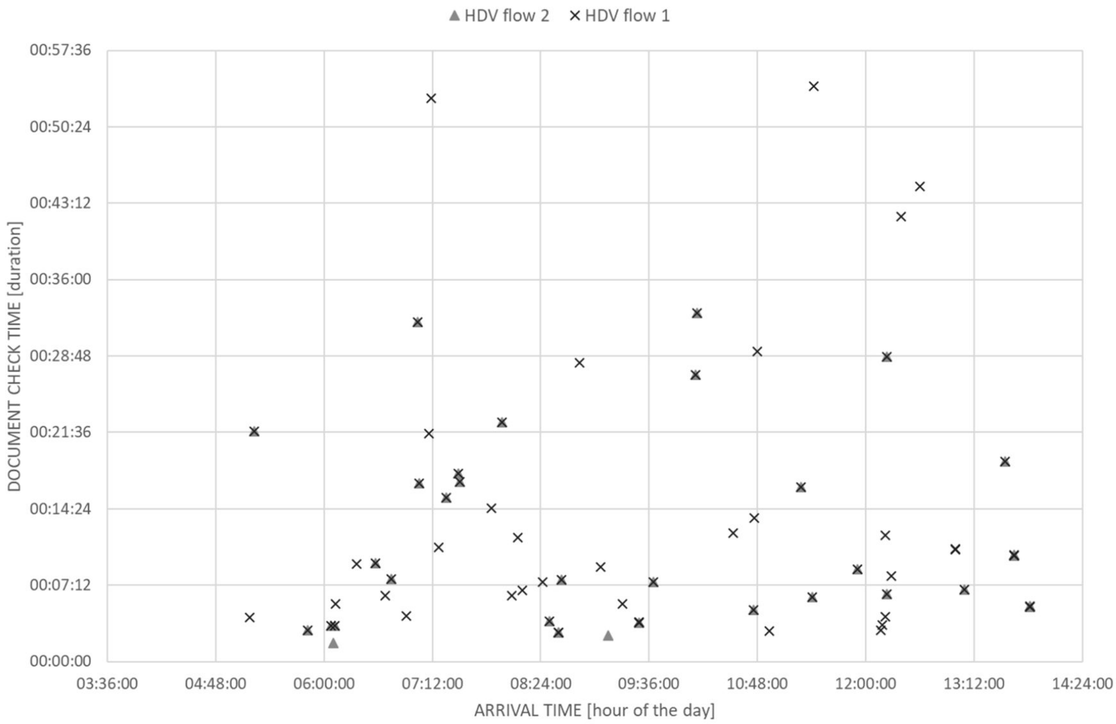

Fig. 12 *Observed document check time interval versus arrival time for both HDV flow classes*

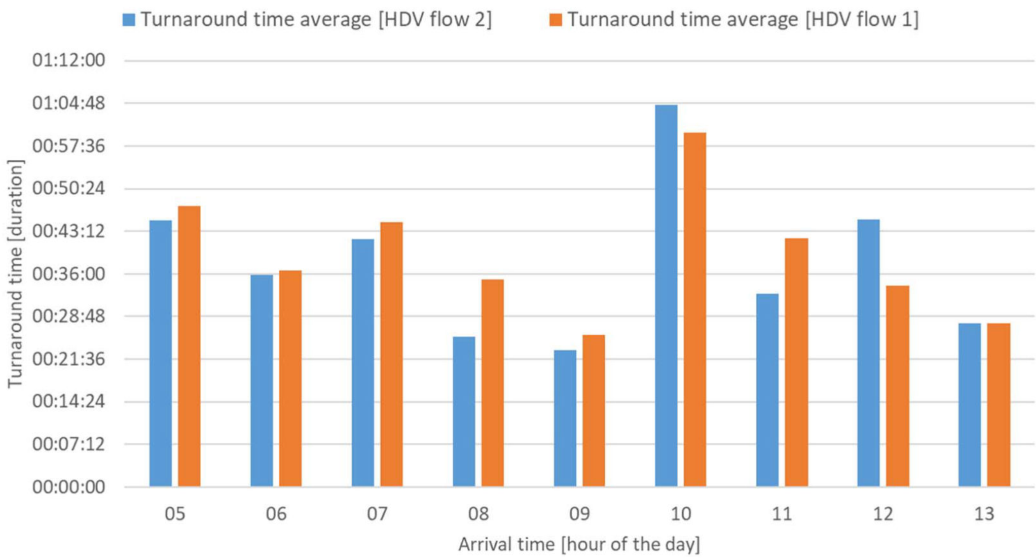

Fig. 13 *Turnaround time versus arrival time for both HDV flow classes*

information on the level of service for their operations, which may significantly change over the time of day, but also to identify the major delays in specific services of the entire process and connect them to the various sectors inside the terminal. This may help to explain the principal causes that can generate lower levels of service and be used also for terminal operators to balance the resources or the tasks assignment.

After the monitoring phase the detection rate was evaluated, thanks to the knowledge of the real HDV flow entering the terminal in the monitored time slots. It is around 20% on average and the selected devices on which the analysis was carried out from the original data collection are about a hundred.

6 Conclusion

The paper presents a pioneer application of BT scanners for monitoring the operation of heavy-duty vehicle flows inside freight terminals, based on a simple methodology of data processing. The selected technologies, as confirmed by the literature review, are relatively inexpensive, guarantee non-participatory tracking of devices, avoiding potential privacy infringements. Moreover, these monitoring activities may be carried out without interfering with the customary terminal operations, which is a fundamental requirement for intermodal freight terminals.

The collected dataset has been processed for the measurement of the time that truck flows spend inside the terminal at relevant points and for estimating KPIs focused on specific operations. The main output from BT data collection and processing is the information about trajectories of vehicles, traced only at selected detection points, and their travel time, because the recorded BT devices are supposed to be on board for vehicles inside the terminal. The method to process the collected data is designed to meet the specific requirements for mapping the terminal processes. Tracking vehicles according to their activities in different sectors inside the terminal is useful to measure the performance of sub-processes, both for users and operators, detecting principal events at selected links. The presented test reveals some specific issues of the application in terminals that are interesting to be presented and discussed. Moreover, results are promising for process monitoring purposes because BT devices are widely used on-board by truck drivers, and the method, according to its intuitive approach, can be easily communicated to stakeholders and transferred without complex coding operation.

Future work includes the analysis of data with the same methodology for an extended time period of on-field tests. Moreover, also Wi-Fi data may be included in the processing procedure, trying to expand the data set of the measurements, although requiring further data analysis techniques. Finally, the methodology of data processing for operations monitoring proposed can be tested also in other freight terminal layouts, such as in ports, where more complex scenarios may require the analysis of RSSI data gathered from devices.

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