

# **Towards Visualisation of Traffic Congestion using Bluetooth MAC Scanners (BMS): Automating the process of BMS links generation**

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## **Abstract**

Bluetooth MAC Scanner (BMS) based traffic data is widely utilised to estimate travel time (speed) on the road network. The seamless availability of BMS data from large urban networks (such as Brisbane) provides opportunities to visualize congestion on the network. However, the baseline road network cannot be directly used for congestion mapping as the BMS scanners are offset from the road network. Thus, it becomes necessary to snap scanner points on the road network thereby creating a BMS based network. The BMS based network lines are currently manually assigned which are inefficient as well as time-consuming. This paper provides a technique that can be adopted for any large-scale network to define the links between the scanner locations. The strategy expresses a procedure based on the restricted path matching technique. As a case study, the proposed methodology is applied on real Brisbane network and utilised for congestion dashboard development.

Keywords: Bluetooth MAC Scanners, BMS Links, Congestion visualization, Spatial Network, Open street map, dashboard

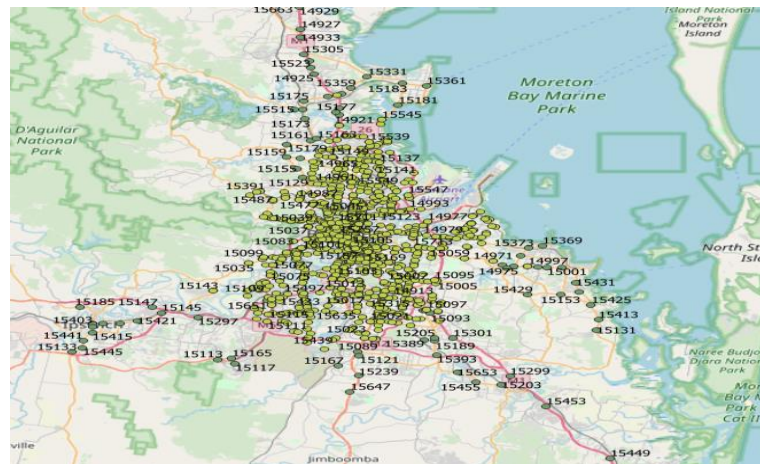
# 1 Introduction

Bluetooth MAC scanner (BMS) is one of the widely collected traffic data in Brisbane and other major cities of the world. Interested reader can refer to Bhaskar and Chung (2013) for understanding the BMS data. This data is utilized for number of applications such as travel time analysis (Bhaskar, Tsubota, Kieu, & Chung, 2014; Khoei, Bhaskar, & Chung, 2013; Kieu, Bhaskar, & Chung, 2015), Macroscopic fundamental diagram (Tsubota, Bhaskar, & Chung, 2014), Origin-Destination (O-D) matrix estimation (Blogg, Semler, Hingorani, & Troutbeck, 2010; Gabriel Michau et al., 2017), vehicle trajectory extraction (G. Michau et al., 2017) and route choice (Hainen et al., 2011).

In Brisbane, we have more than 1200 BMSs monitoring our transport network. Figure 1 illustrates a network of BMSs in Brisbane. The data from these sensors is seamlessly acquired and stored in a database. For easy conceptualization of the information and identify spatial temporal insights, the agencies aim to visualize the information from the datasets. One such application is development of congestion maps and dashboards for business intelligence.

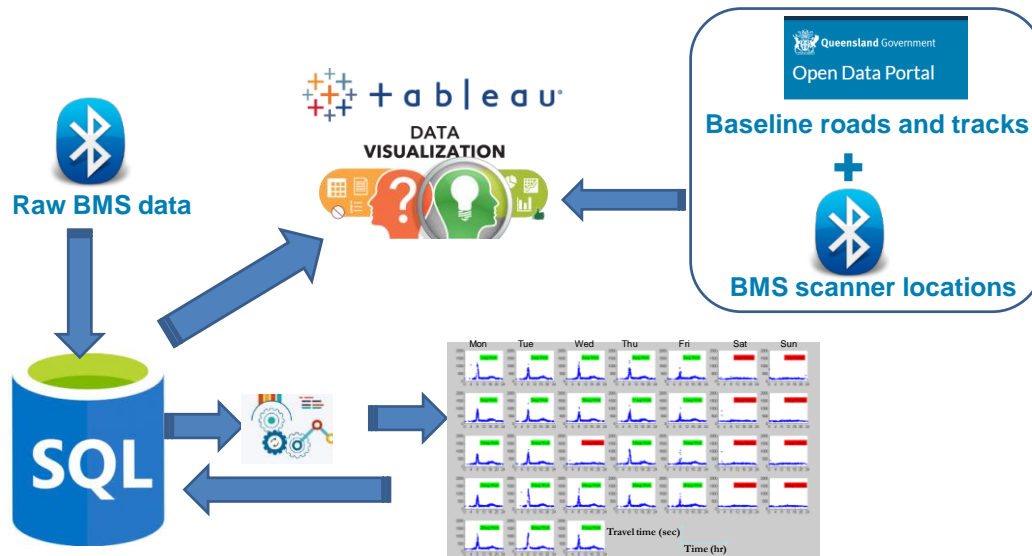
In this paper, we present a framework for the development of congestion visualization tool using BMS dataset with focus on one of the challenges to automate the generation of BMS links for visualization. A methodology to develop BMS links by running a shortest path algorithm among restricted intercepting points is presented. Very few papers in the literature have focused on the method of considering the restricted path (Gheibi, Maheshwari, & Sack, 2015; Zhu, Holden, & Gonder, 2017) and are constrained to map matching applications.

**Figure 1 Location of BMS scanners in Brisbane**



For the current analysis, we have employed a commercial software Tableau for visualization. Tableau is considered for visualization because it is currently considered as cooperate standard by Qld Department of Transport and Main Roads.

**Figure 2 Framework for congestion visualization**



## 2 Developing BMS links for visualization

The baseline road network can be obtained from the open street map or from government open data portal. In Queensland, the Queensland baseline roads and tracks data is available at [data.qld.gov.au/dataset/baseline-roads-and-tracks-Queensland](http://data.qld.gov.au/dataset/baseline-roads-and-tracks-Queensland). This dataset represents street centrelines of Queensland developed in compliance with the provisions of the Queensland Spatial Information Infrastructure Strategy (QSIIS) Standard 3. The street records are polylines with attribution including street name, road classification, route numbers (State and National), and a unique identifier. This dataset is currently maintained for the Department of Natural Resources, Mines and Energy and is sometimes referred to as the SDRN basic (State Digital Road Network).

Figure 3 shows a visualization of the QLD baseline roads and track dataset. Note: In this paper, refer to such baseline road network simply as OSM.

**Figure 3 Snapshot of QLD baseline road and tracks shape files**

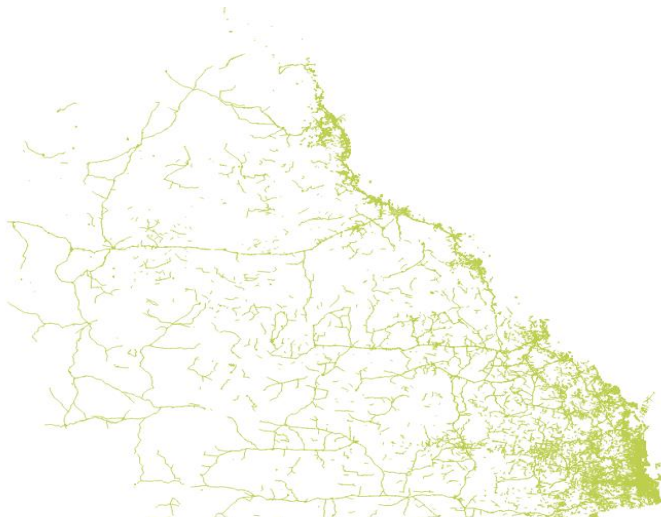
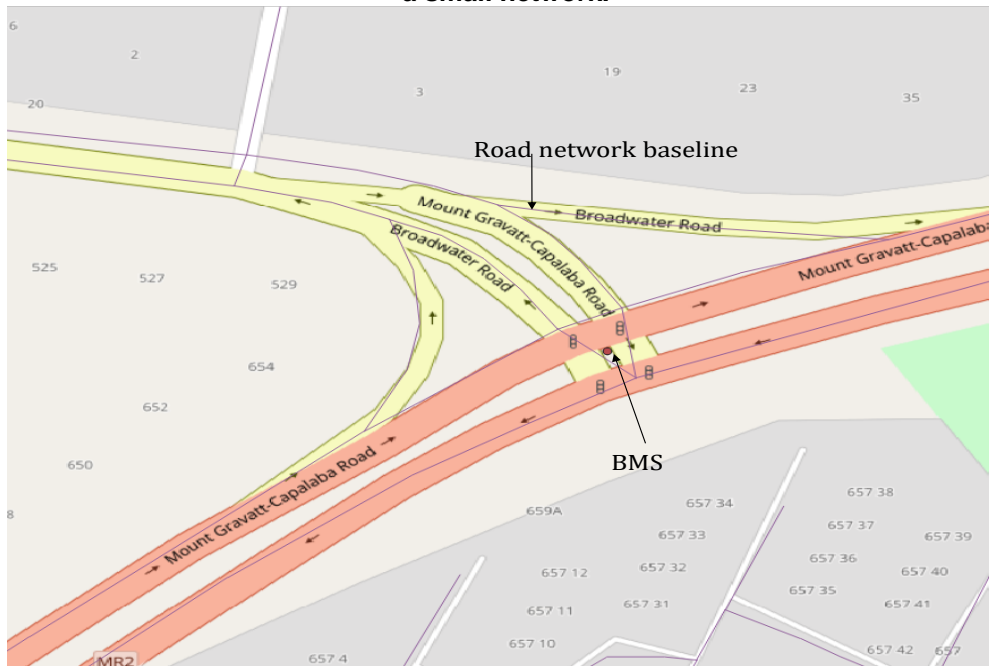
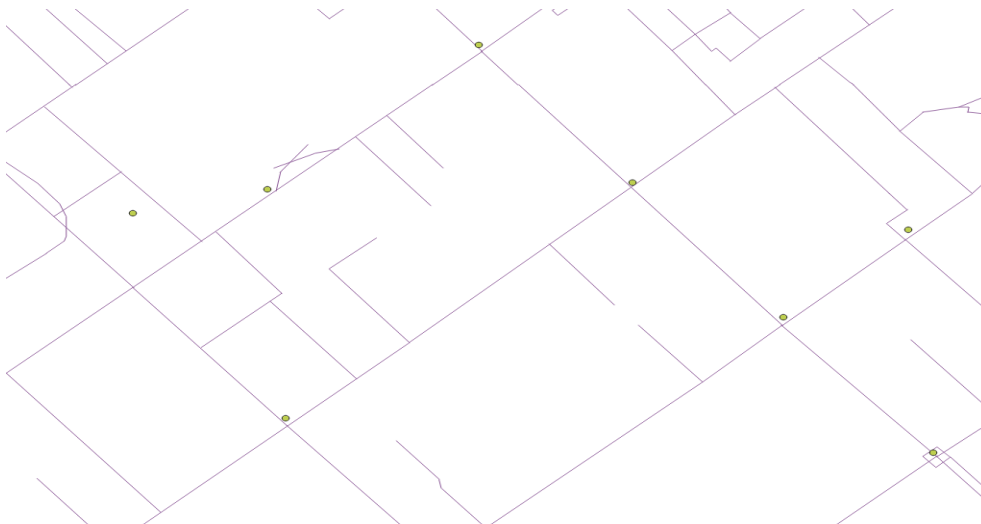


Figure 4 presents BMS scanner located at an intersection and the corresponding baseline road network. It can be seen that the BMS location do not exactly map to the road network. To establish BMS link between the two BMS scanners, we need to map match the BMS scanner to the road geometry. This process can be done manually by assigning the reference coordinate for each sensor on the surrounding links, thereby connecting the links between the sensors. However, this process is tedious and incompetent and cannot be adopted for developing citywide network. Addressing this, we propose a novel methodology to automate this process, which is presented in the following section.

**Figure 4 Illustration of the road network baseline and BMS location a) at an intersection; b) for a small network.**



(a)



(b)

Each link in the OSM layer possesses set of attributes like type of road, terrain, speed limit and so on. The attributes from these links can be adhered to other layers to extract the desired points/ links and is described in the methodological section of this paper. The targeted network comprises of links where the BMS scanners are present. Hence,

it was desirable to remove redundant layers such as footways, pedestrian, and cycle tracks from the base map. This way, the unnecessary layers were filtered out and only the essential layers were considered for the base map. Finally, these two separate datasets were integrated as an input for sensor-based network formulation.

### 3 Methodology

#### 3.1 Challenges and Framework

As stated in previous section, the sensor co-ordinates do not correspond to the point on the road network; rather they are drifted away from the road map. This section explains sequential procedure to snap sensor co-ordinates on the road network thereby developing links among adjacent sensors.

**Figure 5** Overlapping of sensors on the OSM layer

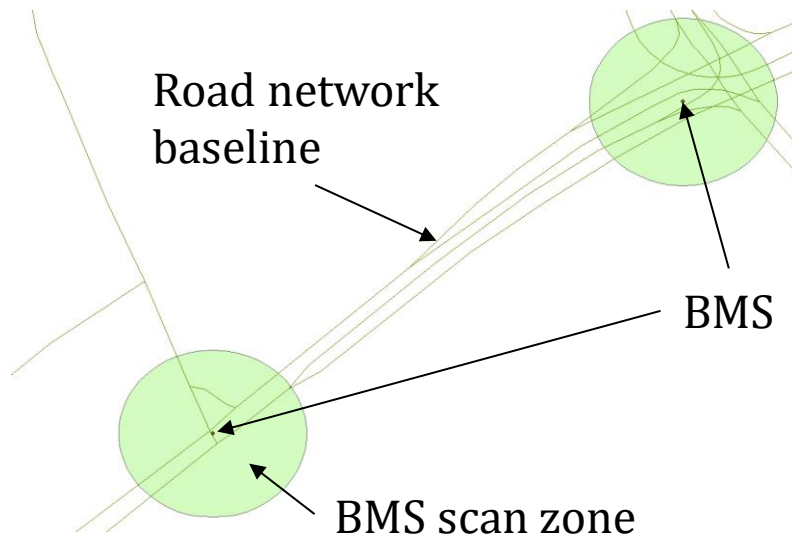
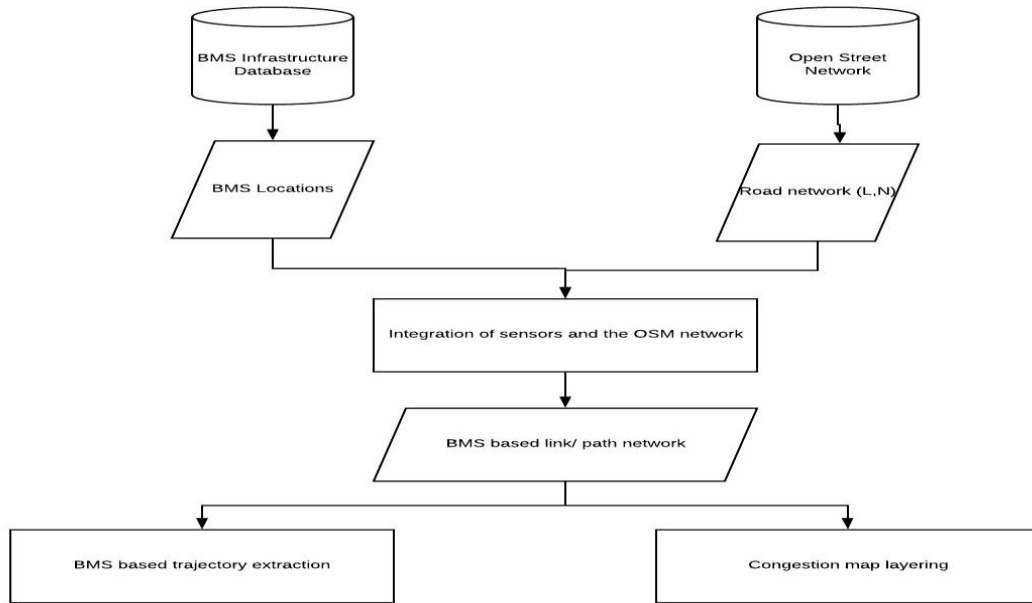


Figure 5 shows two sensors on the road network for which a BMS based link needs to be established. To trace a path between these sensors, the procedure is divided in three stages:

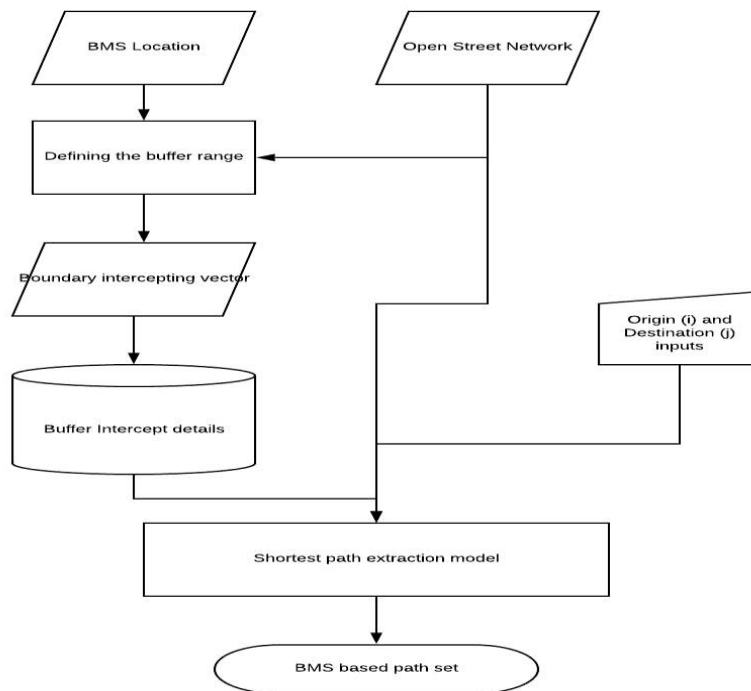
1. Creating buffer zone
2. Defining intercepting vectors
3. Applying shortest path algorithm

To understand the procedure, Figure 6 and Figure 7 presents a self-explanatory flowchart for overall framework and methodology for extracting the network layers respectively.

**Figure 6 Methodology Flowchart**



**Figure 7 Flowchart explaining methodology to extract BMS based path set**



The methodology is expressed in two subsections, i.e. buffer and intercept vector creation and secondly application of shortest path algorithm. The points of the intercepting vector are extracted to construct links between the scanners using the shortest path algorithm. Lastly, the entire process can be automatized to create a citywide network for the scanner-based links developed. The following sections provide a sequential explanation of the adopted method.

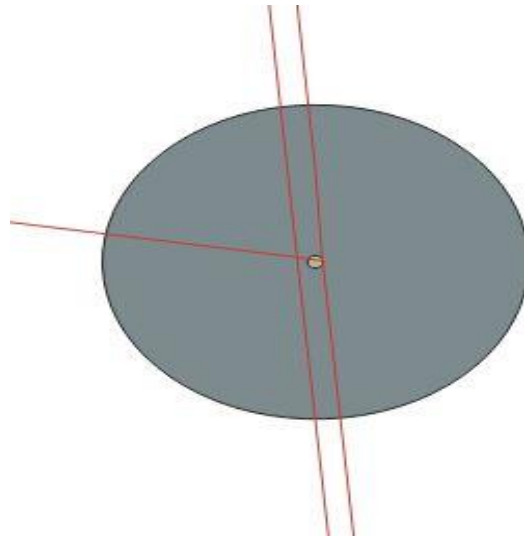


### 3.2 Buffer creation

The sensor database possesses attributes such as id number, latitude, longitude and so on. These coordinates are plotted in GIS software (<https://qgis.org/en/site/>) to create an integrated layer comprising of the OSM layer attributes alongside the sensor location details. Buffer zone is created to dole out a zone of influence (detection zone) for each sensor. For existing study, a buffer zone of 250-meter radius is considered based on the sensor attributes as shown in the

Figure 8. The above-considered radius range is based on the field observed influence area and may vary based on the environmental conditions.

**Figure 8 Buffer zone for the sensor**

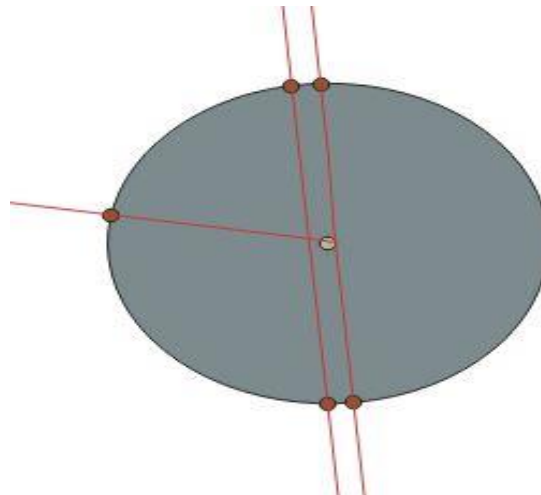


These, buffer zones are utilized to extricate the spatial information using GIS tools from any overlapped layer (here, OSM base map). In this way, buffer creates two different territories: one within the zone of effect and the other is everything beyond the created buffer.

### 3.3 Extracting intercepting vectors

**Intercepting Vector:** Intercepting vector are the set of points obtained by intersecting the buffer boundary layer with the open street-based road network lines.

**Figure 9 Developing Intercepting vector points**



In this way, for each sensor, a set of points defined as intercepting vector are considered as potential set of points that are used to generate link between sensors. The co-ordinates from this vector can be used as a commencing or terminating point for a sensor to follow a way to its adjacent sensors.

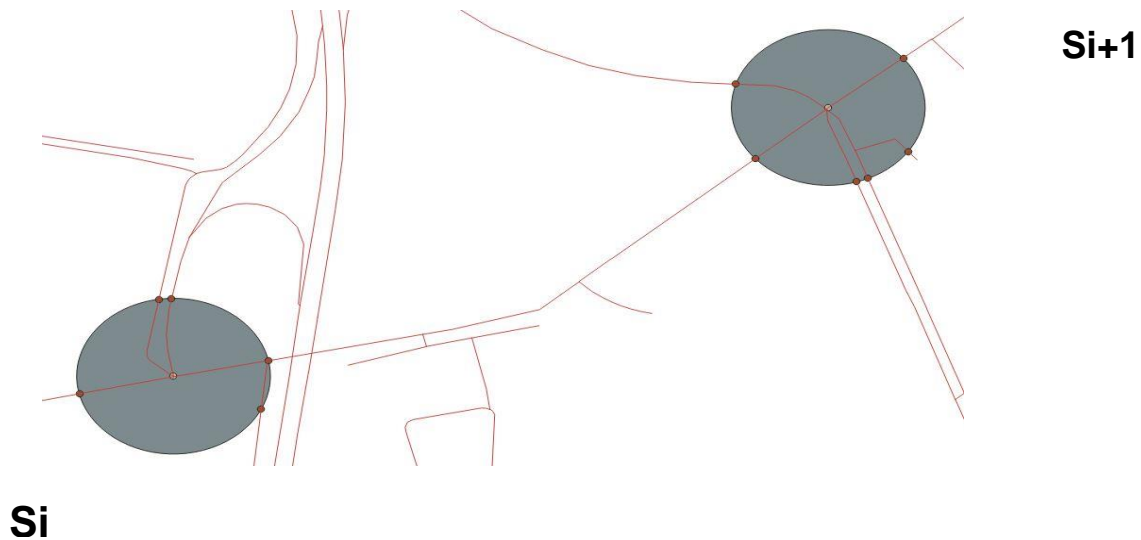
### 3.4 Shortest path Algorithm

A shortest path algorithm runs among the intercepting vector points for a sensor pair. The shortest path method works on the estimation of minimum distance/ cost from a cost matrix for all possible routes between a set of points (Ahmed & Wenk, 2012; Alt, Efrat, Rote, & Wenk, 2003). The cost matrix in GIS tools is either estimated in terms of minimum length (for shortest path) or based on minimum time (for fastest route based on travel time). The study considers only forward directional; distance based shortest paths. For the dataset as observed in our case, two different methodologies can be adapted to find the shortest path between two sensors:

1. Many to many
2. One to many

To highlight the above two approach, a practical example from the Pacific motorway is considered for explanation;

**Figure 10 Real examples of sensors on Pacific motorway with their intercepting vector points**



#### 3.4.1 Many to Many approach

Figure 10 demonstrates the position of two sensors alongside their radial buffer zone marked with their intercepting vector points. The sensor from which link starts ( $S_i$ ) is defined as the upstream sensor whereas the sensor where the link terminates ( $S_{i+1}$ ) is defined as downstream sensor. The first approach i.e. many to many matching, consists of determining the shortest path among all the points in the upstream sensor with that of those in the downstream sensor. Subsequently, supposedly, the upstream intercept vector consist of  $M$  co-ordinates and the downstream sensor consist of  $N$  co-ordinates then this approach searches shortest path for  $M \times N$  pairs. This includes a great deal of computational burden for the network solution and is practically a non-plausible strategy. A viable solution to the problem is the application of one to many approaches where the single point of the upstream sensor is matched with all vector points of the downstream sensor.



### 3.4.2 One to many approach

The matrix  $M \times N$  observed in the above approach is reduced to a  $1 \times N = N$  set of the shortest path, given that the initial point of the upstream sensor is determined. In this way, the one to many approaches is computationally promising with less number of iterations to run for path development. Yet, it is crucial to determine the potential co-ordinate from the intercept vector set that can be considered for shortest path analysis. To understand this,

Figure 11 explains the process of selection of starting and terminating points between upstream and downstream sensors.

**Figure 11 Reference points to establish link**

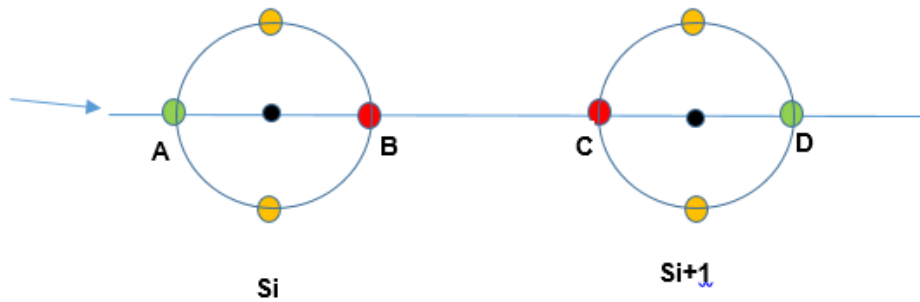


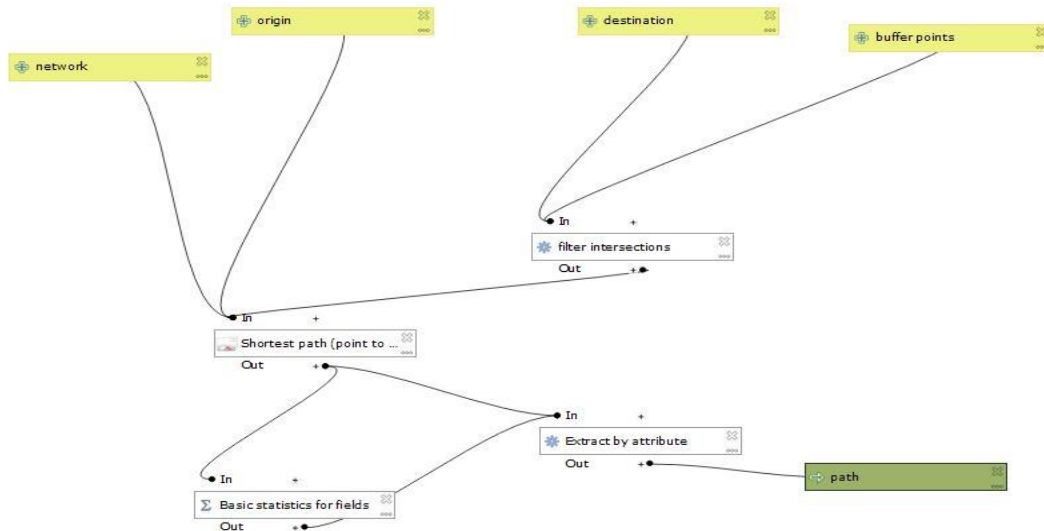
Figure 11 represents a two-sensor network where the link needs to be traced from sensor  $S_i$  (upstream) to sensor  $S_{i+1}$  (downstream). Let us consider the intercept vector for the sensors as  $V_i$  and  $V_{i+1}$  respectively. To trace a path based on one to many approach, a starting point needs to be determined from sensor  $S_i$  that can search the shortest path to all the points in vector  $V_{i+1}$ . Now if  $n_i$  is the starting point of upstream sensor and  $N_{i+1}$  are all the intercept points in downstream, a shortest path runs between  $n_i$  to  $N_{i+1}$  and the path with minimum distance is extracted. For ease of the study,  $n_i$  is always considered as point at which the vehicle enters the upstream sensor. As shown in

Figure 11, A is the point of entrance for the upstream sensor  $S_i$  i.e.  $n_i = A$ . The shortest path is calculated from A ( $n_i$ ) to points in vector  $V_{i+1}$ . This will create a link from A to C. Similarly, in the next iteration i.e. for path from  $S_{i+1}$  to  $S_{i+2}$ ,  $S_{i+1}$  acts as an upstream sensor. In this iteration, a shortest path algorithm will be executed from point C ( $n_{i+1}$ ) to all the points ( $N_{i+2}$ ) for  $S_{i+2}$  and a link among these two will be generated. The process is iterated until a path is traced from origin to destination sensor.

The entire procedure can be visualized in a path between multiple sensors. The model is a cluster of various GIS tools, integrated together to generate BMS link between sensor pair.

Figure 12, which is an integrated model developed in the QGIS platform to extract the path between multiple sensors. The model is a cluster of various GIS tools, integrated together to generate BMS link between sensor pair.

**Figure 12 Automatized network generation model in QGIS**



The model uses a GIS platform that requires a network layer on which the sensor coordinates can be plotted as well as the shortest path can be computed. The origin and destination sensor id are inputs to the model and the shortest path between the set of two vectors is generated. Based on this, the shortest path runs between all possible point set as discussed in e path between multiple sensors. The model is a cluster of various GIS tools, integrated together to generate BMS link between sensor pair.

Figure 12 and the cost vector for all possible paths are created. The algorithm fetches the minimum cost (usually length) from all the paths generated and the path with minimum cost is extracted and saved as a layer/shape file in GIS platform. Similarly, for the next iteration, the output co-ordinate (destination) of the previous iteration serves as an origin and the entire process is repeated until the last sensor is detected for the trip. Consequently, for each iteration, a layer file is generated that interfaces the link between the origin sensors to its immediate downstream sensor. The layer file for each iteration is stored in a database and then merged to create a single layer network file. The example in the next section demonstrates the implementation of the stated methodology on a real network.

## 4 Case study: Brisbane Motorway

To validate the stated method, a real-world network is considered to develop a network for a group of sensors on the Brisbane city. The network developed comprises of seven sensors, which connects four major intersections of the city.

**Figure 13 Brisbane Motorway network for path generation**



As shown in Figure 13, sensors are labelled with a unique id and the study displays a connected network between 4 major intersections with sensor id 15159, 14965, 14961 and 15129 respectively. The algorithm as explained in Figure 12 is implemented after which the path network is traced as shown in Figure 14.

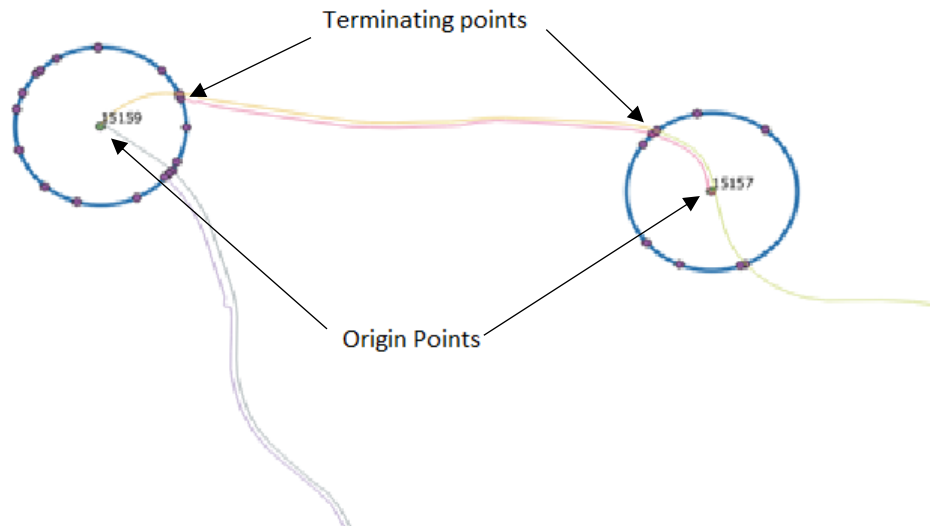
**Figure 14 Extracted network for motorway section**



The outcome demonstrates that the adopted methodology is reasonable for implementation to any network having the traits as considered for the Bluetooth sensors. A closer look at the network can provide a better insight into the path developed. Figure 14 shows a two-way path developed between pair of sensors. For better understanding, let us consider the path between sensor id 15159 and 15157. For the first case, a path was extracted considering 15159 as the origin id and the 15157 as the destination id. Here, initially based on the inputs, the algorithm determines the nearest point to the origin sensor co-ordinate after which it determines

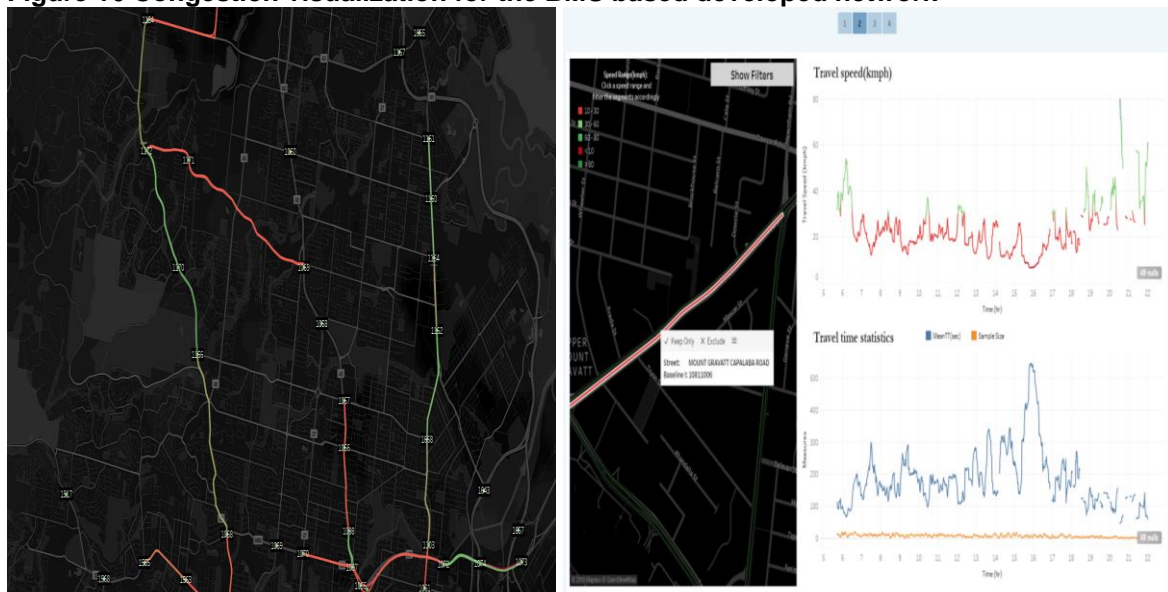
a set of paths to the intercept vector of the destination coordinate (here id 15157). Thus, after creating a set of paths with their cost value, the algorithm further extracts the path with the minimum cost (length) and creates a layer connecting the two. The same process applies when the co-ordinates are reversed and is shown in the Figure 15.

**Figure 15 Validation of the developed links**



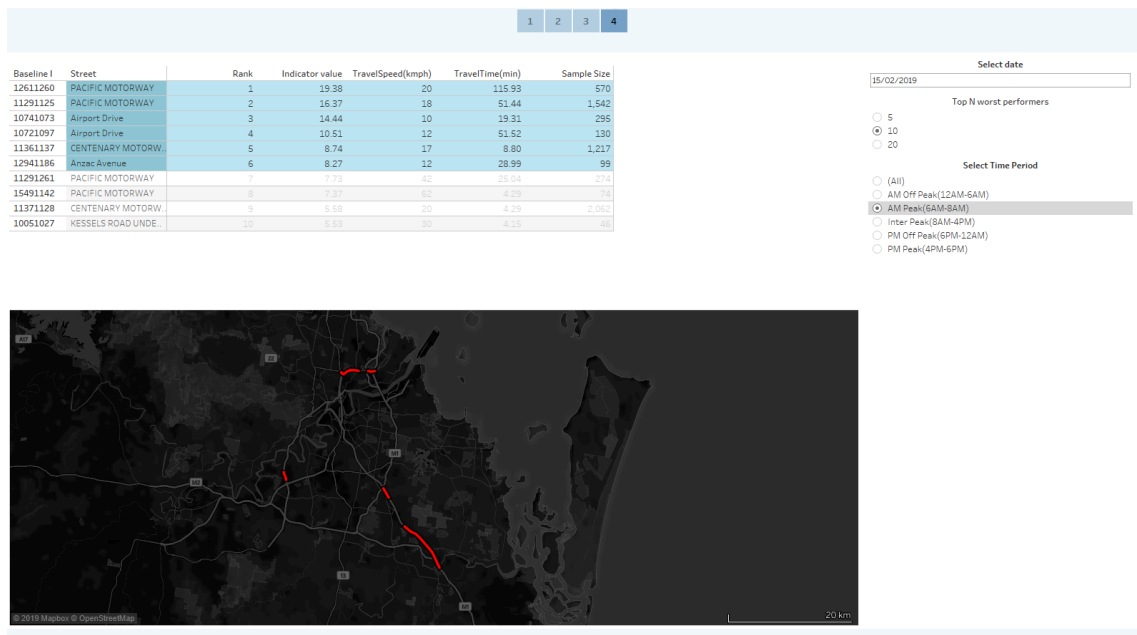
The adopted strategy was reached out to the entire city network after which the congestion plots were visualised in the tableau software based on the derived travel time statistics. It is important to note that, the input layer in the Tableau software is the network layer developed by the stated technique. Accordingly, each link in this network is based on the shortest path between a pair of sensors rather than the layer from the open street or any other base map. Figure 16 shows the visualisation that demonstrates the practicality of the procedure adopted. This consists of portraying congestion maps for the developed BMS links.

**Figure 16 Congestion visualization for the BMS based developed network**



The visualisation (left) shows variation in colour over the links based on the observed travel speed. The figure (right) shows the snapshot of the Tableau dashboard where the congestion attributes i.e. travel time and travel speeds variation are presented for a specific BMS link. These attributes and statistics are inputs to the software for the congestion mapping. Similar congestion patterns are analysed for different periods of the day. Based on the congestion statistics, a dashboard representing Bluetooth based link ranking was prepared as shown in Figure 17. The dashboard allows visualisation of the critical links for various period of the day. These ranking are based on the criticality of the links, i.e. in the descending order of the observed delays for a given time period.

**Figure 17 Tableau Dashboard for estimating Bluetooth based link ranking**



In this way, the developed network is an important element for visualization applications using BMS sensors. The methodology can also be stretched out in building up the trajectories using the ids of the vehicle detected at several sensors. Thus, the stated solution is the state of the technique that is efficient and computationally inexpensive, making it suitable for application to any large-scale networks.

## 5 Conclusion

A large volume of data is available from the Bluetooth scanners-based network established for the Brisbane city. This paper conceptualises a framework for visualization of congestion maps using BMS dataset. The method focuses on challenges to automate the generation of BMS links used for congestion visualisation in dashboard and that can be suitable for business intelligence. The methodology involves generation of BMS based links by integrating the Bluetooth scanners and the Open Street Map network. The issue regarding the drifted coordinate, which makes it difficult to generate the scanner-based links, has been addressed. The paper suggests the state-of-the-art method for developing the BMS based network using restricted path matching technique. It begins by developing a buffer zone of 250 meters radius thereby extracting all the points intersecting between the buffer boundary and the base line road layer. The intersecting points were defined as an intercept vector and were



used as reference points to trace the link among sensors. Thus, for developing these links, distance based shortest path algorithm was adopted using one to many approaches. In this way, a path with minimum cost (distance) was extracted and a layer file was then generated. The paper provides a QGIS model used to automatize the process of creating a network layer for a set of scanners. The stated methodology was tested on a network considering seven sensors, connecting four major intersection from the city network. The results were considerable, and the method was extended to develop BMS based links for the entire Brisbane city network. The extracted network was utilized to develop congestion visualisation plots using tableau platform. Lastly, the results were exploited to rank the BMS links based on their level of congestion for different duration of the day. Thus, the stated method is convincing as well as ready to implement for any large city network.

## 6 Acknowledgment

The authors are thankful to Transport Department of Main Road (TMR) and Queensland University of Technology for providing the Bluetooth data used in the study. The conclusions of this paper reflect understanding of authors, who are responsible for the accuracy of the research findings.

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