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Analysis of Ghost Driver Hazard of Road Junctions by Graph Technique

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RESEARCH ARTICLE

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Abstract

Due to the increased traffic, improving road safety is one of the major issues in the transportation policies of most countries. Our primary goal is to locate possible spots where vehicle travel against the traffic direction is possible. Vehicle driving on the wrong side of the road also known as ghost driver. This paper presents a technique in junctions based on graph analysis to locate possible ghost driver spots. The paper demonstrates a safety technical application in the case of different type of road crossings and gives an overview about the thematic data modelling and the applied technology.

Keywords

traffic, transportation, graph, Ghost driver, intelligent transportation systems, road safety, radio frequency identification

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1 Introduction

One major consequence of the motorization growth is the increasing number of wrong way driving cases caused by distraction or fatigue. Obviously, there is always a chance of drivers deliberately traveling in the opposite direction. The vehicle against traffic (Ghost Driver) is especially dangerous on high-speed roads. Their appearance is becoming more common in urban environment, which can have many causes. Extreme weather situations (dense fog, heavy rain) or driving under influence (alcohol or drugs) can be causes of potential ghost driving that leads to serious accidents. Following incorrect/outdated instructions of the navigation device may also cause such accidents (e.g. Hungarian M6 motorway wrong-way crash accident in 2011). Although human observers can recognize ghost drivers, their automated sensing and detection would be more expedient. Besides the immediate report cannot be guaranteed, the observer may miss the accurate direction and position of the wrong-way driver in case of an extensive, complicated junction. The automated system's error rate is low, as it can give well-defined position for the vehicle being in opposite way (Krausz et al., 2009; Krausz and Barsi, 2010; 2016).

Accidents are the most serious side effects of road transportation. In many countries the outcome and cause of the mass car accidents are carefully investigated. According to statistics, numerous accidents involve ghost drivers: in Austria 358 and 383 cases were reported in 2014 and 2015, respectively [www.ots.at - Geisterfahrerstatistik]. Mostly fatal accidents occur between the frontally colliding vehicles because of the big speed difference. In addition, due to high traffic on motorways, mass accidents are happened with personal injury and substantial property damage (Safespot, 2008; M. Pour-Rouholamin et al., 2016; Mahdi Pour-Rouholamin et al., 2014; Xing, 2015).

2 Junction overview

In this paper five junctions from three countries will be presented explaining the analysis process; these are as follows:

- Dunakeszi M0 Highway – Hungary
- Hannover A2 Motorway – Germany
- Torino-Caselle Motorway – Italy

- Mogyoródi út – Mexikói út – Budapest, Hungary
- Rákóczi híd – Pázmány Péter sétány – Budapest, Hungary.

Basically, the research is focused on high-speed roads, but our investigation involved two urban intersections to enable providing new aspects for the analysis. In case of the selected urban nodes it is important to note that wrong-way crash accidents already happened there, one of them was fatal (Fig. 1).

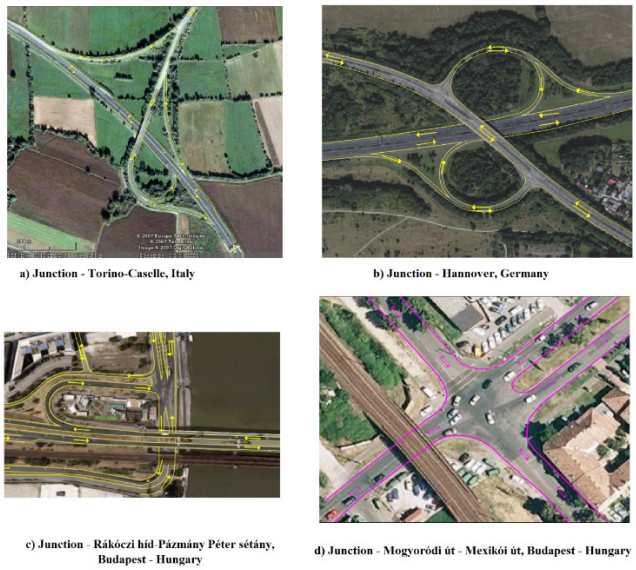


Fig. 1 Junctions overview

3 Developed analysis method

3.1 Basic theory

We investigate specific intersection types regarding the potential factors of wrong-way driving. Civil engineers – in close collaboration with traffic engineers – have to create the road network junctions safe in terms of the smallest mistake potential regarding wrong way entrance. Primarily, high-speed road junctions were considered, but two urban intersections were also included to provide new information for the criteria system.

Wrong direction drivers appear in urban environment more frequently, but the slower traffic leaves more opportunity for the driver to avoid collision. The intersections can be classified according to their spatial features; whether it's a level crossing or a partially grade-separated level crossing or a grade-separated level crossing or it includes railroad crossing. If there enough space to build roundabouts instead of normal crossing it is preferred because is more safer for the traffic flows. Partially grade-separated level crossings only have a part of the traffic flows in level crossing like the trumpet and the diamond-type intersection. In case of a partially grade-separated level and grade-separated level crossing the dominant characteristics of the hazard are as follows:

- topography/ terrain complexity: generous alignment and the big radius of the joining road/access road,
- construction limitation: existing tracks, land borders,
- traffic volume.

Our aim is to identify junctions based on some characteristics, in which wrong-way driving vehicles are expected because of the intersections' design and topographical features. To set up the parameters several junctions have been analyzed considering junction design and the rank and type of the connecting roads. The test junction types are as follows:

- motorway-motorway,
- motorway-main road/expressway,
- widening to dual carriageway with staggered section,
- trumpet and diamond type,
- cloverleaf type,
- crossing with bridge.

Characteristics of the test crossings are as follows:

- trumpet and diamond slip road – merging lane,
- large, elongated geometry - difficulty to understand for an inexperienced driver,
- difficult orientation due to the level difference,
- bridge on- and off ramp.

The basic assumption is that the dangerous sections can be detected based on their geometry, and therefore deployment of automated detection system can be recommended. The geometric-topological analysis is preferred, because the necessary data can be easily acquired, it doesn't require costly research. The basic hypothesis is used in the graph analysis, which provides supposed wrong-way traffics' potential location as follows:

If $A_{ij} = A_{ji} \neq 0$ then A_{*_i} edge being "suitable" for ghost driving,
A_{*_j} edge being "suitable" for ghost driving,

where A is the adjacency matrix.

The usual definition of adjacency is the following:

$$A_{ij} = \begin{cases} 1 & \text{if there is an edge from node } i \text{ to node } j \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

Because the road graph of a city is "sensitive" for one-way streets and other road segments, the used adjacency matrix is created for directed graph. The size of the adjacency matrix is determined by the number of points. The adjacency matrix is a square matrix.

So, the two-way links between two edges have to be examined. Moving opposite direction on the selected node's arriving edges is ensured the possible location of oncoming traffic.

3.2 Modeling of junctions

The analysis of specific junctions is affected by road geometry. Primary to determine the model's elaboration and its basic elements, also known entity. The selected mapping entity is the roadway. In our case several constraints have been applied to form the road's topology:

- the basis of the mapping is the roadway,
- two or more traffic lanes in the same direction are identified as a single unit,
- dual carriageways (separated lanes), are represented by two separate edges,
- two-way edges without physical separation have common start and end node,
- merging lane and diverging lane are represented by node, the entry and exit slip roads by edge.

As soon as the typical nodes are available based on the criteria list the coordinates (WGS84) will be determined for visualization. The next step is to create the graph and its adjacency matrix which describes the junction. Names are given to the directed edges between the nodes, which are also stored in matrix format. Attributes could be stored with the edges, however, during the analysis only the neighborhood information is concerned enabling rapid and affordable analysis. It is necessary to record the different constraints of the traffic rules for the intersection – for example, prohibited left turn – in the junction connectivity matrix by setting particular values to zero. Based on the geometry, the topology for the specific node is defined. To determine the shortest paths between nodes the Floyd-Warshall algorithm is applied (Palácz, 2001; Gutenschwager et al., 2012; Höfner & Möller, 2012). The Floyd–Warshall algorithm compares all possible paths through the graph between each pair of vertices. The input distance matrix is filled by the direct distance values for edges, otherwise the matrix elements are infinite (or practically the highest possible value for storing the matrix). The basic operation of Floyd-Warshall algorithm is a "tricky" minimum function call:

$$\min\left(D_{ij}, D_{ik} + D_{kj}\right) \tag{2}$$

where D is the input distance matrix for the graph. As it can be seen, Eq. (2) returns a smaller distance, whether directly (from i to j) or by inserting a point k (from i to k then to j).

Using the algorithm, the node and edge list of the path between the nodes are obtained. More comprehensive is to identify the passing route by specifying the ordered list of the edges instead of the nodes. For the analysis the logical structure of the selected junction is used. The logical structure of the graph contains the minimum required number of nodes for the correct and complete mapping of the junction, so it includes all the required elements needed to represent turning, connecting and exiting rules. For visualization additional vertex are required (Fig. 2). The data were sorted and selected manually from OSM (Open StreetMap) in QGIS software [https://www.openstreetmap.org; http://www.qgis.org]. Selection of the nodes and vertices will be performed by a function based on the number of connecting edges.

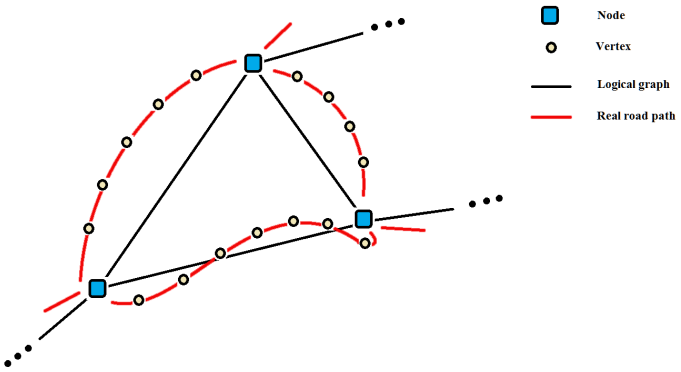


Fig. 2 Node and vertex-based junction structure for modeling and visualization

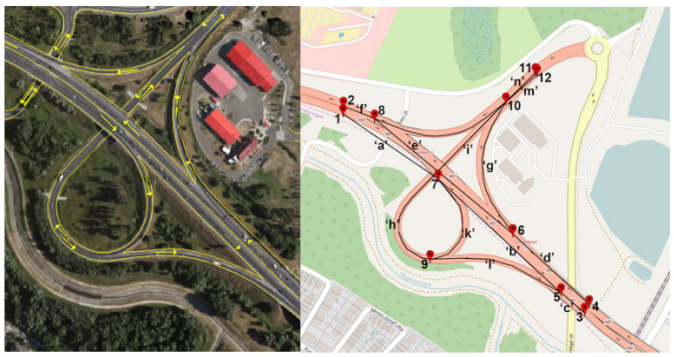
Table 1 contains the basic parameters of the test junctions. The minimum required nodes column shows the necessary number of nodes to create the logical structure. The following two columns show the number of edges and corresponding number of nodes that are potentially considered for wrong-way traffic. The concerned nodes may include repetitive nodes because the edges of ghost driving can have common edges. This problem can be observed at locations where dual carriageway changes to two-way traffic road. The transition of the two road types with inappropriate track geometry could cause problems to the driver without local knowledge. The adjacency matrix of a big junction (Table 1) can contain relatively few nodes while that of a city intersection can include more elements. Fig. 3 shows the results of the junction mapping with vertices and represents the differences between the pure logical structure and the enhanced representation.

Table 1 Parameters of the test junctions

	Minimum required nodes	Possible Ghost driver routes	Concerned Nodes
Dunakeszi M0 Highway	12	2	4
Hannover A2 Motorway	22	2	4
Torino-Caselle Motorway	13	2	4
Mogyoródi Str. – Mexikói Srt.	10	3	4
Rákóczi bridge	13	1	2

During the analysis the start- and endpoints of the graph network could be isolated with a source-sink test. These nodes aren't observed separately due to the continuous connection to carriageway. The generalized adjacency matrix graphic representation can be seen in Fig. 4 where the blank fields represent zero connection. Self-connection is defined also as zero. The

number of edges relating to a node provides information on the load of that particular node. Nodes associated with a lot of edges are always potential accident black spots. The higher the number of passing edges, the greater of the likelihood that the driver makes a mistake so special care should be taken on these nodes when conducting the test. The developed MATLAB program generates a list of shortest paths between the nodes that contains all included node IDs (Table 2).



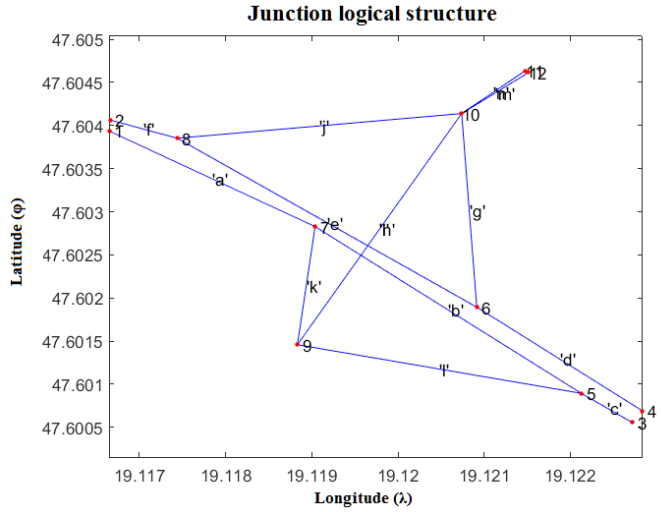


Fig. 3 Creating graph from map with vertices and the junction logical structure, Dunakeszi-Hungary

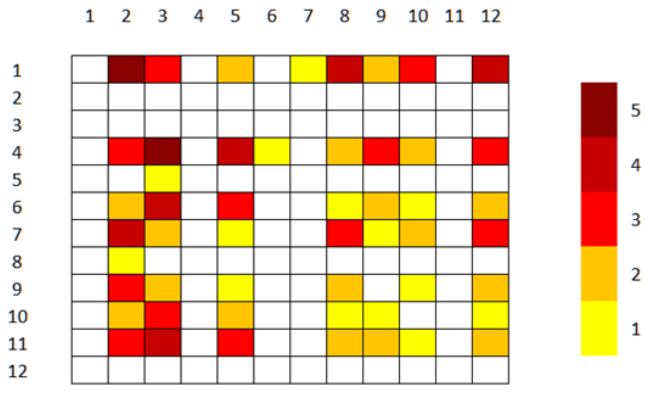


Fig. 4 The generalized adjacency matrix of the junction, Dunakeszi-Hungary

Table 2 Result data from the developed algorithm

Node connections	Number of edges	Path - Node list	Path - Edge list
(1-2)	5	1 7 9 10 8 2	a k h j f
(1-3)	3	1 7 5 3	a b c
(1-5)	2	1 7 5	a b
(1-7)	1	1 7	a
(1-8)	4	1 7 9 10 8	a k h j
(1-9)	2	1 7 9	a k
(1-10)	3	1 7 9 10	a k h
(1-12)	4	1 7 9 10 12	a k h m
(4-2)	3	4 6 8 2	d e f
(4-3)	5	4 6 10 9 5 3	d g i l c
(4-5)	4	4 6 10 9 5	d g i l

Edges between nodes are also defined in list format, and separate lists are made for the connected node triplets; these triplets are start-crossing-end nodes based on their orientation. The node ID with most of the fitting edges is selected from the general adjacency matrix. An own developed function select nodes with bidirectional link. These nodes are the “hot spots”, where drivers’ error and therefore wrong-way driving is expected. Between the starting node of an incoming edge and the selected back and forth type node ghost driving is possible. Incoming and starting paths fitting onto the nodes identified by our algorithm are selected from the determined shortest path list. The directly incoming edges are listed based on a separate query. The results are shown in Fig. 5 where a potential wrong-way driving can be seen on ’k’ edge between node 9 and node 7 where the ghost driver direction is 9→7, while the allowed traveling direction on ‘k’ edge is 7 → 9. Another result of the junction analysis is also marked on edge ‘g’, but after a visual check on Fig. 3 its probability is low due to the width of the roadway.

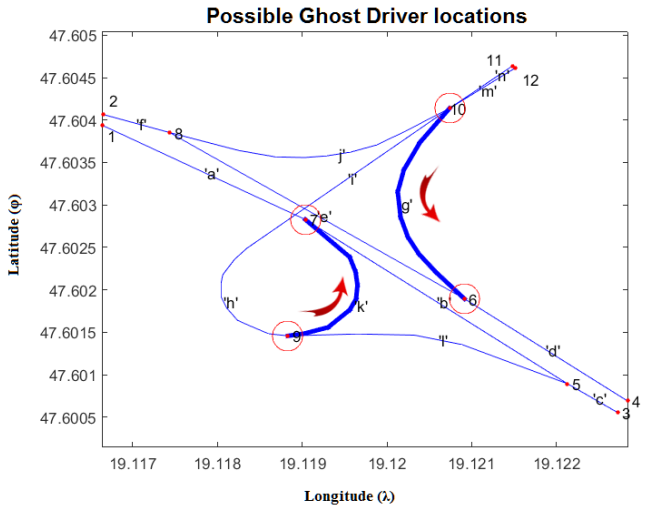


Fig. 5 Possible Ghost Driver locations; expected wrong-way direction on ’k’ and ’g’ edges (marked by red arrows).

4 Results

Our developed method has been tested on all selected junctions. By checking the results in case of the highway crossings, no difference was found between the received result and that of manually specified. The investigation of urban junctions required considering new aspects. For dual carriageways their digital representations depend on the separation: above a certain size (e.g. median strip) they are stored by two graph edges, otherwise by a single edge with two directions. Defining parameters are the geometric distance between lines and speed limits. For this a new module is to be developed, which generates a new graph in an automatic way from the available geometric information.

The results are presented in Fig. 6. For better understanding the node and edge names are omitted, only the relevant node IDs are presented.

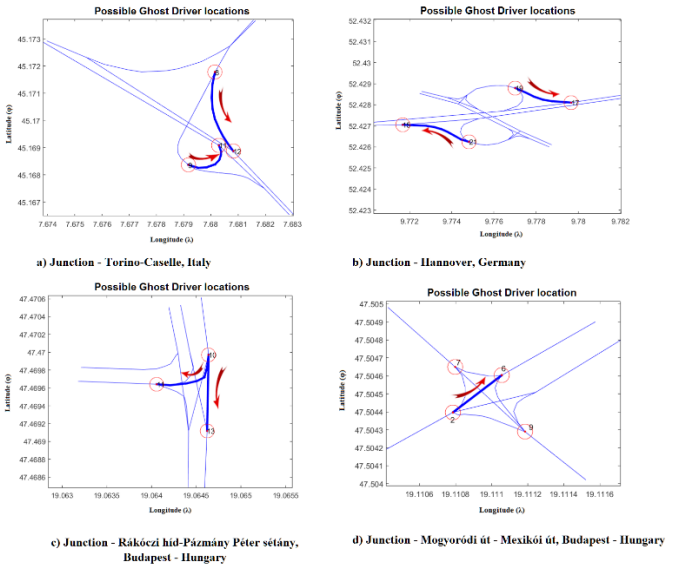


Fig. 6 Potential ghost driver locations– overview of results

5 Conclusion

The developed algorithm is capable of providing potential ghost driving locations based on graph analysis. The possible approach to a given node and the wrong driving direction is also part of the output (Fig. 5). The algorithm gives solution in the case of particular junction structures, the others require further topological and geometric data analysis to determine possible ghost driving locations. The algorithm will be capable of automatic data access; data from OSM (or similar databases) can be quickly imported and used. Sorting nodes and vertices is executed by a developed function where the number of connecting edges (outgoing and incoming) determines whether that point is only a break point in the system or a node in the graph. After determining the points the logical structure is created and the analysis is executed. The representation is followed by visual checking and verification.

Wrong way driving can be detected by several methods. We have created a system based on radio frequency identification (RFID) (Finkenzeller, 2005), which is able to label the ghost driver vehicle in the traffic. The advantage of the technique is the communication without direct line of sight in a completely automatic way. The system is weather independent and can provide simple and fast data collection. In the readers' range the vehicles are to be send their identifiers -stored in their RFID chip- with a time stamp which are then stored by the central system for a given time interval. From the incoming data an algorithm chooses, which identifiers are likely to be travelling in the wrong direction. The operation and performance of our system have been proven by tests (Krausz and Barsi, 2016; Krausz, 2013; Krausz et al., 2017).

Running the analysis on urban junctions has been brought up a new aspect of geometry and topology mapping considering dual carriageways. In case of certain conditions a new network topology should be derived from the primary graph, where the separate carriageways, which are close to each other, merged to a single road. The actual geometric distance between the separated lanes and the speed limits are factors to be concerned by allowing the lane-merging. If in urban environment the requirements of merging the lanes are not fulfilled, lane-level graph representation can be necessary that enables defining optimal RFID antenna locations to effectively monitor the traffic directions in the area. In this case, the system sends information from improper progress. The built RFID system is also suitable for detecting turning rule violation which is also not authorized travel option.

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