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ROAD TRAFFIC ACCIDENT HOTSPOT IDENTIFICATION USING MODIFIED VORONOI PROCESS

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Abstract; The Information Communication Technology (ICT) tools such as Geographical Information Systems (GIS) technology have a number of applications including road safety analysis. Hence it has provided a powerful tool for developing reliable database which can be used in the analysis of road accident data. This paper presents such a development of road traffic accident hotspots identification technique along a road using a Modified Voronoi Process (MVP) technique developed by the authors. This was facilitated by the development of GIS-based road accident database. Three consecutive years' data on Gadong road were acquired and used in the study. The analysis incorporated the computation of hotspot zone dimension (HZD) that led to the definition of a Road traffic Accident (RTA) hotspot for Brunei. Such ICT applications were non-existent in Brunei Darussalam and this research has shown the potential of this technique and the consequent tangible benefit that will facilitate the Brunei Road Department in their effort to carry out road maintenance program for the national road network. The application of this technique has already contributed to the work in road safety inspection of the current road network and is being used as a future tool for assessing the road safety level of an individual road with time and between two or more roads

1. Introduction:

Brunei Darussalam lies between the two East Malaysian states, Sabah and Sarawak and Indonesian Eastern state, Kalimantan with a tropical climate and uniformly high humidity temperature and heavy rainfall. It has a road network totalling 3,357.50 km and the total population was 348,800 with a growing rate of 2.4% per year. 69.6% were concentrated within the Brunei-Muara District (Brunei statistical Yearbook, 2003). Road Safety is a growing problem in ASEAN region. Over the last 5 years, nearly 200 have died and 2800 have been injured and the country lost at least BND\$73 millions (USD\$45 million) each year (equivalent to 1% of GDP in 2002) (Brunei

AP1, 2005-2010). Brunei is a private car community where 87% are private cars out of total 206,994 vehicles registered in 2000 (Brunei statistical yearbook, 2003). Although Brunei has a lower traffic injury and death rate than all other ASEAN countries, excluding Singapore (Country report CR1, 2004), this issue needs to be addressed for the country's sustainable development.

This paper presents the development of road traffic accident hotspot identification technique along a road using a Modified Voronoi Process (MVP). A technique developed by the authors. The analysis incorporated the computation of hotspot zone dimension (HZD) that led to defining a hotspot statement for Brunei. This

innovation pioneered the technological research on road safety issue and contributed to the advancement of the current state of GIS technology in Brunei. A further tangible benefit was to facilitate the Brunei Road Department in their effort to carry out road maintenance program for the national road network. GIS application proved to be an ideal tool for developing road accident database using geocoding process. The output was a display of road accident clusters along a road on a GIS platform. The cluster display, thus, paved the way for identification of hotspots along this road using the MVP technique.

This study focused on road accident problem along a selected Gadong road which is a 10.5km long dual-carriageway road located within the capital city, Bandar Seri Begawan, in Brunei. Traffic accident records for Gadong road was obtained from the Royal Brunei Police in an hard copy format and the raw data were then data mined, cleaned and entered as tables in an Excel program as a database file. This attribute data were further improved by adding two more field columns for spatial coordinates (Easting and Northing) of all the accident locations. Brunei Survey Department provided the basemap which comprised of several layers that include single hair-line road network. The geocoding process used ArcGIS Software (ArcMap and ArcCatalog) that can perform variety of query functions in order to establish an enhanced road accident database. Linking the attribute accident data with the GIS basemap enabled a display of road accident clusters along Gadong road. The MVP hotspot identification technique utilized the cluster displays on a GIS platform, GIS voronoi mapping and linear referencing tools functionalities with excel spreadsheet to display hotspots along the Gadong road chainages.

2. Review of Definition of Road Traffic Accident Hotspot:

In the past, there have been efforts to identify road traffic accident hotspots (blackspots), problem zones or hazardous locations using GIS technology by those such as Saxena et al (1998), Souleyrette, et al (1998), Karasahin et al (2002) and Robert et al (2004). The hotspots along a road are identified using an Excel graphical representation. However, there is no clear definition on the term 'spot' as in that what are the dimensions from a selected accident point on the road to consider the 'spot' as an accident hotspot.

Australian Bureau of Transport Economics (Abte, 2002) confirmed that: "There is no universally accepted definition of a black spot. Sites are classified as black spots after an assessment of the level of risk and the likelihood of a crash occurring at each site." In the United States of America, the United States Federal Highway Agency used 76m distance from a particular intersection for its base models to predict total accident frequency per year for intersection-related accidents (FHWA US, 2000). Although this is not a definition statement, the distance perspective is an indication of zone limitation from the intersection.

Malaysian definition of a blackspot is; "If there are more than 5 accidents within 50m radius over 3 (three) consecutive years or more than 3 accidents of the same type within 50m radius over 3 (three) consecutive years" (Royal Malaysia Police, May 2004). On the other hand, the Malaysian Public Works Department defined accident blacksites as: "9 or more injury accidents, [or 15 points or more], within 50m of a junction [or on a 200m road section], over the past 3 years" (Malaysia PWD guide, 1995). The three (3) years is really the minimum period needed to smooth out any

abnormally large random fluctuations, to produce a reliable ranking of hazardous sites. The Malaysian Highway Planning Unit adopted an accident points weighting system as given below for accidents involving:

Fatality	6
Serious Injury	3
Slight Injury	0.8, and
Damage only	0.2.

3. RTA Hotspot Zone Dimension (HZD) Definition for Brunei:

Greater percentage of road accidents in Brunei involves private cars and are mostly damage-only or non-injury accidents. Accidents involving bicycles, motorcycles, animals and pedestrians are only few. However fatal accidents and serious injuries are comparable in numbers to that of the other ASEAN countries (Rose, 2004). The inclusion of the weighted severity for these fatality and injury accidents is a necessary and vital input within the definition. The Brunei Roads Department (BRD) adopted an informal definition of RTA hotspot as *any location when there have been 5 (five) or more accidents over a period of one year*. However, unlike Malaysia, BRD did not specify a dimension for the accident location. Malaysia considered the location (hotspot) dimension to be a 50m radius or 50m of a junction or on a 200m road section. On the roadway, RTA hotspot cannot be a point but has to be necessarily a zone. This zone can comprise of the distance traversed during the time whenever a driver perceive that something wrong is going to happen, application of the brakes, skidding and vehicle coming to rest after the crash. Thus, the hotspot zone dimension (HZD) can be best defined as:

HZD = SSSD from a selected accident point.

SSSD is therefore the Safe Stopping Sight Distance. The equation to obtain SSSD is that used by Flaherty, 1986 and is shown in Equation 1:

$$SSSD=HZD = V(0.278t + V/254f)--- Eq.1$$

where t = perception-reaction time (sec),
 V = Initial speed (km/h) and
 f = coefficient of friction between the tyre and the road surface.

As for Gadong road with a speed limit of 65 km/h, the HZD is found to be 80m radius from a point (with an assumption that the driver drives at this speed prior to the crash). The definition is applicable to all type of road. In reality, accidents could occur at any locations on the road carriageway or even off the road and even on the opposite lanes. This scenario assumed that there is no road safety feature such as accident crash barrier installed along the Central Reserve of the road. Contrarily, if a crash barrier is installed along the Central Reserve, then accident happens only at locations within half the carriageway. Hence, rational factors corresponding to various types of road safety features were established by the authors. These factors, which were established for a dual-carriageway road, affected the hotspot identification process and can have a value ranging from 0.5 to 1.0. These values can be applied to all types of roads. For a single-carriageway road, k=1.0 as there is no central reserve / crash barrier along the road centreline.

Table 1: Road safety feature factor (k) for dual-carriageway road where $0.5 < k < 1.0$

Road Category	Speed Limit (km/h)	Road Safety Features	F	Brief Rationale
Primary/ Secondary Road 4-Lanes Dual Carriageway	80	Sealed/Semi-Sealed	0.6	High-risk impact of a high speed vehicle onto the Central Reserve.
		Crash Barrier along Road Central Reserve		
		Non-Sealed	0.9	High-risk impact of a high speed vehicle into the opposite lanes.
		No crash Barrier along kerbed Central Reserve		
		Non-Sealed	1.0	High-speed vehicle accident occurs at any location across the road carriageway.
No crash Barrier along open Central Reserve				
Secondary Road 4-Lanes Dual Carriageway	65	Sealed/Semi-Sealed	0.5	Impact only within half width of the road – Low risk of impact onto the Central Reserve at this speed
		Crash Barrier at Road Central Reserve & Edge		
		Non-Sealed	0.8	High risk impact into the opposite lanes
		No crash Barrier along kerbed Central Reserve		
		Non-Sealed	1.0	Accident occurs at any location across the road carriageway.
No crash Barrier along open Central Reserve				

Table 1 shows the factors suggested for various road safety feature factors that exist along a dual-carriageway road. The road safety feature factor is known as 'k' factor and was used in the hotspot identification for the selected Gadong road. The weighted severity factor for fatality and injury accidents is also taken into consideration when defining and identifying hotspot locations. As mentioned earlier, Malaysia adopts the accident point weighting system of 6: 3: 0.8: 0.2 for fatality: Serious Injury: Slight Injury: Damage-Only accidents respectively. In this study, the authors adopted a weighted severity factor of 5.5: 2.5: 1.5: 1. This is based on the ratio of national cost of accident severity and damage-only accident for Brunei (Hartini et al, 2005). These factors have already been incorporated within the RTA database prior to the hotspot identification.

Other country's definition cited already in this study such as that of Australia used inconclusive statement of; 'locations that have an abnormally high number of crashes' as accident threshold limit to describe hotspots. United Kingdom Highway Agency used a fifth of the accident rate and Malaysia adopted 9 or more injury accidents or 15 or more points based on points weighting system defined by the Public Works Department in 1995 and more than 5 accidents or 3 accidents of the same type defined by the Royal Malaysia Police in 2004 as their threshold limits. At this stage, a threshold limit of 5 or more accidents for Brunei was considered by the authors to be ideal and justifiable.

The period of monitoring varies from one country to another. Malaysia specified 3 consecutive years to justify repetitive pattern. The 1-year period in Brunei was extended to a minimum period of 2 consecutive years in order to justify repetitive pattern.

Based on the above reasonings, the authors recommended the RTA hotspot statement definition for Brunei to be;

“Hotspot is a location on the road having a dimension of SSSD when there is a repetitive occurrence of 5 or more accidents each year taking place over 2 consecutive years. The accident severity and road safety feature also needs to be incorporated”

Engineers can use this definition to work out the zone dimension for road segment, signalised or non-signalised intersections and roundabout. As calculated, the $HZD = SSSD$ for road segment along Gadong road with posted speed limit of 65km/h was 80m from a selected accident location.

4. Modified Voronoi Process (MVP):

The Brunei definition for hotspot explained in section 3.0 was used for the identification of hotspots using MVP for Gadong road. From Table 1, the ‘k’ factor for Gadong road is 0.8. The Flow chart in Figure 2 illustrates the steps of MVP analysis and the road accident point patterns displayed on a GIS map is used as a base map.

MVP uses a combination of the Voronoi mapping tool of ArcGIS, linear referencing tool (using road centreline as route event layer) and Microsoft excel spreadsheet to perform the accident hotspots identification process along a road stretch and the use of RTA hotspot definition for Brunei is incorporated within this process.

At the pre-identification stage, Voronoi Mapping tool of ArcGIS is applied to the road accident clusters displayed along Gadong road GIS map for the year 2000. The diagram indicates that there are no

coincidental points of accidents present and thus the Voronoi diagram is as in Figure 1.

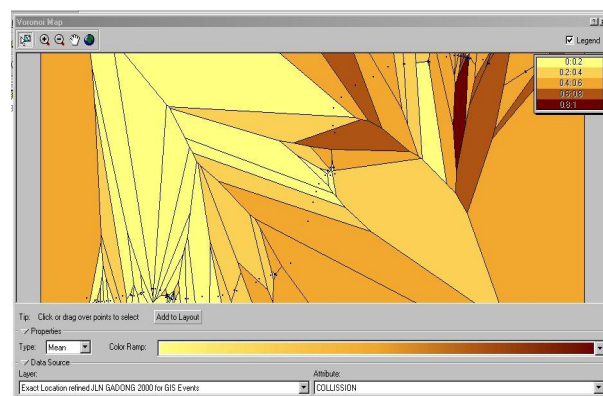


Figure 1: Voronoi diagram for road accident clusters along Jalan Gadong for year 2000.

Voronoi mapping tool displays Voronoi diagram to represent scatter of points and in this research context, the accident locations along the road stretch. The Voronoi diagram is a universal data structure for representing points' proximity and it supports a multitude of nearest neighbour queries as shown in Figure 3. The closer the accident points, the more it represents the accident concentration, thus hotspots. On a road stretch, the voronoi diagram only displays these nearest neighbours of accident points but their chainage locations along this road cannot be justified and also problem of coincidental points. The use of GIS linear referencing tool eliminates these problems by creating route event layer to produce the chainage locations and hence producing event table of chainage locations.

This table is incorporated into the road accident excel database and plotted against the Wvoronoi5 (Wv5) to locate the accident hotspots locations along the road. Any ‘troughs’ on the graph that lies below the overall average are considered hotspots. Wvoronoi5 (Wv5) is a term adopted by the author that corresponds to the hotspot definition for Brunei.

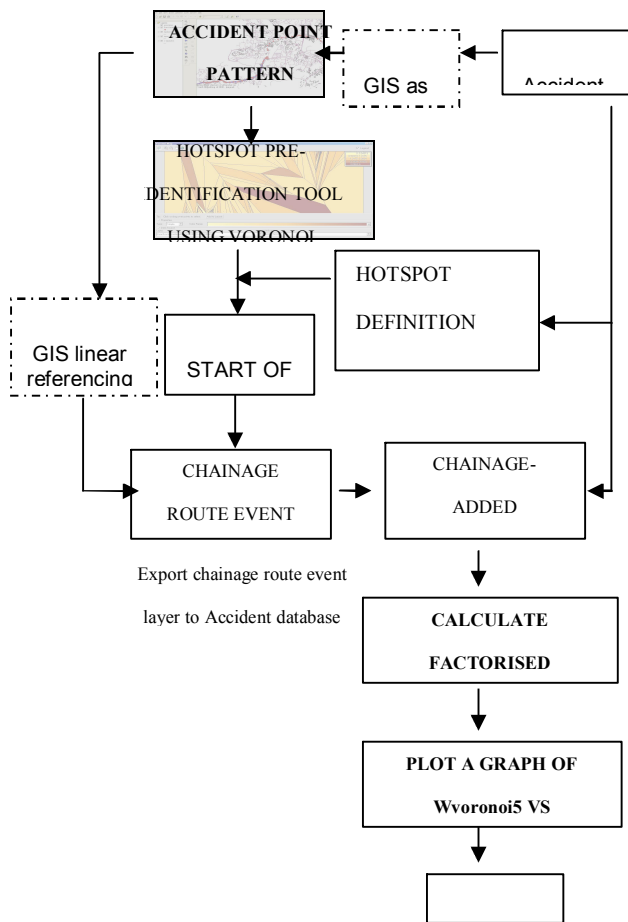


Figure 2: MVP flow chart

After the application of ArcGIS linear referencing tool, the accident database (Excel format) is added on with a newly created column for the ‘chainage of all the accident points along the route’ and is called Chainage-Added Accident.

After the application of ArcGIS linear referencing tool, the accident database (Excel format) is added on with a newly created column for the ‘chainage of all the accident points along the route’ and is called Chainage-Added Accident. The Chainage-Added Accident variables is then utilised to plot a graph of $W_{voronoi5}$ against the chainage of accident points along the route. $W_{voronoi5}$ is the sum of five Voronoi

polygons width inclusive of a width of the sample polygon divided by the road safety feature factor, ‘k’ and denoted by $\sum 5 W_{voronoi5} / 5k$.

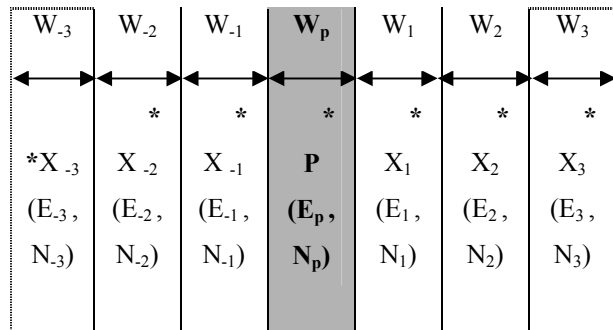


Figure 4: A sample of Voronoi polygons surrounded by neighbouring polygon along a road.

Figure 4 illustrates a sample coordinate point, P (E_p, N_p) on a road, enclosed by a Voronoi polygon of width, W_p . It is surrounded by four neighbouring polygons (nearest neighbour polygons) X_{-2}, X_{-1}, X_1 and X_2 each of which has coordinates as shown in the figure.

$$p = p+2$$

$$W_{voronoi5} = \frac{1}{k} \sum_{s=1}^5 W_s \quad (2)$$

$p = p-2$
 where w_s = Weighted Severity factor

and Distance to mid-point;

$$P \text{ and } X_1 = \frac{\sqrt{(N_1 - N_p)^2 + (E_1 - E_p)^2}}{2} \quad (3)$$

Distance to mid-point;

$$P \text{ and } X_{-1} = \frac{\sqrt{(N_p - N_{-1})^2 + (E_p - E_{-1})^2}}{2} \quad (4)$$

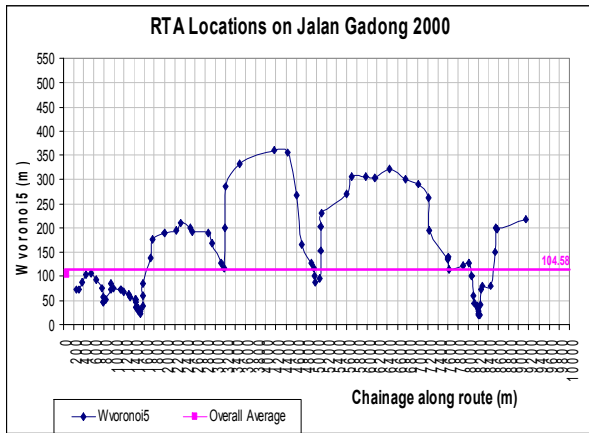


Figure 5: RTA locations along the chainage of Jalan Gadong for the year 2000.

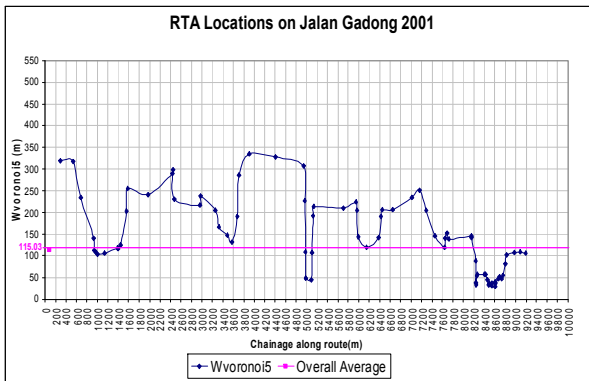


Figure 6: RTA locations along the chainage of Jalan Gadong for the year 2001.

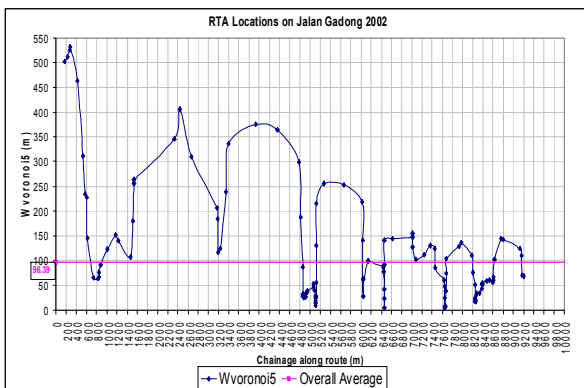


Figure 7: RTA locations along the chainage of Jalan Gadong for the year 2002.

The width of the other four neighbouring polygons can also be calculated using equations 3 and 4 where:

- W_{-1} = Distance to mid-point X_{-1} and P + Distance to mid-point X_{-1} and X_2
- W_{-2} = Distance to mid-point X_2 and X_{-1} + Distance to mid-point X_2 and X_3
- W_1 = Distance to mid-point X_{-1} and X_2 + Distance to mid-point X_1 and X_p
- W_2 = Distance to mid-point X_2 and X_3 + Distance to mid-point X_2 and X_1

Table 3: Types of Trough corresponds to hotspot points or zones

Types of Trough	Width	Hints of a probable causes of accident	Zoning effect
Point trough	< 0.5HSD	<ul style="list-style-type: none"> • 2veh+ accidents at Traffic Light Junction • Accidents at U-turn facility. 	Point location
V-shaped	0.5HSD – HSD	<ul style="list-style-type: none"> • Accidents at roundabout • 2veh+ accidents at Traffic Light Junction 	Single zoning
U-shaped	> HSD	<ul style="list-style-type: none"> • Wet road surface along certain stretch • Existence of multiple minor junctions along certain stretch of road 	2HSD- Double zoning 3 HSD – Triple zoning and >3 HSD – Multi zoning

W-shaped	> HZD	<ul style="list-style-type: none"> • Wet road surface along certain stretch • Existence of multiple minor junctions along certain stretch of road • Accidents at series of Traffic Light junctions 	2HZD- Double zoning 3 HZD – Triple zoning and >3 HZD – Multi zoning
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After all these values are derived, the W_{voro} is determined using equation 2. The number '5' used incorporates the hotspot definition stated in section 3.0. If the accident points are closer or even coincident to each other, then in reality the polygon width would be smaller and thus indication of RTA hotspots or vice versa. The inclusion of 'k' factor is to give consideration to the road safety feature installed along the road. The weighted severity factor has been incorporated within the RTA database prior to the MVP.

5. RTA Hotspots along Gadong Road:

Figures 5, 6 and 7 show graphical plots of the Gadong Road traffic accident locations along its chainage for the years 2000, 2001 and 2002. Any accident locations that lie below the overall average line was considered as a potential hotspot. In the year 2000, there are five (5) troughs observed along this road, which corresponds to five potential hotspots that comprised of three (3) v-shaped troughs along a 1.35km stretch from chainage 250m to 1600m,

isolated v-shaped troughs at chainage 5000m and at chainage 8200m extended to chainage 8500m. At this stage, the relevant authorities can annotate the presence of these specific locations and put in place the necessary justification to carry out maintenance. One example is the 1.35km stretch where three v-shaped troughs identified and the engineers would not want to maintain at these specific points only as accidents did occur along the stretch and ideally should carry out maintenance measures along this stretch. The pattern of the potential hotspots observed in 2000 were again identified in the year 2001 although this time only one u-shaped trough along the 1.35 km stretch, similar v-shaped trough at chainage 5000m and a change of v-shaped to w shaped trough along a 600km stretch from chainage 8200m to 8800m.

In the year 2002, in addition to the hotspots identified in the year 2000 and 2001, four (4) new potential hotspots were observed at chainage 6000m, 6450m, 7650m and 9200m.

These hotspots can only be justified if data is available for the following year 2003. The identification of these potential hotspots depends on whether these hotspots are at a specific point on the road where the trough of the graph is of point trough or at a certain dimension less than the HZD where it will take a V-shaped trough or could even take a U or W-shaped trough where double, triple and multi-zoning occur. In the presence of the latter effect, the hotspot considered in this case would be a road segment of certain stretch long. There are four types of troughs in table 3; a point, a V-shaped, a U-shaped and a W-shaped suggested by the authors for hotspot identification purpose.

6. Conclusions:

An application of ICT with GIS technology is presented to obtain road accident clusters on a digital map (Supry Ladi et al 2005). The hotspot identification technique will provide tangible benefits in facilitating the Brunei Road Department in their effort to carry out road maintenance program following road safety inspection of the current road network and provide a future tool for assessing the road safety level of individual road with time and between two or more roads. There is a pressing need to adopt this technique using GIS technology requires commitment from all stakeholders in Brunei's continuous effort to reduce further accident death rate in Brunei Darussalam.

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