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Intelligent Decision Support Capabilities for a Law Enforcement GIS

Bel G. Raggad
Pace University

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Research-in-Progress

Bel G Raggad, PhD
Pace University
Pleasantville, NY 10570
braggad@pace.edu

Abstract

Most GIS systems process huge amounts of data but lack the capability to produce useful knowledge and actionable information. Unless GIS information generates a Bayesian update (a surprise or information that decision makers cannot anticipate), this GIS remains weak and a simple storage of dead data. Furthermore, even if this GIS stores valuable data, it still remains weak if it lacks the ability to generate the decision support that users need.

This work in progress aims at adding decision support capabilities to a standard law enforcement GIS in terms of two main features: 1) visual decision support at the functional management and control levels in remote locations of police stations protecting their urban zones, and 2) evidence-based decision support at the strategic management level in the police department protecting the conurbation constituting the urban zones under its jurisdiction.

The visual decision aids employ dynamic choropleth maps that are revised on a monthly basis. The evidence-based decision process is provided using Dempster and Shafer theory. While some of the tools are primarily used by police departments to devise effective policing strategies, police chiefs supervising the police stations can also locally benefit from adopting them.

This study provides a numerical example to demonstrate the working of the proposed decision aids.

Keywords: GIS, Security, Evidence, decision support, choropleths, spatial data.

1. Introduction

A Geographical Information System (GIS) is simply a computer-based information system that processes geographic information in terms of data locations and their informational attributes. A GIS process can capture data associated with their geographic locations, store them is user-defined forms, and produce output information in user-defined visual or other intermediary forms. Those forms can be special cubes of data, digital maps, or any other actionable output designs. Alternate definition may be found in Burrough and McDonnell, 1998, Campbell et al. 2001, Church 2002, Baker 2005, Wilson et al. 2010, etc.

In addition to the main definition of a GIS, it is also playing the role of an intelligent decision support system that promotes visual thinking, simulated solutions, and scientific research. For example, GIS have been adopted as geographic intelligent systems in logistics to facilitate travel information, traffic control or assisted navigation, and many other transportation applications (Pons and Perez 2000, and Schmitt and Jula 2006).

The computing environment of a GIS consists of technology (hardware and software), data, communication networks, and multidisciplinary staff who fully understand the application domain. All the data collected, stored, and processed, and all the information produced relate to the studied specific geographic locations (Uneca, 2001). Major GIS applications are concerned with land management, marketing research, educational planning, and demographic projects. Even though GIS applications started as costly projects, due to the expensive computing power needed to process spatial databases, data collections and data entry and digitization, and staff training, they have become relatively affordable because of the advances in micro-computing technologies and pre-packaged development tools (Burrough, and McDonnell, 1998).

GIS systems process huge amounts of data but lack the capability to produce useful knowledge and actionable information. Unless the information you obtain from a GIS generate a Bayesian value (a surprise or information that the decision maker cannot anticipate), this GIS remains weak and a simple of storage of dead data. Furthermore, even if this GIS stores valuable data, it still remains weak if it lacks that ability of generate the decision support that users need. Can users be part of the data population of GISs and can these systems be planned to satisfy prospect users in terms of their data requirements and their access needs (Petit et al. 2007).

Most GIS systems cannot produce evidence if the probability distribution of the selected data cannot be obtained. Most often, the valuable information stems from data that is associated with great ambiguity and uncertainty and for which the probability distribution cannot be constructed. A GIS should then include the intelligent capability of generating decision support despite the presence of ambiguity and uncertainty.

The literature also reported on many law enforcement applications. Unfortunately, many of those GIS applications remain traditional in the way they collect and process their geographic data. Many police departments still manually process GIS data in cartographic manners. Such a geographic data processing mechanism may include graphic entry devices, coordinate digitizers, optical scanners, textual files, etc. Often times, police clerks still manually record the coordinates and produce the map display on a line printer (Church, 2001, Jankowski and Nyerges. 2001).

This paper proposes the automating of the policing geographical analysis needed to devise sound policing strategies. Our contribution stems from our adoption of evidential processing to enhance GIS data for the police department of a large conurbation in terms of information collected at various police stations in distributed urban zones making the conurbation. Dempster and Shafer theory is used to process evidence throughout the conurbation and Dempster's rule of combination is used to fuse evidence collected at various urban zones.

Special data is also enriched by expending its attributes using statistical models. Attributes will then hold new information on the crime rate per 1000 persons, and the crime rate per type of crime per 1000 persons of the population in the urban zone. We can also enhance GIS data by adding belief values on the state of police stations on the ability of each police station to protect its own urban zone. They will serve in future decision making in relation to policing strategies decided at the police department (Campbell at al. 2001, Bellatore et al, 2010, Schlossberg and Shuford, 2005).

2. GIS enhancement

2.1 The enhancement model

Consider a standard law enforcement GIS application that consists of a spatial database E. Law enforcement in a well delineated conurbation is assured by a security department. The security department manages N police stations assuring the security of N urban zones constituting the conurbation. The GIS database at the police department holds N spatial records $\{e_i\}$, i=1,N containing the geographic location of the urban zone and attributes defining prescribed properties of the urban zones. Those attributes are often data-based and not necessarily model-based that hold significant decision support capabilities.

Our model recommends the addition of two types of information: statistical decision support, and evidential decision support. The statistical decision support information $\{g_i(t)\}$, i=1,N will be used locally at the police stations to protect their assigned urban zones while the evidential decision support information $\{h_i\}$, i=1,N will be used by the police department to protect the entire conurbation.

Let us consider a conurbation a region comprising a number of cities or other urban areas that, through population growth and physical expansion, have merged to form one continuous urban area. Let us assume that this urban zone is organized into N police departments represented in the geographic information system as polygons with fixed locations. The conurbation is represented on a map stored in a geographic data structure made of polygons E_i, i=1,N:

$D=\{d_i\}i=1,N$
$d_i=\{p_i, a_i\}i=1,N$
$p_i=(x_i, y_i)$ i=1,N: Geographic coordinates
$a_i=(f_i, g_i, h_i, r_i)$ i=1,N; f_i: Crime Rate
$g_i=(G_{ij})j=1,5$, i=1,N:
G_{i1}: Common Crime Rate;
G_{i2}: Cyber-Crime Rate;
G_{i3}: Economic Crime Rate;
G_{i4}: Common Crime Rate;
G_{i5}: Common Crime Rate;
$h_i=\{\Omega_i=\{E:Elevate, R:Reduce, S:Sustain\}\ m_i: 2^{\Omega_i} \rightarrow [0, 1]\}$
$r_i=Risk(h_i)$.

Below is a numerical example showing the new structure of the enhanced GIS database:

New GIS structure with Decision Support Capabilities									
	Location	Data-based	Visual decision support at time t					Evidence-based decision support	
d	p	f	g: the letter indicate the decision support					h	r
		F1	G1	G2	G3	G4	G5	H1	R1
d_1	[1.874862143378, 48.834371283832]	212	62:E	52:E	62:R	20:S	18:S	$m_1(E, R)=.2$, $m_1(\Omega)=.8$	?
d_2	[1.8656030688715, 48.831612507285]	243	42:E	23:S	52:R	12:S	62:S	$m_2(R)=.3$, $m_2(\Omega)=.7$	?
d_3	[1.8515105581603, 48.834338209867]	187	62:R	52:E	68:R	52:R	11:S	$m_3(S, R)=.4$, $m_3(\Omega)=.6$	?
d_4	[1.8466221791684, 48.828669687135]	251	61:E	23:S	62:R	24:S	12:S	$m_4(R, S)=.3$, $m_4(\Omega)=.7$	?
d_5	[1.8415374906793, 48.828818416443]	321	52:E	42:E	72:R	62:R	62:R	$m_5(E, R)=.5$, $m_5(\Omega)=.5$	?
d_6	[1.8392188748285, 48.830163082204]	234	58:E	25:S	62:R	17:S	31:S	$m_6(E)=.3$, $m_6(\Omega)=.7$	?
d_7	[1.8419058888315, 48.843509743804]	311	52:E	22:S	62:R	62:R	29:S	$m_7(S, R)=.2$, $m_7(\Omega)=.8$	?
d_8	[1.8472716401406, 48.849200964455]	235	32:S	42:E	62:R	45:E	24:S	$m_8(S, R)=.3$, $m_8(\Omega)=.7$	?
d_9	[1.8375210341485, 48.856814659389]	432	58:E	22:S	62:R	12:S	55:E	$m_9(S, E)=.4$, $m_9(\Omega)=.6$	?
d_{10}	[1.8383984699903, 48.87125874614]	231	69:E	62:E	17:S	64:E	31:S	$m_{10}(R, E)=.4$, $m_{10}(\Omega)=.6$	?
d_{11}	[1.8572939822902, 48.871944300476]	344	52:E	23:S	62:R	25:S	67:E	$m_{11}(R)=.2$, 5$m_{11}(\Omega)=.8$	?
d_{12}	[1.874663272221, 48.877028568925]	233	72:E	12:S	62:R	68:E	25:S	$m_{12}(R, S)=.4$, $m_{12}(\Omega)=.6$	?
d_{13}	[1.8831026195664, 48.874535338148]	215	14:S	65:E	62:R	11:S	23:S	$m_{13}(E)=.2$, $m_{13}(\Omega)=.8$	?
d_{14}	[1.9127169447188, 48.860849357594]	251	52:E	42:E	62:R	14:R	21:S	$m_{14}(E, S)=.3$, $m_{14}(\Omega)=.7$	?
d_{15}	[1.9030441003473, 48.846352529476]	324	54:E	62:E	62:R	23:S	24:S	$m_{15}(R)=.3$, $m_{15}(\Omega)=.7$	?
d_{16}	[1.8932786620468, 48.847377864779]	203	53:E	52:E	13:S	17:S	62:R	$m_{16}(R, E)=.4$, $m_{16}(\Omega)=.6$	?
d_{17}	[1.8885787644301, 48.846659731042]	198	62:E	62:E	62:R	18:S	34:S	$m_{17}(S, E)=.2$, $m_{17}(\Omega)=.8$	?

While the statistical decision support information is produced by applying statistical models, the evidential decision support information is the result of human processing by the police chiefs of various police stations at the urban zones making the conurbation. Both the statistical effort and the human processing mechanism are discussed in greater details in special sections below.

2.2 Enhancing GIS data by adding policing labels as belief functions

The evidence at the police department and the distributed evidence at remote police station throughout the conurbation are assembled in a hierarchic manner. The concept being tested is the validity of the main assertion that the police department would have the ability to adequately protect the conurbation. The hierarchic evidential diagram consists of assertions, evidence and their interrelationships. Assertions include the sub-assertions at individual police stations. The evaluation of the security department's ability to adequately protect the conurbation is estimated in terms of the abilities of the individual police stations to protect their assigned urban zones. The main assertion is 'the security department would have be able to adequately protect its conurbation.' The ith sub-assertion corresponding to the ith police station is 'the ith security station would have be able to adequately protect its conurbation.' The hierarchic evidential structure is depicted in Figure 3.

2.3 Statistical effort for enhancing GIS data

The statistical effort is limited to 6 quantities: a data-based attribute fi that adds the rate of crimes per 1000 people in the urban zone i at time t in months; the statistic-based composite attribute gi that includes 5 quantities {Gi(t), i=1,5} that store every month information on common crimes, cybercrimes, economical crimes, domestic crimes, and traffic crimes; and two evidential attributes, namely a belief function H_i proving the assertion that the police station would have the ability to adequately protect its urban zone; and finally, an evidential attribute R_i expressing the risk that the police station would not be able to assure the adequate protection of its urban zone.

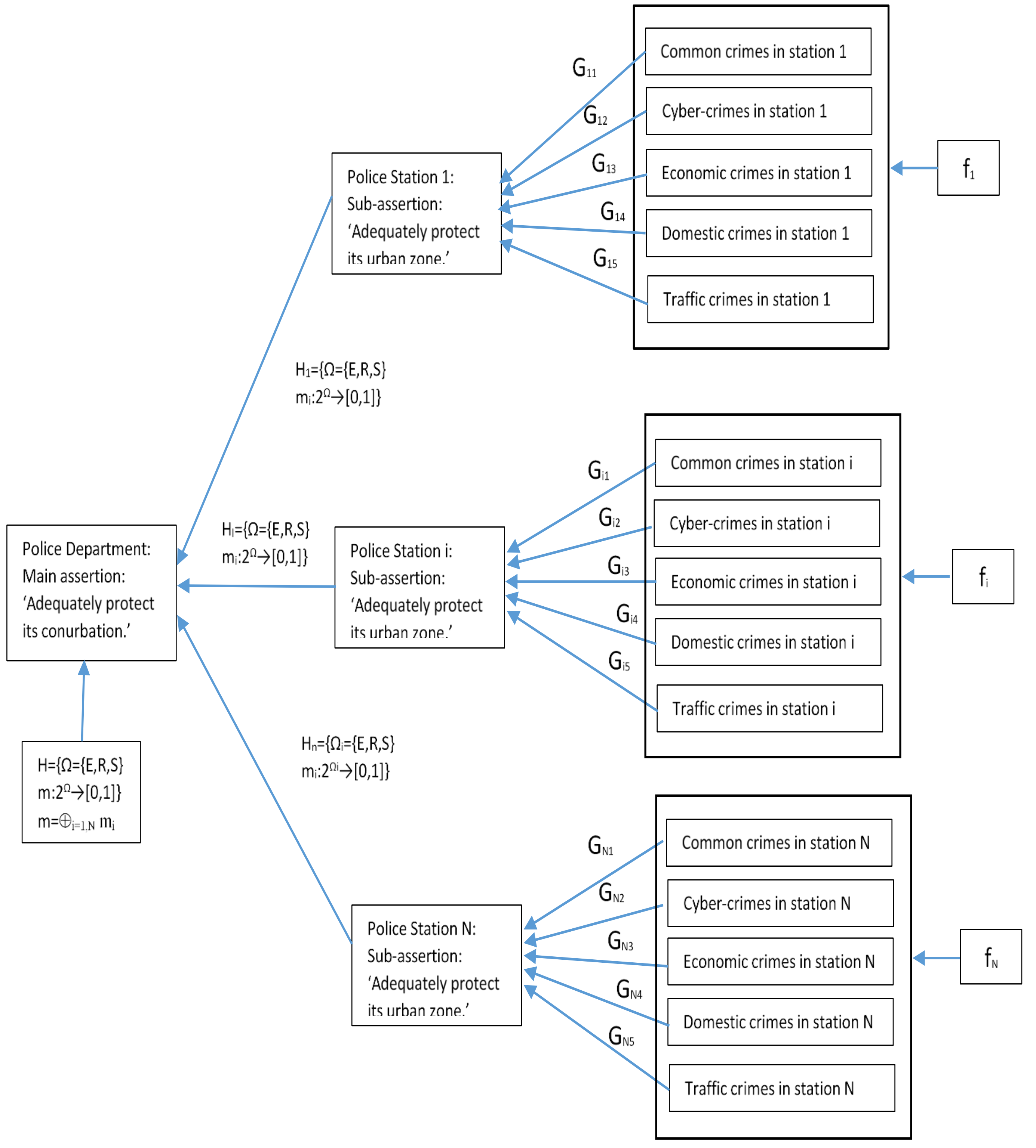
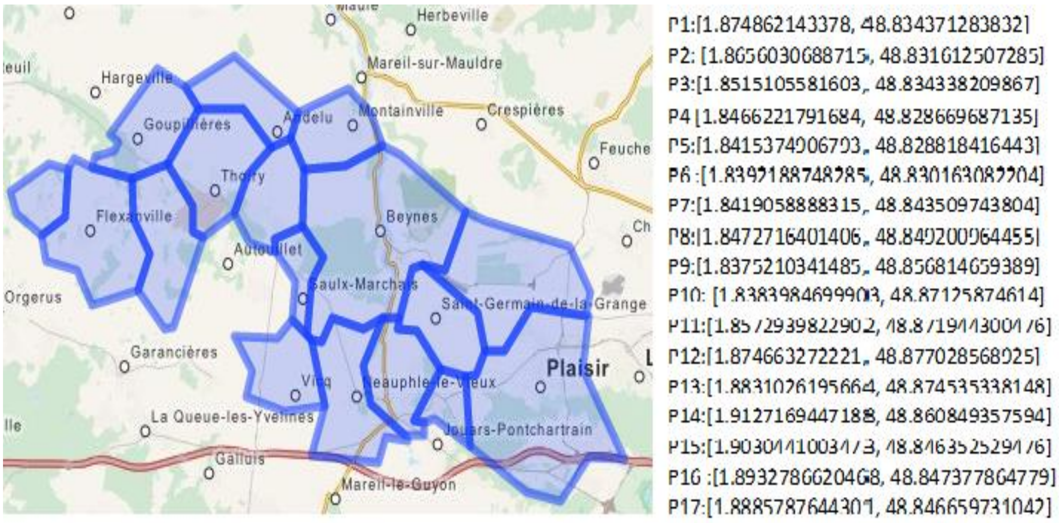


Figure 1: Enhancing GIS data by adding policing decision labels and risks

2.4 Enhancing GIS choropleth maps by layering overlays

It is importing to observe that not all types of crimes are committed at all urban zones. For example, more domestic crimes are committed in residential urban zones than in industrial zones and more economic crimes may be committed in commercial zones. The layer overlays of the choropleth maps will serve in fusing the evidence pieces obtained at the same polygons on crime type choropleth maps. Here is the choropleth map that we will use to demonstrate the working of our GIS enhancement process:



Source: http://gis.stackexchange.com/questions/118223/merge-geojson-polygons-with-wgs84-coordinate

Figure 2: Example of a choropleth maps

The possible values collected at any of the polygons are as follows:

(green)	0-10 crimes/1000 p per month
(yellow)	11-20 crimes/1000 p per month
(orange)	21-50 crimes/1000 p per month
(red)	>50 crimes/1000 p per month

The intensity of crimes is estimates every month for every type of crime. The rate to store in the GIS database that we will use in producing the choropleth maps is the number of crimes per month per 1000 people in the urban zone.

Figure 3 is a simple illustration where given a specific month, we compute the rates of crimes for every type of crime and define the color that corresponds to it. Once we obtain the values of the rates, we can then produce the choropleth naps for the purpose of providing visual aids to police chiefs to discuss with his/her aids and agents.

The choropleth maps also represent an efficient visual aid to study the map layers individually and capture any description of the spread of the specific crime types over time. The maps can also be combined by overlaying the layers in a stack manner and visually capture the overall effect on crime evolution over time and over all types together.

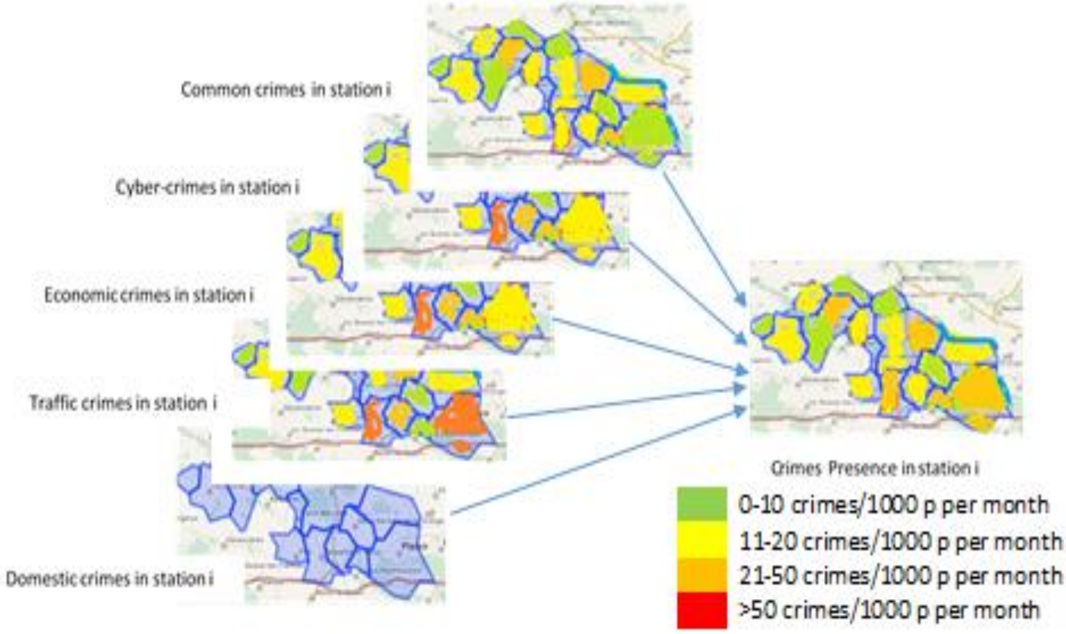


Figure 3: Outlaying choropleths to visualize overall impressions

3. Evidence-based attributes

3.1 Adequate Protection of the conurbation

Evidence represents the information collected at various nodes that supports or negates assertions. Evidence nodes are represented by rectangular boxes in the evidential diagrams. Examples of evidence include the intensities of all types of crimes defined at the police department managing the individual police station in the conurbation. Evidence nodes are connected to the corresponding assertions.

The process of propagating basic belief assignments or m-values is modelled using Dempster's rule of combining evidence as follows:

Given the enhanced GIS data described earlier $\{D=\{d_i\}i=1,N;\ e_i=\{p_i, a_i\}i=1,N;\ p_i=(x_i, y_i)\ i=1,N;\ a_i=(f_i, g_i, h_i)\ i=1,N;\ f_i=(F_{ij}\}j=1,n1,\ i=1,N;\ g_i=(G_{ij}\}j=1,n1,\ i=1,N;\ h_i=(H_i\}i=1,N\}$, each police station provides evidence in terms of sub-assertions as described in the following diagram:

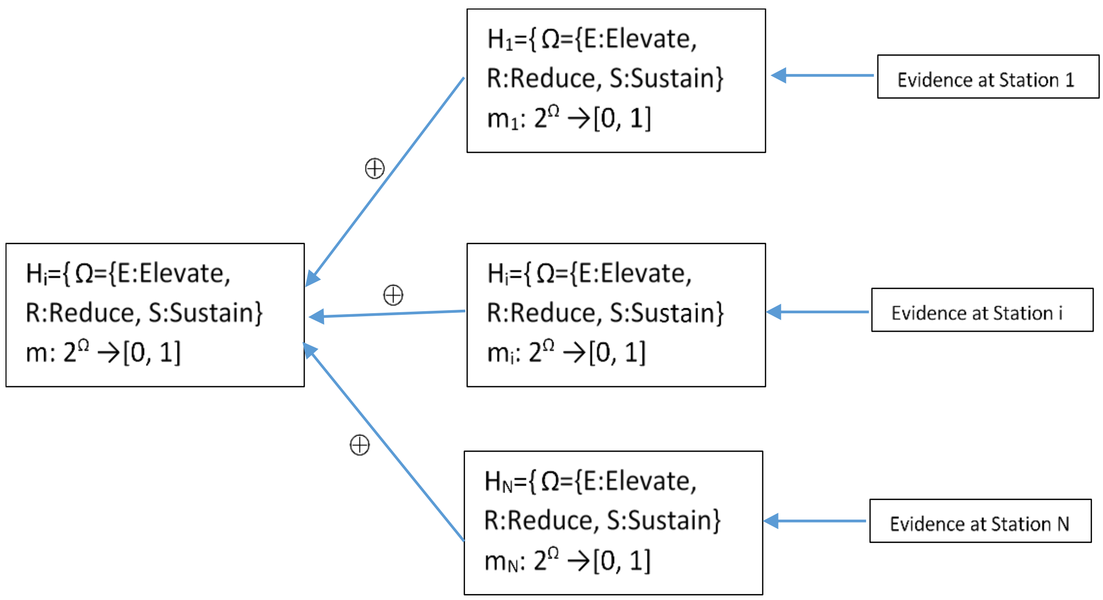


Figure 4: Evidential processing to prove the main assertion that the police department would have the ability to protect its conurbation.

Evidence is fused using Dempster's rule of combination of evidence as follows:

$$m_{12}(Z)= m_1 \oplus m_2(Z) = 1/(1-k_{12}) \sum_{X \cap Y = Z} m_1(X)m_2(Y)$$
$$\text{where } k12 = \sum_{X \cap Y = \varnothing} m_1(X)m_2(Y)$$

$$m(Z)= m_3 \oplus m_{12}(Z) = 1/(1-k_{123}) \sum_{X \cap Y = Z} m_3(X)m_{12}(Y)$$
$$\text{where } k123 = \sum_{X \cap Y = \varnothing} m_3(X)m_{12}(Y)$$

Let us in a first step apply Dempster rule to combing m1 and m2. The following table is only needed to show the intermediary computations:

	$m_2(\{E, S\})=.3$	$m_2(\Omega)=.7$
$m_1(\{E, R\})= .4$	{E}: .12	{E,R}: .28
$m_1 (\Omega)=.6$	{E, S}= .18	Ω= .42

m12 ({E}) = .12/(1=k) = .12
m12({E, S}= .18/(1-k_{12}) = .18
m12({E, R})= .28/(1-k_{12}) = .28
m12(Ω)= .42/(1-k_{12}) = .42
k12 = $\sum_{X \cap Y = \varnothing} m_1(X)m_2(Y) = 0$

Let us in a second step obtain the final belief function by combining m_{12} and m_3, as follows:

	$m_3(\{E\})=.5$	$m_2(\Omega)=.5$
m12 ({E}) =.12	{E}:.06	{E}:.06
m12({E, S}= .18	{E}:.09	{E, S}:.09
m12({E, R})= .28	{E}:.14	{E, R}:.14
m12(Ω)=.42	{E}:.21	Ω:.21

$m(\{E\}) = (.06 + .06 + .09 + .14 + .21)/(1-k_{123}) = .56/(1-k_{123}) = .56$
$m(\{E, R\}) = .14/(1-k_{123}) = .14/(1-k_{123}) = .14$
$m(\{E, S\}) = .09/(1-k_{123}) = .09/(1-k_{123}) = .09$
$m(\Omega)=.21/(1-k_{123}) = .21$
$k_{123}= 0.$

That is, the basic belief assignment at the police department defining the main assertion that the conurbation is adequately protected is obtained as follows:

PS: {H_1={ Ω={E:Elevate, R:Reduce, S:Sustain},
m: $2^{\Omega} \rightarrow [0, 1]$,
m ({E}) = .56;
m({E, R}) = .14;
m({E, S}) = 09;
m(Ω)= .21}.

3.2 Enhancing GIS data by adding the risk attribute

In order to prevent police department security assurance deficiencies, police departments use controls and counter measures to safeguard their capabilities from various types of threats by identifying and remedying their weaknesses. But, even in the presence of good policing strategies their capabilities of security assurance can be undermined by weaknesses in the police stations members of the security department. Thus, risk analysis is a critical step for the management of a police department capabilities to protect the conurbation.

Many risk analysis methodologies have been developed by both academic researchers and practitioners, including quantitative methods such as expected value analysis, stochastic dominance approach, qualitative methods such as scenario analysis, etc.

We certainly believe that diverse risk methodologies have strengths and weaknesses. Most methods however estimate risks by estimating the probabilities of negative outcomes to model risk while ignoring the residual uncertainty and ambiguity that remains after available evidence is considered.

In this article, we circumvent this deficiency by using Dempster and Shafer's theory to model the uncertainties involved in the assessment process for the presence of the weaknesses. The Dempster and Shafer's framework has been used in various domains including healthcare and business. We can then use a structured approach to incorporating the impact of risk factors and the impact of the police stations capabilities. The fusion of police stations risks will produce the overall security department risk. This approach will simplify risk assessment by decomposing the overall information security assurance risk into its individual stations constituting the conurbation.

We use the plausibility of a negative outcome which has been used by Srivastava and Shafer [50] to define security assurance risks. Under the DS theory of belief functions, risk is defined to be the plausibility of security assurance not being adequate. This definition of risk is a somewhat conservative measure of risk as it is based on the worst case scenario where any ambiguity in the situation is added to any direct evidence of security assurance risk.

To illustrate this definition, consider a situation where a police station's chief has some belief, say 0. 30 that his/her station would not be able to protect its urban zone, 0.20 level of belief that he/she would do so, and 0.5 level of ignorance indicating whether the capabilities his/her station has is unknown, based on what he/she knows about the presence of weaknesses in protecting his assigned urban zone.

This information indicates that the plausibility that the urban zone in question is not secure is 0.7 which is to say that the plausibility that the urban zone would not be protected is 0.7. This latter value is the police station's security assurance risk. This also means that there is 70% risk that the urban zone in question would not be adequately protected given the current weaknesses in the police station. If the police chief takes actions to elevate the station's security assurance capability by adding new technology and by enhancing his/her police force then one would assess the impact of these actions on the station weaknesses. Dempster's rule may be adopted to produce the overall plausibility that the police department would not be able to provide adequate security assurance capability given the evidence obtained from individual police stations.

That is, risk is modelled as the plausibility of a negative outcome; in this case, the inability to protect the conurbation. This definition of risk is a somewhat conservative measure of risk as it is based on the worst case scenario where any ambiguity in the situation is added to any direct evidence of security assurance risk.

4. Conclusion

The paper propose the addition of decision support capabilities to a standard law enforcement GIS in terms of two main features: 1) visual decision support at the functional management and control levels in remote locations of police stations protecting their urban zones, and 2) evidence-based decision support at the strategic management level in the police department protecting the conurbation constituting the urban zones under its Jurisdiction.

The visual decision aids tool employed dynamic choropleth maps that are revised on a monthly basis. The evidence-based decision process is provided using Dempster and Shafer theory. While some of the evidence-based decision support aids are primary available to police departments to devise effective policing strategies, police chiefs managing the local police stations can benefit primarily from the visual decision support aids.

The decision support aids proposed in this article most often concern the police stations constituting the conurbation even though many members can produce decision support that benefit the police department.

The next extension of this study will be to automatically generate decision support after completing the data population of the GIS. Decision support information should be regenerated every time the GIS system is updated.

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