Knowledge representation for missing persons investigations

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Abstract

Purpose

The application of situation calculus for knowledge representation in missing persons investigations.

Design/methodology/approach

The development of a knowledge representation model for the missing persons investigation process based upon situation calculus, with a demonstration of the use of the model for a missing persons example case.

Findings

Situation calculus is valuable for knowledge representation for missing persons investigations, since such investigations have state changes over time, and due to the complexity of the differing investigation activities applicable to different situations, can be difficult to represent using simpler approaches such as tables or flowcharts.

Research limitations/implications

Situation calculus modelling for missing persons investigations adds formalism to the process beyond that which can be afforded by the current use of text, tables or flowcharts. The additional formalism is useful in dealing with the uncertainty present in such investigations.

Practical implications

A simplification of the application of the current police guidelines, and thoroughness in the application of such guidelines for missing persons investigations via situation calculus modelling.

Social implications

Supporting the management of missing person investigations, by utilizing the most critical variables in a missing persons investigation to determine relevant investigation and search activities applicable to the circumstances of a given case.

Originality/value

The novelty of the knowledge representation approach is the application of situation calculus via state and action vectors and a matrix of fluents to the process of missing persons investigations.

Keywords: Knowledge, Representation, Missing, Person, Investigation

1. Introduction

Situation calculus allows a dynamic system to be modeled through a series of situations that result from various actions being performed within the system. A situation can represent a history of the occurrence of given actions. In this paper we examine the use of situation calculus to mathematically describe the situations resulting from performing given actions to model the missing persons investigation process used in the UK, and in particular to model the actions that constitute the investigation and search aspects of a missing person investigation based upon the circumstances of a given missing persons case. The motivation and justification for using situation calculus is that given all the variables (such as age, medical conditions, and risk levels) involved in a missing persons case, the current simpler approaches such as tables or flowcharts can fail to fully capture the complex and time dependent nature of the missing persons investigation process (for example the work flow diagram and step guide to missing or absent persons within the UK Association of Chief Police Officers Interim Guidance on the Management, Recording and investigation of Missing Persons (ACPO, 2010; ACPO, 2013)).

At the outset of a missing persons case the situation is that a person is initially reported missing. Various actions such as interviewing relevant individuals or searching a particular area changes the situation, which also changes over time (Parr and Fyfe, 2012; Parr et al, 2015). For example the longer a child or an old person was missing, different actions might be taken e.g. increasing the number of officers involved in the case. The elements of situation calculus for modelling a missing persons investigation include: The actions that can be performed as part of the investigation (investigation components, and search strategy components), the fluents that describe the states of the missing person case (states concerning missing person investigation protocols) and the situations (the characteristics of the missing person and the nature of their being missing).

The application of situation calculus to knowledge representation for missing persons investigations adds formalism to the process beyond that which can be afforded by the current use of just text, tables or flowcharts. The additional formalism is useful in dealing with the uncertainty present in a missing persons investigation. The approach presented in this paper supports the management of a missing person investigation, which has an extensive set of variables and relies upon the knowledge and experience of police officers with local knowledge of the geographical area in which a person went missing. The approach presented in this paper aims to utilize the most critical variables in a missing persons investigation and a classification approach to model via vectors and a matrix of fluents the most relevant investigation and search activities applicable to the circumstances of a given missing persons investigation. The approach described in this paper supports the UK Association of Chief Police Officers Interim Guidance on the Management, Recording and investigation of Missing Persons (ACPO, 2010) which advises the use of 'scenario-based searching' for missing people. Overall the approach adds formalism to provide decision support for the main investigative and search actions relevant to a given missing persons case based upon analysis of the characteristics of the case. This is an important area of research since responding to reports of missing persons represents one of the biggest demands on the resources of police organizations (Fyfe et al, 2013; Greene, and Pakes, 2014).

The novelty of the knowledge representation approach examined in this paper is the application of situation calculus via state and action vectors and a matrix of fluents to the process of missing persons investigations. The technical challenge addressed in this paper is the complexity of representing the knowledge involved in the management of missing persons investigations. Currently UK Association of Chief Police Officers Guidance on missing persons investigations (ACPO, 2010) and guidance within individual UK police forces is mainly text based, with limited use of tables and flowcharts. Textual guidance which requires natural language interpretation can be inherently ambiguous. Tables can be used to categorize missing persons guidance, but can only provide limited assistance in terms of splitting the process into steps or different types of investigations. Flowcharts can provide more detailed knowledge representation for missing persons investigations management, however, flowcharts are based upon specific decisions in a set order. Situation calculus can provide a more detailed and flexible approach to knowledge presentation for missing persons investigations, since the investigation process changes over the time period covered by a given investigation, and involves consideration of a number of state elements that together with a matrix of fluents determine the required actions. The aim of this approach presented in this paper is to provide a decision support system rather than an expert system for providing support for police officers making decisions during a missing persons investigation. Policing information systems are typically based upon decision support rather than expert systems, due to the highly volatile, variable and complex nature of police investigations. The real benefits from situation calculus modelling are a simplification of the application of the current police guidelines, and thoroughness in the application of such guidelines for missing persons investigations.

2. Literature review

2.1 Missing persons investigation guidance

The circumstances relating to individuals being reported missing can be complex. Factors which may be involved with an individual going missing can include mental health issues, drug and alcohol abuse, relationship breakdown, and financial stress (Parr et al, 2015). The UK Association of Chief Police Officers (ACPO) Guidance for the Management Recording and investigation of Missing Persons (ACPO, 2010, ACPO, 2013) provides a list of factors for consideration in a missing persons case. This includes personal circumstances such as the age of the missing person, their ability to interact safely with others or an unknown environment and whether the missing person has any physical or mental health problems, and other circumstances of the disappearance such as suspicion of murder, suicide or other factors which might indicate that the disappearance might result in harmful outcomes to the individual concerned. Overall the UK Association of Chief Police Officers guidelines provide an overview level of the management of missing persons investigations and covers areas such as initial reporting, the assessment of risk, the processes of investigation and working with other agencies. The Grampian Police guide for missing persons (Grampian, 2007) provides more detailed guidance covering specific mental health factors that may relate to a missing persons case such as depression, suicide, dementia, psychosis / schizophrenia, bipolar disorder, Attention Deficiency Disorder (ADD), as well a guidance relating to missing children and how to search for people missing in water. There are various investigation and search activities that will be undertaken during a missing persons investigation (Woolnough et al, 2015). Newiss (2005) commented upon the usefulness of experienced police officers and other experts identifying factors that should be considered by police officers assessing the risk posed to a missing person, and the use of empirical information regarding the characteristics of missing persons experiencing specific outcomes.

The majority of the academic research undertaken into the nature of missing persons cases and missing persons investigations has been undertaken by psychologists or sociologists who typically perform qualitative and quantitative studies of past missing persons cases (Lampinen et al, 2012; Woolnough et al, 2015; Alys et al, 2013, Bantry White and Montgomery, 2015), and geographers who undertake geographic profiling (Parr and Fyfe, 2012; Parr et al, 2015; Yarwood, 2010) in conjunction with researchers in policing studies. Overall there appears to have been little if any formal modelling work on active missing persons investigations processes.

2.2 Situation calculus

Situation calculus is a versatile logic for reasoning about actions and formalizing dynamic domains (Kiringa and Gabaldon, 2010). Situation calculus is one of the most established formalisms for reasoning about action and change (Lakemeyer, 2010). In situation calculus a special binary function *do(a, s)* is used to describe the situation resulting from performing action *a* in *s*. A process may involve moving from one situation to another by performing an action. The function *do* can record the history of actions that lead to the situation referred to by the *do* term. Fluents describe what is true at a given situation. Fluents are predicates and functions whose last argument is a situation term (Lakemeyer, 2010). For example, $Searchradius(B, do(lastseen(B), S_0)$ could be read as: assign the search radius from the geographic location identified as the place a missing person was last seen.

Situation calculus can be applied to real world activities by a domain expert axiomatizing relevant aspects of an application, including its dynamics, and then using reasoning mechanisms to derive conclusions about the domain of interest, in particular, about situations following the performance of a number of actions (Lakemeyer, 2010). Situation calculus has been applied to a variety of different organizational activities and settings such as electronic commerce (Al-Kaddo and Al-Neaimi, 2013), education (Radoyska et al, 2011), and supply chain management (Chandra et al, 2007).

2.3 The use of knowledge representation for missing person investigations

Although the UK Association of Chief Police Officers (ACPO) Guidance for the Management Recording and investigation of Missing Persons (ACPO, 2010) uses flowcharts and tables to represent knowledge and guidelines regarding missing persons investigations, such techniques can have difficulty in fully representing the operational complexities involved in such investigations. Fyfe et al (2015) commented upon the complexities of capturing and representing knowledge related to police investigations since policing is enmeshed in a web of situational and structural contingencies. Agrez (2015) stated that codification of the knowledge within organizational processes can provide the opportunity to overcome some of the limitations of knowledge management in organizational processes that may be uncertain or unstable. Knowledge representation for procedural aspects of an organization's activities based upon situation calculus has been used in different areas such as manufacturing (Solano et al, 2014), construction (El-Diraby, 2013), business management (Di Ciccio et al, 2015; Weldemariam, and Villafiorita, 2011) and healthcare (Aziz et al 2013). However, there appears to have been limited research into the use of situation calculus for knowledge representation for police activities (Bosse et al, 2011) and missing persons investigations in particular.

3. Research method

The research methodology used was literature review and guidance from police officers from a police force within the North West region of England, followed by theoretical research to develop a framework for supporting decision making in missing persons investigations. The framework is then demonstrated using a practical application to an example missing persons investigation.

The research problem was the difficulties faced by police officers in managing missing persons investigations. The research questions were:

How can the missing persons investigation process be modelled?

How can appropriate investigative actions be derived from data regarding a missing person?

The missing persons investigation process was researched via a literature review and guidance from police officers from a police force within the North West region of England. The UK Association of Chief Police Officers (ACPO) Guidance for the Management Recording and investigation of Missing Persons (ACPO, 2010, ACPO, 2013) describes the investigation cycle whereby from an initial report of a missing person (in situation calculus terms *state 0* S_0) a series of investigation and search actions will take place (in situation calculus terms actions such as *investigate* and *search*) that will alter the state of the missing persons investigation.

The situation calculus modelling reported in this research was implemented using vectors to represent the state of a missing persons investigation, vectors to represent the investigation and search actions undertaken during a missing persons investigation, and a 'matrix' of fluents (time dependant missing persons investigation protocols) that relate a given set of actions to a given state.

The elements of a missing person investigation state, namely age of missing person, medical conditions of missing person, location type, risk level (Low, Medium, High), mode of transport, and time last seen were derived from the UK Association of Chief Police Officers (ACPO) Guidance for the Management Recording and investigation of Missing Persons (ACPO, 2010, ACPO, 2013) and the UK Missing Persons Bureau (MPB, 2016) guidelines, and guidance from police officers from a police service in the North West region of the UK. The classifications for the values of the different elements of the missing person investigation state vector were also derived from these sources and were:

Age (1 = less than age 18, 2 = age 18 to 64, 3 = age 65 or greater)

Medical condition (0 = not applicable, 1 = of concern, 2 = urgent)

Location type (1 = urban, 2 = rural)

Risk level (1 = low, 2 = medium, 3 = high)

Mode of transport (1 = on foot, 2 = bicycle, 3 = public transport, 4 = personal vehicle)

Last seen (1 = within 1 hour, 2 = 2 to 24 hours, 3 = 1 to 14 days, 4 = 14 or more days)

The UK Police National Missing Persons Bureau must be informed no later than 14 days after initial report of a missing person (ACPO, 2010). The classification of high risk in a missing persons case might typically arise if going missing was viewed as being out of character for the individual concerned, if the individual might be likely to come to harm or to might harm the public or themselves, if the individual might be vulnerable due to their medical history, had no money, or was not adequately dressed for the prevailing weather conditions (Fyfe et al, 2015).

The missing person investigation actions vector elements (Interview relatives / friends / associates, investigate online activity of missing person, contact external agency (other agency involved with the missing person e.g. social services, care home providers), search radius (from home or place missing), search type (police / police and fire and rescue services / police and public), search pattern, number of officers) were derived from the ACPO (2010) and UK Missing Persons Bureau (MPB, 2016) guidelines and guidance from police officers from a police service in the North Western Region of the UK.

The classifications for the values of the different elements of the missing person investigation actions were also derived from the ACPO (2010) and UK Missing Persons Bureau (MPB, 2016) guidelines and guidance from police officers from a police service in the North Western Region of the UK and were:

Interview relatives / friends / associates (1 = initial interview, 2 = follow on interview)

Investigate online activity of missing person (0 = not required, 1 = of concern, 2 = urgent)

Contact external agency (0 = not required, 1 = of concern, 2 = urgent)

Search radius (1 = up to 1 mile, 2 = 1 to 5 miles, 3 = 5 to 10 miles, 4 = 10 miles or more)

Search type (1 = police officers, 2 = police and fire and rescue officers, 3 = police officers and dogs, 4 = police officers and aerial search, 5 = police officers and public)

Number of officers (1 = less than 5, 2 = 5 to 10, 3 = 10 to 20, 4 = 20 or more)

The elements of the matrix of fluents that map the space of missing persons investigation situations vectors to the space of missing persons investigation actions vectors were also derived from the ACPO (2010) guidelines, the UK Missing Persons Bureau (MPB, 2016) guidelines and guidance from police officers from a police service in the North Western Region of the UK. For example, if the missing persons risk level is high then fire and rescue services may be involved in a search alongside police officers. In terms of physical searching for a missing person, initial searches might typically be done by local patrol police officers. Typically initial searches might focus on the immediate geographical area and would be informed by information gained from interviews with family and friends regarding the typical routes taken and places frequented by the missing person (Fyfe et al, 2015).

The research presented in this paper concerns a decision support approach rather than an expert systems approach for supporting police officers during missing persons investigations. Due to the wide variability of missing persons circumstances and the complex nature of missing persons investigations, an expert system approach would be less appropriate. However, a decision support system approach that can codify missing persons investigation states and missing persons investigation actions and represent the knowledge involved in making decisions during a missing persons investigation is more viable. Due to the great variety of circumstances encountered in missing persons investigations it would be inappropriate to attempt to provide definitive ‘answers’. Rather what would be more appropriate is to provide a relevant set of possible actions based upon the time dependant state of the missing persons investigation, from which the officers involved in the case can make an informed decision.

4. Research results

The knowledge representation approach for missing persons investigations examined in this paper involves codifying the characteristics of the actions, the fluents and the situations involved in a missing persons case. In mathematical modelling terms a vector of missing persons characteristics is acted upon by a ‘matrix’ of fluents (time dependant missing persons investigation protocols) to give a vector of investigation / search actions. In this manner the practical use of the knowledge representation approach for supporting missing persons investigations is demonstrated. In terms of an actual usable software application for supporting missing persons investigations, if the codification process for the situation was implemented in a series of drop down menus, then with appropriate training any police officer could use this system as they would just need to choose appropriate menu choices and then the software system would produce the relevant investigation and search actions output in descriptive form.

4.1 Formal model

A missing person situation vector for a given missing persons case is derived from:

Missing person characteristics (e.g. age, known medical conditions, risk level)

Geographic nature of locations (e.g. urban, or rural)

Mode of transport (e.g. on foot, bicycle, public transport, personal motor vehicle)

Temporal data (e.g. time last seen, hours missing)

In mathematical terms a *missing person situation vector* would include:

(Age, medical condition, location type, risk level, mode of transport, last seen)

A missing person *action vector* would include:

(Interview relatives / friends / associates, investigate online activity of missing person, contact external agency, search radius, search type, number of officers)

An example of a missing person investigation *fluent* (time dependant missing person investigation protocol) might be:

S = Situation (Age < 18, medical condition = urgent, location = rural, risk level = high, mode of transport = on foot, last seen > 12 hours)

→ ***A*** = Action (Interview = Initial interview, online activity search = not required, contact external agency = not required, search radius up to 5 miles from last seen location, police only search, 20 officers)

In mathematical symbols:

do(*A*,*S*) represents the fluent that defines the action (Interview = Initial interview, online activity search = not required, contact external agency = not required, search radius 5 miles from last seen location, police only search, 20 officers) for a given situation (Age < 18, urgent medical condition, location = rural, risk level = high, mode of transport = on foot, last seen > 12 hours).

To make the notation easier to work with the elements of the situation and the action can be expressed as numerically labelled categories as described above e.g.

S = Situation(Age < 18 = 1, urgent medical condition = 2, rural location = 2, risk level = 3, on foot =1, time last seen > 12 hours = 2)

→ ***A*** = Action(Interview relatives = 1, online activity search = 0, contact external agency = 0, search radius up to 5 miles from last seen location = 2, police only search = 1, 20 officers = 4)

In mathematical symbols:

do(Misper (1, 2, 2, 3, 1, 2), 1, 0, 0, 2, 1, 4) represents the fluent that describes the protocol that defines the action (initial interview, search radius 5 miles from last seen location, search type police only, 20 officers) for a given situation (Age < 18, urgent medical condition, rural location, on foot, time last seen > 12 hours).

The fluents that map the space of missing persons investigation state vectors to the space of missing persons investigation actions are implemented in a matrix.

A state vector ***S*** maps to an action vector ***A*** via a matrix of fluents $\boldsymbol{f_{mn}}$

S = (Age, medical condition, location type, risk level, mode of transport, last seen)

= (a, c, l, r, m, s)

A = (Interview relatives / friends / associates, investigate online activity of missing person, contact external agency, search radius, search type, number of officers)

= (i, o, e, d, t, n)

In mathematical terms the matrix of fluents transforms the state vector to the action vector:

$$(a, c, l, r, m, s) \begin{pmatrix} f_{11} \cdots\cdots f_{16} \\ f_{21} \cdots\cdots f_{26} \\ f_{31} \cdots\cdots f_{36} \\ f_{41} \cdots\cdots f_{46} \\ f_{51} \cdots\cdots f_{56} \\ f_{61} \cdots\cdots f_{66} \end{pmatrix} = (i, o, e, d, t, n)$$

For the example missing persons case above, the missing persons investigation state vector has the values **(1, 2, 2, 3, 1, 2)**, and the missing persons investigations action vector has the values **(1, 0, 0, 2, 1, 4)**.

Examples of the fluents involved in the missing persons investigation process are:

F_{12} : If age < 18 years then investigate online = 1 (of concern)

F_{12} : If a = 1 then o = 1

F_{42} : If risk level = medium then investigate online = 1 (of concern)
If risk level = high then investigate online = 2 (urgent)

F_{42} : If r = 2 then o = 1
If r = 3 then o = 2

F_{43} : If risk level = medium then contact external agency = 1 (of concern)
If risk level = high then contact external agency = 2 (urgent)

F_{43} : If r = 2 then e = 1
If r = 3 then e = 2

F_{52} : If mode of transport = 3 (public transport) then investigate online = 1 (of concern)

F_{52} : If m =3 then o = 1

F_{54} : If mode of transport = 1 (on foot) then search radius = 1 (up to 1 mile), or 2 (1 to 5 miles)
If mode of transport > 1 then search radius = 2 (1 to 5 miles), or 3 (5 to 10 miles) or 4 (10 miles or more)

F_{54} : If m =1 then d = 1 or 2

If $m > 3$ then $d = 2$ or 3 or 4

F_{61} : If last seen =< 3 then Interview = 1 (initial interview)
If last seen = 4 then Interview = 2 (follow on interview)

F_{61} : If l =< 3 then i = 1
If $l > 3$ then $i = 2$

F_{62} : If last seen >= 14 days then investigate online = 2 (urgent)
If last seen >= 1 and < 14 then investigate online = 1 (of concern)

F_{62} : If l >= 14 then o = 2
If l >= 1 and <14 then o = 1

The fluents in each column in the matrix $\boldsymbol{f_{mn}}$ act together to derive the values of each given element of the action vector from the values of the elements of the state vector. Thus the search radius might be indicated to be 2, 3, or 4 from the mode of transport, but might be indicated to be 3 or 4 if the location was rural.

This approach is more relevant than an expert systems approach that would typically suggest a particular given action. The decision support approach presented in this paper aims to provide a set of relevant actions from which the officers concerned in a missing persons case might choose, or might combine as appropriate. For example, there can be different instances in which an online search might be more relevant at different stages in a missing persons investigation, for example early on when a child might be missing, or in high risk cases, or in other cases, later on in the investigation, especially after 14 days. Similarly different sets of circumstances can be used to inform the determination of a relevant search radius, which may also change over time. The flowcharts and tables currently provided in UK police guidelines cannot provide a similar level of decision support due to their less flexible nature. In comparison, expert systems which typically provide a particular ‘answer’ are also less useful due to the volatility, variability and complexity of missing persons cases for which at any given stage of the investigation a number of factors will be involved in decision making. A decision support approach using situational calculus provides both a more detailed and flexible approach to decision support for police officers conducting a missing persons investigation.

4.2 Usage scenario

As an example of the use of situation calculus for supporting missing persons investigations we will use the case of a missing middle aged person with mental health difficulties missing for 2 days in an urban area with access to a personal motor vehicle. In this case the initial state would be:

Age (2 = age 18 to 64)

Medical condition (2 = urgent)

Location type (1 = urban)

Risk level (3 = high)

Mode of transport (4 = personal vehicle)

Last seen (3 = 1 to 14 days)

Application of the matrix of fluents would indicate the following potential actions:

If medical condition = urgent then contact external agency = 2 (urgent)

If location = urban then search type = 1 (Police only)

If risk level = high then contact external agency = 2 (urgent)

If risk level = high then investigate online = 2 (urgent)

If risk level = high then number of officers > 5 (2 = 5 to 10, 3 = 10 to 20, 4 = 20 or more)

If mode of transport > 1 then search radius = 2 (1 to 5 miles), or 3 (5 to 10 miles) or 4 (10 miles or more)

If last seen =< 3 then Interview = 1 (initial interview)

In terms of the information presented to police officers this would take the form of an explicit list of actions that in this case would include:

- Contact GP / hospital regarding medical condition of missing person
- 10 to 20 police officers to be involved in search (search and rescue officers not required)
- Investigate recent on-line activity of missing person.
- Search radius – 10 miles or greater
- Interview relevant relatives / friends / colleagues

As can be seen by the application of the matrix of fluents in this case, the set of possible actions detailed above would be difficult to represent using just a table or flowchart. In addition an expert system would attempt to present an exact action set, which would not really accurately provide the more complex set of possible actions that might be required. Later states of the investigation would change with time and with the outcomes of the actions taken.

The benefit of situation calculus is that situation calculus provides a model-based approach, so there is a formal mathematical model about which you can reason. The formal mathematical model also facilitates reuse and modification. Expert systems do not really provide such features since they mainly operate based upon a database of facts and rules. In addition, situation calculus was specifically designed to model situations that change over time (Stefik, et al, 1982), which is relevant for missing persons investigations. Situation calculus provides the ability to model the time dependent state of a missing persons investigation. After different time periods in a missing persons investigation, for example in the case of a missing child, the search area would be increased, and the number of officers involved would be increased, and follow on interviews would be conducted. In this manner the matrix of fluents maps the state of the investigation onto a set of possible actions, and the actions themselves change the state of the investigation. For example, having searched in a localised area initially, the next search area would typically be a larger geographical area. Thus, a changed state of the investigation is then mapped to a different set of possible actions. The change of state based upon both elapsed time and the actions taken would be much more difficult to attempt to model via an expert systems approach, for example based upon a bi-temporal database. Each individual missing persons case will have its own characteristics, and although similar in some ways to previous missing persons cases there will always be unique elements to each case. In addition, different actions may have different results in each different case, which then changes the state of the investigation. Situational logic supports missing persons investigations by providing sets of possible actions based upon the state and timeframe of a given case, rather than attempting to predict specific actions required.

Situation calculus provides a chain of temporally linked states of a missing persons investigation, that are not just linked by the passage of time, but also linked through the results of actions undertaken based upon each state in a given investigation. Thus for example in the case of a missing child, at an initial time and set of circumstances a set of possible actions would be indicated by the matrix of fluents. At a later time in the investigation a different set of possible actions would be indicated by the matrix of fluents, not just because of the difference in time, but also due to changes in state brought about by the actions themselves, for example an online search or information retrieved from an external agency might indicate a higher level of urgency in search activities, or searches in wider areas, or in specific areas. It would be far more difficult to attempt to represent successor states in missing persons investigations using an expert systems approach.

5. Implications

The implications of situation calculus modelling for missing persons investigations are a simplification of the application of the current police guidelines, and thoroughness in the application of such guidelines for missing persons investigations. By simplifying the analysis of the state of a missing persons investigation to the categorisation of the major aspects of a given case at a given time, and then providing the possible investigative actions required, this approach helps to reduce the time and effort required to apply the guidelines which are lengthy text based documents with limited use of tables and flowcharts. In addition, the approach provides thoroughness in terms of the provision of the set of possible investigative actions required to ensure that the guidelines are followed. This helps to reduce the reliance upon police officers having to remember the guidelines, and interpret them correctly during a missing persons investigation.

The mathematical modelling via situation calculus for knowledge representation for missing persons investigations could be implemented in software code via matrix processing. In order to support ease of use of the software by police officers involved in a missing persons investigation, the values of the elements of the state vector relevant to a given timeframe of the investigation could be generated via drop down menus that show the categories of values relevant to each given state vector element. For example, a risk level drop down menu would show choices relating to low, medium and high risk levels for a given missing persons case. In terms of ergonomic interface design, the police officer would select options from each of the drop down menus relating to each of the variables of interest such as age, medical condition, type of location, mode of transport etc. The system would then present recommended actions based upon the current state of the investigation using the information available.

6. Conclusions

In this paper we have examined the use of situation calculus for knowledge representation for missing persons investigations. The situations, actions and fluents used for the situation calculus modelling were derived from the ACPO (2010) guidelines, the UK Missing Persons Bureau (MPB, 2016) guidelines and guidance from police officers from a police service in the North Western Region of the UK. The missing persons investigation situations and actions were modelled using vectors, and the fluents were modelled using a matrix.

We have explicitly demonstrated how situation calculus via state and action vectors and a matrix of fluents can be used to represent the state of a given missing persons investigation, the actions required by the investigation team, and the combination of functions within the matrix of fluents that map the space of investigation states to the space of investigation actions. Situation calculus proved valuable for knowledge representation for missing persons investigations, since such investigations have state changes over time, and due to the complexity of the differing investigation activities applicable to different situations, can be difficult to represent using simpler approaches such as plain text, tables or flowcharts. Since missing persons cases can consume a significant amount of police resources, police forces can realize benefits by managing the missing persons investigation process in an effective manner that complies with the relevant ACPO guidelines, enabling response in an efficient manner.
The advantages of the approach examined in this paper for practical policing were the generation of lists of explicit investigative actions (based upon data regarding the missing person) and the reduction of effort required to interpret ACPO guidelines by police officers which can be time consuming and inefficient in terms of police resource utilisation. Future work on the application of situation calculus for supporting missing persons investigations will involve software simulations of the mathematical modelling implemented in software code via matrix processing and ergonomic interface design for use by police officers involved in such investigations.

References

ACPO (2010) UK Association of Chief Police Officers (ACPO), Guidance on the Management, Recording and investigation of Missing Persons, ACPO, London, UK.
http://library.college.police.uk/docs/npia/missing-persons-guidance-2010.pdf
(date last accessed 02/07/2016)

ACPO (2013) UK Association of Chief Police Officers (ACPO), Interim Guidance on the Management, Recording and investigation of Missing Persons, ACPO, London, UK.
http://library.college.police.uk/docs/college-of-policing/Interim-Missing-Persons-Guidance-2013.pdf
(date last accessed 02/07/2016)

Agrež, J. and Damij, N., (2015) Knowledge dynamics assessment in complex organizational systems: a missing person investigation case study, Central European Journal of Operations Research, 23, 3, 527-545.

Al-Kaddo, A., Al-Neaimi, A. (2013) Requirements Analysis Modelling for Buyer-Driven E-commerce Using ConGolog Agent-Oriented, International Journal of Software Engineering and Its Applications 7, 6, 375-390.

Alys, L., Massey, K., Tong, S. (2013) Investigative decision making: Missing people and sexual offences, crossroads to an uncertain future, Journal of Investigative Psychology and Offender Profiling, 10, 2, 140-154.

Aziz, A. Ahmad, F., ChePa, N., Yusof, S. (2013) Verification of an Agent Model for Chronic Fatigue Syndrome, International Journal of Digital Content Technology and its Applications, 7, 14, 25-32.

Bantry White, E., Montgomery, P. (2015) Dementia, walking outdoors and getting lost: incidence, risk factors and consequences from dementia-related police missing-person reports, Aging and mental health, 19, 3, 224-230.

Bosse, T., Gerritsen, C., Hoogendoorn, M., Jaffry, S., Treur, J. (2011). Agent-based vs. population-based simulation of displacement of crime: A comparative study, Web Intelligence and Agent Systems: An International Journal, 9, 2, 147-160.

Chandra, C., Grabis, J. and Tumanyan, A (2007) Problem taxonomy: a step towards effective information sharing in supply chain management, International Journal of Production Research, 45, 11, 2507-2544.

Di Ciccio, C., Marrella, A., Russo A. (2015) Knowledge-Intensive Processes: Characteristics, Requirements and Analysis of Contemporary Approaches, Journal on Data Semantics, 4, 1, 29-57.

El-Diraby, T. (2013). Domain Ontology for Construction Knowledge, Journal of Construction Engineering Management, 139, 7, 768-784.

Fyfe, N., Stevenson, O., Woolnough, P. (2015) Missing persons: the processes and challenges of police investigation, Policing and Society, 25, 4, 409-425.

Grampian (2007) Grampian Police, Missing Persons, http://www.sipr.ac.uk/downloads/MISSING_PERSONS_UNDERSTANDING.pdf (date last accessed 02/07/2016)

Greene, K., Pakes, F. (2014) The cost of missing person investigations: Implications for current debates, Policing, 8, 1, 27-34.

Kiringa, I., Gabaldon, A. (2010) Synthesizing advanced transaction models using the situation calculus, Journal of Intelligent Information Systems, 35, 157–212.

Lakemeyer, G. (2010) The Situation Calculus: A Case for Modal Logic, Journal of Logic, Language and Information, 19, 4, 431-450.

Lampinen, J., Miller, J., Dehon, H. (2012) Depicting the missing: Prospective and retrospective person memory for age progressed images, Applied Cognitive Psychology, 26, 2, 167-173.

MPB (2016) UK Missing Persons Bureau, Has someone you know gone missing? A reference guide, http://missingpersons.police.uk/download/36
(date last accessed 02/07/2016)

Newiss, G. (2005) A Study of the Characteristics of Outstanding Missing Persons: Implications for the Development of Police Risk Assessment, Policing and Society, 15, 2, 212-225.

Parr, H., Fyfe, N. (2012) Missing geographies, Progress in Human Geography, 37, 5, 615-638.

Parr, H., Stevenson, O., Fyfe, N. (2015) Living absence: the strange geographies of missing people, Environment and Planning D: Society and Space, 33, 191 – 208.

Radoyska, P., Ivanova, T. and Spasova, N. (2011) Flexible Simulation e-Learning Environment for Studying Digital Circuits and Possibilities for it Deployment as Semantic Web Service. Journal of Educational Technology Systems, 39, 4, 349-369.

Solano, L., Rosado, P., Fernando Romero, F. (2014) Knowledge representation for product and processes development planning in collaborative environments, International Journal of Computer Integrated Manufacturing, 27, 8, 787-801.

Stefik, M. Aikins, J. Balzer, R., Benoit, J. Birnbaum, L., Hayes-Roth, F., Sacerdoti, E. (1982) The organisation of expert systems, a tutorial, Artificial Intelligence, 18, 2, 135-174.

Weldemariam, K. and Villafiorita, A. (2011) Procedural security analysis: A methodological approach. Journal of Systems and Software, 84, 7, 1114-1129.

Woolnough, P., Stevenson, O., Parr, H. (2015) Investigating missing persons: learning from interviews with families, Journal of Homicide and Major Incident Investigation, 10, 1, 1-14.

Yarwood, R. (2010) Risk, rescue and emergency services: The changing spatialities of Mountain Rescue Teams in England and Wales, Geoforum, 41, 2, 257-270.

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