THE DEVELOPMENT OF AN *OIL SPILL RESPONSE INFORMATION SYSTEM* TO MINIMIZE THE EFFECTS OF AN OIL SPILL

Ibrahim Busu, Norkhair Ibrahim, Ghazali Desa and Surya Afnarius

Faculty of Geoinformation Science & Engineering

Universiti Teknologi Malaysia, Malaysia

Abstract

Managing an oil spill disaster requires an enormous effort and resources. Many countries in the world, which have been hit by the disaster, realise that if a proper management procedure is available, the job becomes more efficient and economical. This paper explores a possibility of putting together a number of new technologies, namely GIS, multi-media and expert system, to form a system that can serve as a tool for assisting the management of the disaster. A conceptual model of the system shows how the components of the selected technologies are put together to form the foundation. In general, the proposed system comprises of three main components: 1) The development of an oil spill trajectory model using GIS, 2) The development of an Expert system module for oil spill response and its integration with the oil spill trajectory model within a multimedia environment, and 3) The development of the Oil Spill Response System itself which will act as a decision support tool. Functions of each component in the systems are carefully examined in order to establish a link between them as well as the user.

In developing the oil spill trajectory model, physical factors such as wind speed, surface current and tides will be taken into account in determining the movement of the oil spill. These factors will be grouped together in a grid format. The model will take into consideration the direction of the oil spill movement and the area covered by its spread.

Environmental elements such as shoreline classes, wildlife and human activities are mapped using GIS. Texts, pictures and videos are added to increase the value of information. When an oil spill occur, the oil spill trajectory model is used to predict the wildlife and elements that will be affected. Hence, priority can be given as to which element should be given immediate attention and the type of response can be decided upon. The response can be carried out according to a specified time in which the grid location of the oil spill can be predicted. Data on wind speed, surface current, wave height and tide level at that particular location will be used by the Expert System module to suggest a particular type of response. This suggestion will be displayed using multimedia.

In its implementation, the study uses Visual Basic 6.0 as the programming language, Arc View as the GIS software, Clips as the Expert System Shell library and MSHTML as the multimedia component library. The data is obtained from the Straits of Malacca. The final product of this study is an Oil Spill Response Information System which includes an oil spill trajectory model working on a GIS environment and making use of multimedia elements. It is hoped that the developed system can be used to predict the type of environmental elements that will be endangered by oil spill and the type of response that can be carried out to minimise its effects.

1. Introduction

After a number of major oil spills such as the one involving the oil tanker Torrey Canyon in 1967 which spilled 117,000 tons of oil into the sea, oil spill incidents have been given much attention throughout the world (Doerffer, 1992). Many countries started to develop a protection plan for their coastal areas and waters to enable them to manage the crisis effectively. Thus, countries whose coastlines are most likely to be threatened by the oil spill started to look into setting up a protection, response, as well as a management plan. According to Low et al. (1994), BOI (1998) and AMSA (1999), the response system developed consist of an oil spill trajectory model, the coastline map and map of areas which are sensitive to the spill, resources which are threatened, notification of affected bodies, cleaning standards and financial management. It is hoped that by implementing a response system, a country will be able to safeguard human activities and reduce the effects of an oil spill to a minimum.

The countries located along a busy shipping lane such as the Straits of Malacca are always exposed to the oil spill disaster. In 1997 and 1998 a number of oil spill incidents occurred in the Malacca Straits. During the incident at Tanjung Karang, some 20-km of shoreline was polluted with crude oil (Sa'odah and Shen-li, 1997). The oil spill has caused problems to the fishing industry and tourism and disrupted wildlife and their natural habitats.

The disaster in 1997 and 1998 was managed in the best possible way by the responsible agencies. Tracking of the movement of oil slick using an airborne camera provided an extra information for monitoring the spill but a proper management plan has not yet been implemented. The crisis management team had to deal with the situation using whatever resources available to them at that time. The technological advancement, specifically in the information technology, has brought forward hope and ways for the

development of a proper oil spill protection and management plan for the Straits of Malacca.

This paper describes a study being conducted to develop an oil spill response information system in Malaysia. Emphasis is given on the already completed oil spill trajectory model, which is the initial part of the response system.

2. Theoretical background

The action plan, which is part of the protection and management plan for the oil spill incident, to be developed in this study comprises of the following components:

Oil spill trajectory model
Map of the areas sensitive to oil spill
Chart or map of the areas (waters)

Oil spill trajectory model is required for monitoring movement of the spill and also for determining which part of the shore will the sludge settle. The map and charts provide important information such as location of public services and accessible route. These information and data will enable the management team to plan their mission carefully. In fact if the situation is permissible, a simulation (drill) can always be conducted before hand for evaluation purposes. This will give some time for the management team to react or lay down their protection plan before the spill strikes.

New technologies such as GIS, database and expert system, if incorporated with the trajectory model will certainly enhance the information system. Many research works have been conducted to further develop and integrate the new technologies to form a system useful in the management of oil spill.

3. Oil spill trajectory model

An oil spill trajectory model is a model that predicts the direction and speed of the oil during an oil spill (Beauchamp and Lefaivre, 1996). It is very useful for predicting the landing site and it also acts as one of the important components when drawing a contingency plan or oil spill response scheme.

According to Mackay et al. (1980), oil spills are subjected to a complex array of

physical, chemical and biological processes. These processes can be divided into two, namely a) Processes which are related to location such as advection and spreading and b) Change and loss of composition which include evaporation, dispersion, dissolution, emulsification, biodegradation, oxidation and sedimentation. Yapa (1994) stated that advection is a physical process which involves the drifting of the surface oil slick and the subsurface oil. This drifting is a horizontal mechanical spreading due to the imbalance of forces of inertia, gravity, viscous, and interfacial tension. Spreading is an important process that occurs during the initial stage of an oil spill.

Parameters that provide a significant influence onto the transport processes are:

a. Surface current
b. Surface wind
c. Tide (if in coastal waters, straits)

These parameters will define the drift vector of the spill.

Over the years, a number of transport equations have been suggested for defining the position of an oil spill at a particular instant. One of the general equations put forward by Low et al. (1994) is used in this preliminary study:

$$\mu = \alpha V_w + \beta V_c \qquad \text{(EQ.1)}$$

Where μ = drift vector of the spill
V_w = wind speed vector
V_c = surface current vector
α , β = functions that are related to wind and surface current

For areas where tidal influence is more prominent than surface current, surface current vector in the transport equation should be replaced with tidal current. Values for α and β as suggested by some researchers are 3.3% and 56% respectively.

In order to ensure a higher accuracy, Ekman effect is included in the calculation of the wind-induced drift. The direction of the wind-induced drift deviates by an angle ϕ towards the right of the wind vector (in the Northern hemisphere). The angle of deviation can be in the range of 0^0 to 25^0.

For the horizontal spreading, Lehr et al. (1984) attempted to measure the radius of the oil spill and suggested the equation:

$$A = 2.27\,[(\rho_w - \rho_o)/\rho_o]^{2/3}\,V^{2/3}\,T^{1/2} + 0.04[(\rho_w - \rho_o)/\rho_o]^{1/3}\,V^{1/3}\,W^{4/3}\,T \quad \text{(EQ.2)}$$

where A is the area of oil spill, ρ is the density of oil and water, V is the volume of the spilled oil, and T is time.

4. Decision and response to oil spill

McLeod (1994) sated that there are five choices of responses to an oil spill. These are:

a. No action, other than monitoring the oil slick
b. Containing or recovering the oil at sea
c. Chemical dispersion at sea
d. Shore clean up
e. A combination of response actions.

Other authors also suggested in-situ burning and bioremediation. These responses can be categorised as mechanical and non-mechanical methods. Mechanical clean up methods uses physical tools to collect and dispose the oil from the sea surface. If this is an effective method, it is more preferred and is considered as the traditional method. By employing this method, the spilled oil can be reused. However the method is very much dependent on wind, wave and tides.

According to White (1994) the following factors have to be carried out before deciding on actions that should be taken to handle the oil spill incident:

a. Determination of type of substance (oil, sludge or crude oil)
b. Determination of the movement of the slick for a particular interval
c. Air surveillance to gather more information
d. Identification of any resources or area under threat
e. Notification of affected population.

Once all the above factors have been carried out, the clean up method can then be decided. Either mechanical or non-mechanical clean up methods can be employed to remove oil slick from the environment. The choice is entirely up to the availability of

resources, environmental condition and amount of the spill. Fig. 1 and 2 show decision trees that can be utilised in the cleaning process. Baker (1994) suggested the steps and possibilities, which should be considered before (leading) to the use of dispersant for cleaning the oil slick (Fi. 1). Fig. 2 shows a decision tree suggested by Hayes (1994) for strategically dealing with the oil spill.

When the oil slick lands on a beach, cleaning up operation can be carried out using any technique that is suitable to the conditions of the beach. Apart from the technique used, accessibility of heavy machinery, location of resources, manpower, and disposal of gathered slick (sludge) should also be carefully considered when planning for a shore clean up operation.

5. GIS and expert system

The spatial capability of GIS makes it a very suitable tool in developing a response system. Various systems have been developed such as that by McMaster University in Canada known as GIS based Oil Spill Prediction Model (McMaster University, 1999). National Oceanic and Atmospheric Administration (NOAA) in America has also developed a GIS based oil spill trajectory model. In Australia, Oil Spill Response Atlas is also integrated with GIS and an oil spill trajectory model (Gilbert, 1998). This is then combined with a Coastal Resource Atlas to form a Spatial Decision Support System (SDSS) and supported by various media such as text, photographs and video.

The integration of GIS and expert system produces a new hybrid known as intelligent GIS. An intelligent GIS is composed of a system consisting of an expert system and a GIS linked by a command bridge. The expert system serves as a module that provides intelligence decision and GIS acts as an interface between the user and the database. Whenever an oil spill occur, the knowledge (gathered from various experts) stored in the expert system is accessed and integrated with the information in the GIS database. The expert system will use the rules set out in the knowledge base to come up with the best response action suitable to the local condition.

Research works on the integration of GIS and expert system can be found in many disciplines such as agriculture and marketing. A simple structure of an expert system for spatial analysis is shown in Fig. 3. Intelligent GIS will be one of the important components in the proposed Oil Spill Response Information System (OSRIS). It will play a central role in managing all kinds of data and spatial information required by the

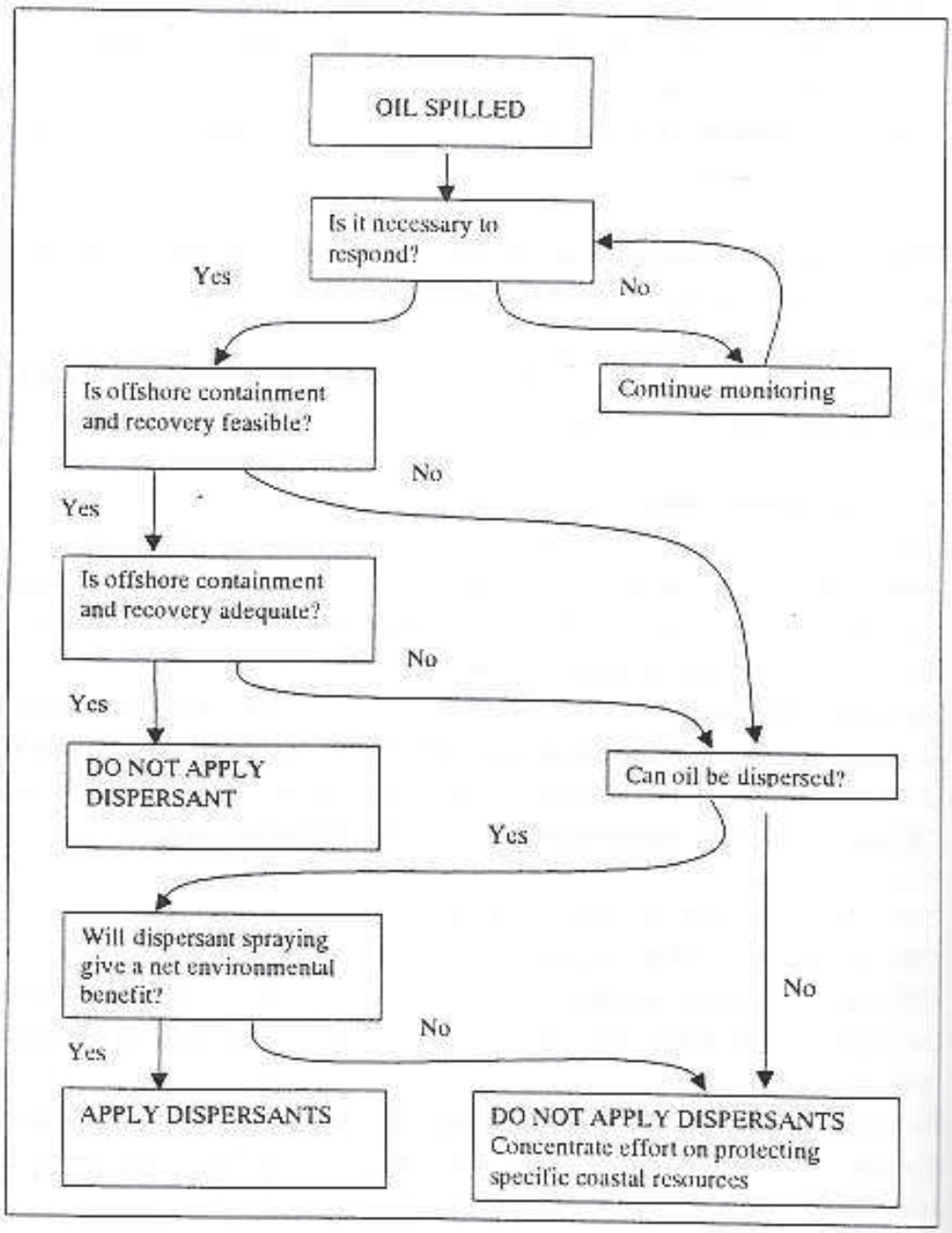

Fig. 1. Decision tree for using dispersant (Baker, 1994).

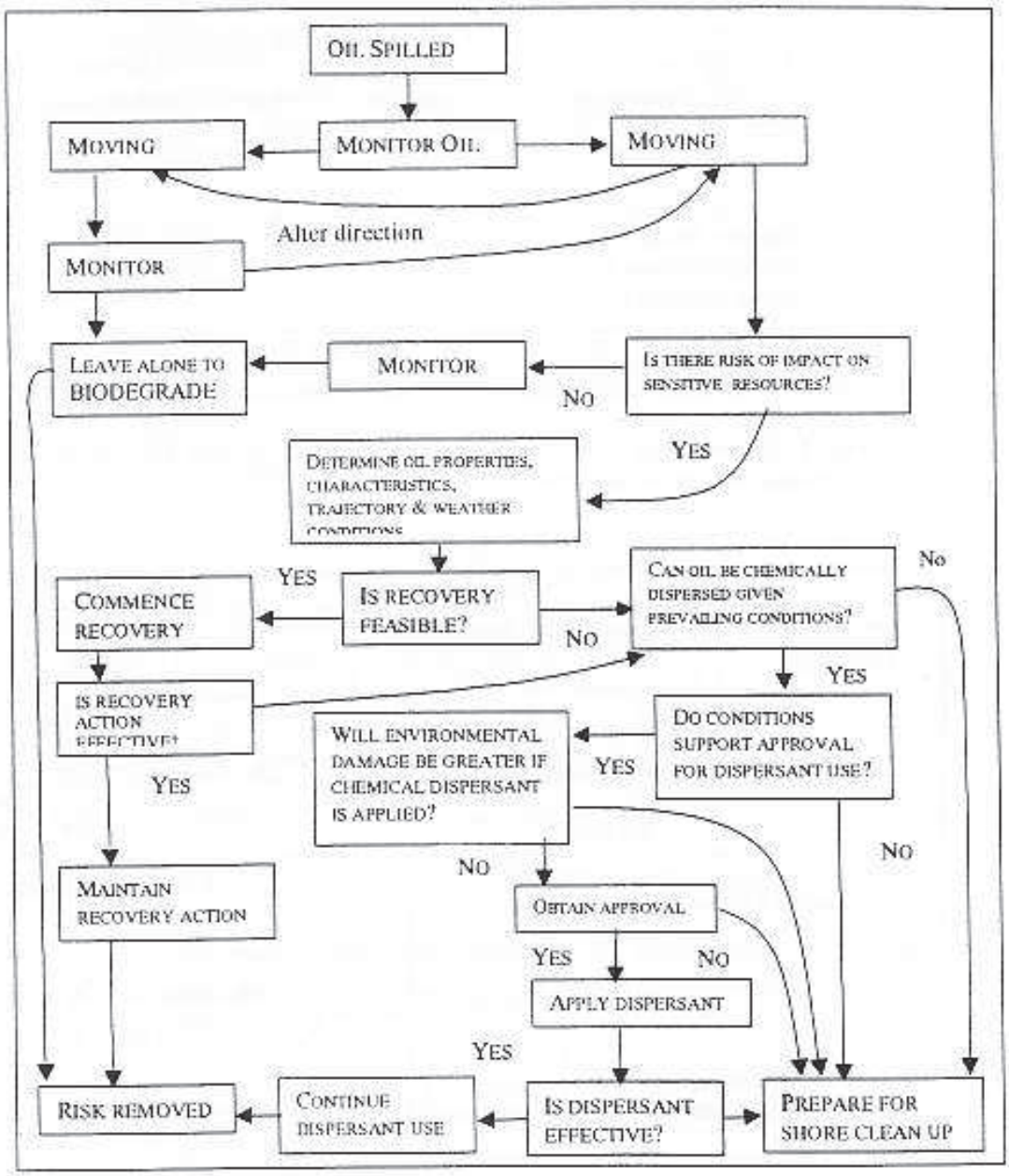

Fig. 2. Decision tree for a strategic oil spill response (Hayes, 1994).

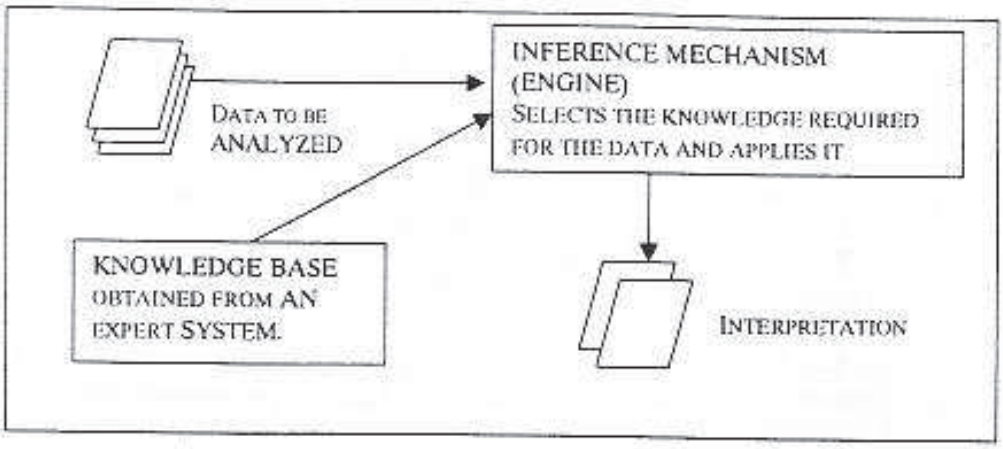

Fig. 3. Simple view of the structure of an Expert system for spatial analysis (Sinivasan and Richards, 1993).

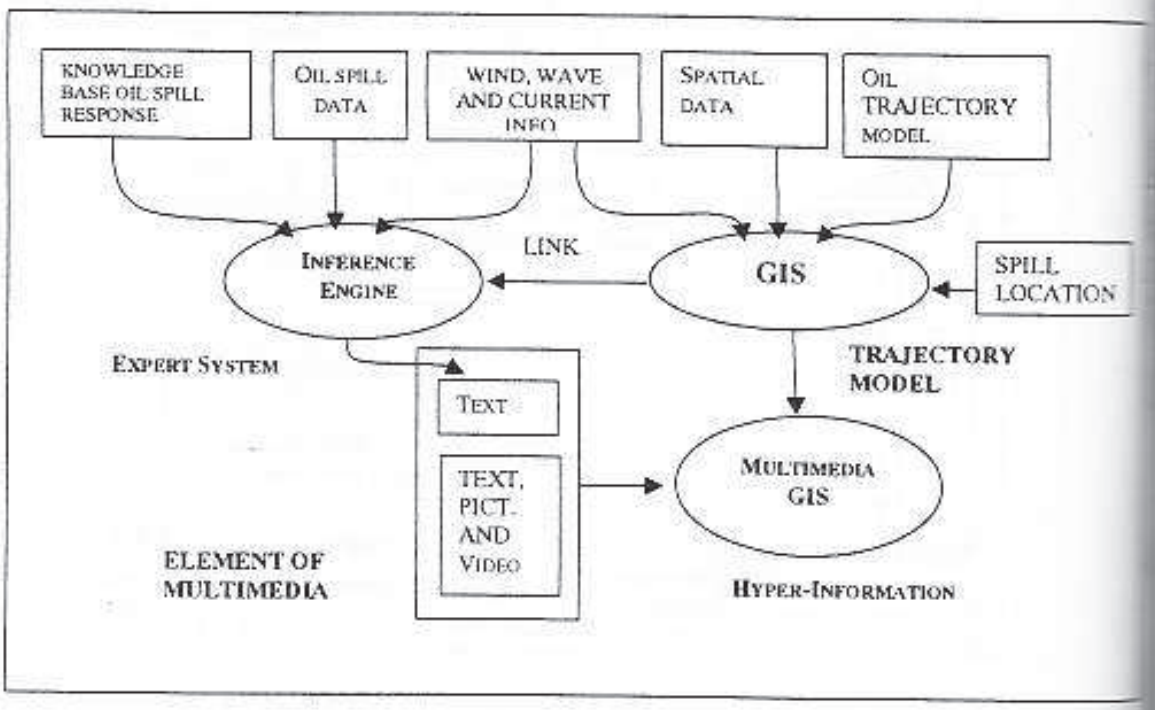

Fig. 4. Architecture of the proposed Oil Spill Response Information System.

system.

6. Logical model for OSRIS

The proposed system will have the following components as its foundation:

a. GIS
b. Expert system
c. Multi-media

These components are linked together logically to form a backbone of the system. Figure 4 shows how these components are linked together to form a unit. The GIS component manages spatial data which contain 16 different layers established in the database as shown in the table below:

Data Layers	
1. Grid layer that holds data for wind, current, tide and other data in coastal environment	2. Control
3. Public services	4. Ocean data
5. Coastal / land	6. Mud
7. Road network	8. Mangroves forest
9. Industrial sites	10. Recreational spots
11. Utilities	12. Vegetation
13. Animal	14. Wildlife
15. Oil slick movement	16. ESI

Besides handling and manipulating spatial data, the GIS component also holds the transport model for the oil spill. The model is based on the transport equation provided earlier (Eq.1 and Eq.2).

The expert system component requires information (data) on the spill, drift vector of the spill, wind, current and tide at the initial location. Besides these data rules and conditions for deciding the response are also required by this component. The rules and conditions utilised by the expert component for making a decision will be developed based on the decision tree shown in Fig. 1 and 2.

The multi-media section serves as an interface to the user. It will display the movement of the oil spill and other information, which are related to the areas under threat. This

section is developed using a hyper-information concept.

In general the system is going to be developed using two components and a software library. The two components are GIS and multi-media which will be developed using MapObjects (a module released by ESRI) and MSHTL (a module released by Microsoft) respectively. The software library, which is part of the expert system, will be developed using CLIPS 6.0 (a library containing an expert system released by NASA). Microsoft Access will handle attribute data and Visual Basic will be used to write a program that puts every component of OSRIS together. By using Lotus Notes, OSRIS will be made accessible to selected users via the internet.

7. Completed work

7.1. Data preparation and entry into MapObjects

The map of the study area was digitised and transferred to ArcView where attribute data were added. The layers were then converted to MapInfo where a program was written to form a grid layer. The layers were then converted back to ArcView and all the data were entered into MapObjects. Fig. 5 shows the interface to enter the spatial data into MapObjects.

7.2. Development of Oil Spill Trajectory Model

The implementation of the mathematical model of the oil spill trajectory model was carried out using Visual Basic 6.0, ActiveX MapObjects and MSHTML library. Two main subprograms were written:

i) To determine the extent of shoreline affected by oil spill
ii) To determine the location of oil spill after a certain period of time

The subprograms contain functions that actively show the spread of the oil spill in ActiveX MapObjects. The ESI layer of the shoreline that is affected by the oil spill is made active. The subprograms also allow related multimedia elements to be highlighted The algorithms of the subprograms are shown in Algorithms 1 and 2 while the interface showing the path of the oil spill is given in Fig. 6.

ActiveX MapObjects possess objects in the form of points, lines, rectangles and ellipse that can be programmed to support the integration of the oil spill trajectory model and GIS. Two layers are required namely the grid layer and the trajectory model. This

```
Variable initialisation line, oil spill layer, spread
Setup variable location, day, hour, oil spill interval

If location at sea Then
   Locate oil spill location
   While location is at sea And Exit = 0
         Locate grid where oil spill is as active grid
         Grab data on wind, current, tide suitable to day and time
         Search for a point of oil spread for next interval
         Form oil spill trajectory in active grid
         If on land Then
            Find intersection point with shoreline
            Form a line where the intersection is the end point
            Calculate required time and sum up the total time
            Calculate area of oil spill
            Calculate radius of oil spill
            Build a box object to form ellipse
            Display oil spill in MapObject
            exit = 1
         Else { oil is at sea }
            Calculate required time
            If xinterval <= 0 Then
               Calculate change in oil spill location at xinterval
               Calculate area of oil spill
               Calculate radius of oil spill
               Display
               xinterval = interval
            Else
               Build a new line for oil spill trajectory
            End If
            Initialise point and 'helping' line; pt and ln and the following interval
         End If
   Wend
   Display message in multimedia, suitable to the affected shore and activate ESI layer
End If
```

Algorithm 1. Determination of shoreline that is affected by oil spill.

```
Variable initialisation line, oil spill layer, spread
Setup variable location, day, hour, oil spill interval

If location at sea Then
   Locate oil spill location
   While location is at sea And Exit = 0
         Locate grid where oil spill is as active grid
         Grab data on wind, current, tide suitable to day and time
         Search for a point of oil spread for next interval
         Form oil spill trajectory in active grid
         If on land Then
            Find intersection point with shoreline
            Form a line where the intersection is the end point
            Calculate required time and sum up the total time
            Calculate area of oil spill
            Calculate radius of oil spill
            Build a box object to form ellipse
            Display oil spill in MapObject
            exit = 1
         Else { oil is at sea }
            Calculate required time
            If xinterval <= 0 Then
               Calculate change in oil spill location at xinterval
               Calculate area of oil spill
               Calculate radius of oil spill
               Display
               Exit = 1
            Else
               Build a new line for oil spill trajectory
               Initialise point and 'helping' line: pt and ln
            End If
         End If
   Wend
   Display message in multimedia, suitable to the affected shore and activate ESI layer
End If
```

Algorithm 2. Determination of location of oil spill after a time period.

integration allows for immediate information of areas which are affected and the location of the oil spill at specific times.

8. Ongoing work and conclusion

This paper has described in general the concept of the development of OSRIS. Emphasis has been given on the already completed development of the oil spill trajectory model. The development of the Expert System module and its integration with the oil spill trajectory model is presently being carried out. The development of OSRIS itself will also be carried out in which Lotus Notes will be used to enable selected users to access the information via the internet. It is hoped that the completion of the system will help in identifying affected wildlife and areas and provide a suggestion for the most appropriate response action in the event of an oil spill incident.

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