Interactive Oil Spill Management, Operation and Administration System

Sistema interactivo de gestión, operación y administración de derrames de petróleo

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Abstract:

This paper presents an oil spill management system that is interactive and real-time. The system uses geo-database and application development modules that are integrated with internet communication systems. It is designed to cover all stages of oil spill management, including before, during, and after an accident. The system can be linked with various satellites, airborne monitoring systems, and ground devices through communication systems to facilitate oil spill early warning, situational analysis, risk analysis, damage analysis, monitoring, and management in real-time. The components of the system include a database, central repository, disaster models, command and control, and communication schemes. This paper illustrates the conjunction of computer software and hardware with a variety of models and technologies for real-time oil spill monitoring and management.

Keywords: Oil Spill; Management; Decision Support System; Geomatic System Design.

Resumen:

Este artículo presenta un sistema de gestión de derrames de petróleo que es interactivo y en tiempo real. El sistema utiliza módulos de desarrollo de aplicaciones y geobases de datos, que se integran con los sistemas de comunicación por Internet. Está diseñado para cubrir todas las etapas de la gestión de derrames de petróleo, incluso antes, durante y después de un accidente. El sistema se puede vincular con varios satélites, sistemas de monitoreo aéreo y dispositivos terrestres, a través de sistemas de comunicación, para facilitar la alerta temprana de derrames de petróleo, el análisis de situación, el análisis de riesgos, el análisis de daños, el monitoreo y la gestión en tiempo real. Los componentes del sistema incluyen una base de datos, un repositorio central, modelos de desastres, comando y control, y esquemas de comunicación. Este artículo ilustra la conjunción de software y hardware con una variedad de modelos y tecnologías para el monitoreo y gestión de derrames de petróleo en tiempo real.

Palabras clave: derrame de petróleo; gestión; sistema de soporte de decisiones; diseño de sistemas geomáticos.

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1. INTRODUCTION

Oil spill hazard is an event that occurs suddenly and has complex implications. It leads to the loss of animal life, property damage, environmental degradation, and significant disruptions to local activities. Addressing such incidents requires extensive resources, equipment, skills, and coordinated efforts from multiple agencies. The vulnerability to oil spills varies across regions, but a substantial part of the country is exposed to these hazards, which can have far-reaching socio-economic consequences and adversely impact coastal communities.

While many contingency plans and procedures for oil spill management and relief are not standardized, some emergency response agencies have adopted systematic and computer-based approaches for oil spill monitoring and detection. Various computer-based emergency response procedures are available in the market, each offering different functionalities for oil spill emergency response. However, the diversity of databases with different formats poses challenges in integrating these systems into a unified framework for oil spill contingency. Consequently, the lack of compatibility between platforms, database formats, and system configurations hampers effective oil spill contingency efforts. Furthermore, most of these systems operate offline, providing results that are not in real-time. Consequently, utilizing these systems for oil spill emergency response can be complicated, costly, inefficient, and time-consuming.

Note that while these systems have their limitations, they still play a crucial role in mitigating the impact of oil spills and facilitating emergency response efforts.

NOAA Emergency Response Division (ERD) has recently adopted a suite of modules tailored to oil spill trajectory modeling and emergency response [1]. These modules, namely Computer-Aided Management of Emergency Operations (CAMEO) and General NOAA Operational Modeling Environment (GNOME), are specifically designed to support first responders and emergency planners [2]. The integration of these modules is a significant milestone in the advancement of oil spill emergency response technology in Canada. However, there is still more work to be done.

The GNOME trajectory model is renowned for its impeccable algorithmic performance. However, the user's expertise is crucial in configuring the model to operate in diagnostic mode for spill response. Despite the integration of these two systems into a unified platform, they do not encompass all the prerequisites for oil spill management and emergency response. A comprehensive system for oil spill management should encompass all the necessary procedures and information required before, during, and after disasters occur.

Oil Spill Information System (OSIS) and Shoreline Oil Cleanup Recovery and Treatment Evaluation System (SOCRATES) are two systems developed by BMT Marine Information Systems Limited and AEA Technology PLC to facilitate oil spill contingency planning [3]. While OSIS is employed for oil spill trajectory simulation, SOCRATES serves as a tool for contingency planning, providing detailed insights into coastal characteristics, sensitive sites, access points, and equipment bases. The system boasts a robust database encompassing oil types and weather information, along with commendable functionalities for oil spill contingency. However, it still lacks certain essential requirements necessary to coordinate disaster mitigation and relief operations. Authorities require more comprehensive information pertaining to disasters to enhance preparedness levels concerning disaster planning and execution of mitigation measures.

To improve readiness for handling oil spill disaster events, disaster teams require a real-time data transaction infrastructure. An operational oil spill disaster data processing and dissemination system is needed to support all operational mitigation and relief procedures during oil spill disaster contingency [4]. The system should be based on proven disaster models and methodologies such as GNOME & CAMEO. It should also include an interactive system that covers real-time disaster management, operation, and administration.

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The optimal design method for oil spill contingency planning should cover all stages of disaster mitigation support. This paper investigates this topic and explains five major components in the system structure graphically. It also discusses major disaster models and disaster management components required to cover all proceedings of monitoring, assessment, mitigation, and management before, during, and after an accident happens.

2. PROPOSED SYSTEM DESIGN

There are five main components of an efficient contingency system for oil spills. These components are as follows:

Database: It serves as a repository for all the information required to model oil spills.

Early Warning System: It provides real-time early warning information.

Disaster Modules: They provide all the necessary disaster products and information.

Command & Control System: It enables disaster management and administration.

Communication Systems: They allow mutual communication to disseminate data among authorized people and disaster players in the fields.

Figure 1 graphically illustrates the major components of an interactive real-time disaster management, operation, and administration scheme.

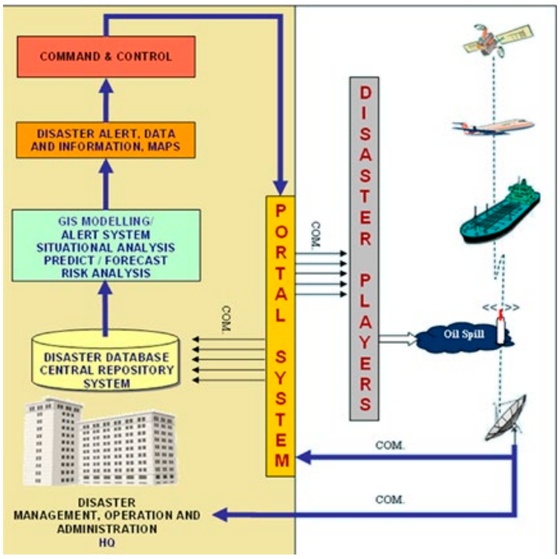

Figure 1. Major components of an interactive real-time oil spill management, operation and administration system, Source: Authors.

The system consists of the following components: a) Alert System: It provides early warning information in real-time. b) Databases: They serve as repositories for all the information required to model oil spills. c) Disaster Models: They provide all the necessary disaster products and information. d) Command & Control System: It enables disaster management and administration. e) Communication System: It allows mutual communication to disseminate data among authorized people and disaster players in the fields.

Figure 2 illustrates a list of data, models, and products required for an oil spill management, operation, and administration system The functionalities of each system component are as follows:

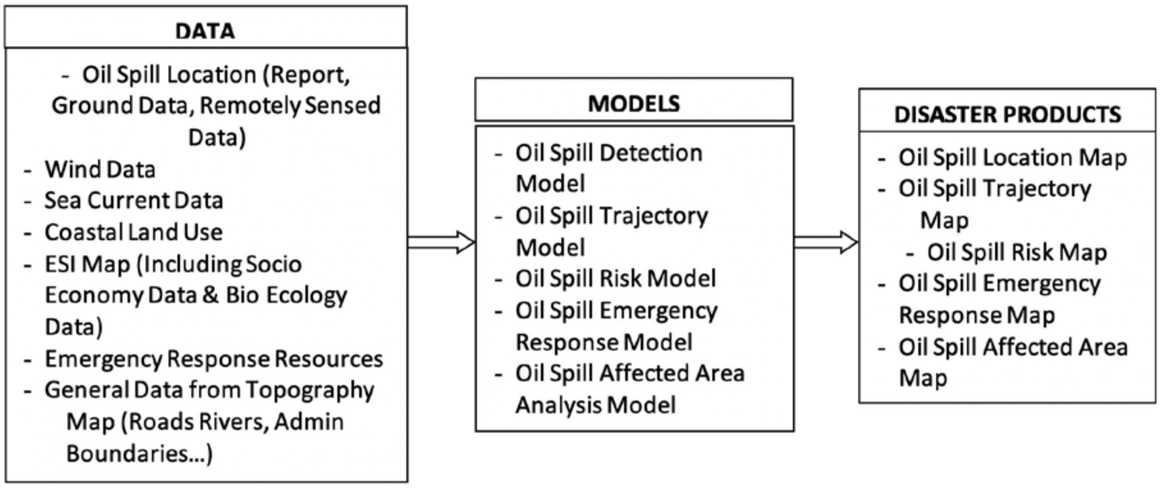

Figure 2. List of data, models and products required for an oil spill management, operation and administration system, Source: Authors.

Alert System

The alert system is a crucial component of the system that provides real-time, medium-term, and long-term early warning information to enable rapid response to oil spill events. The system aims to provide timely alerts for oil spill incidents, catering to real-time, medium-term, and long-term requirements The system receives information about oil spill location through its communication infrastructure and leverages various data sources such as GIS data, remotely sensed data, and monitoring technologies like deployed sensors and observant systems. The Environmental Sensitivity Index (ESI) map serves as a long-term early warning system for oil spill risk, while trajectory simulation results over this map offer medium-term risk early warning. Disaster models play a crucial role in providing essential disaster products and information. The Command & Control System facilitates disaster management and administration. The Communication System enables authorized personnel and disaster players to exchange data effectively. In summary, the alert system is an essential tool that provides timely alerts for oil spill incidents, catering to real-time, medium-term, and long-term requirements. It leverages various data sources such as GIS data, remotely sensed data, and monitoring technologies like deployed sensors and observant systems. The Environmental Sensitivity Index (ESI) map serves as a long-term early warning system for oil spill risk, while trajectory simulation results over this map offer medium-term risk early warning. Disaster models play a crucial role in providing essential disaster products and information. The Command & Control System facilitates disaster management and administration. The Communication System enables authorized personnel and disaster players to exchange data effectively.

Database

To ensure effective situational analysis and disaster modeling, an integrated database plays a pivotal role in consolidating input data from various agencies and departments. These entities act as custodians for essential information required for oil spill modeling, assessment, and emergency response. The integrated database serves as a centralized repository, facilitating seamless access to crucial data. It encompasses a wide range of information, including weather data, sea states, and other relevant parameters. While some of this information is linked to the database online and in real-time, other pre-existing data is readily available for analysis. The database structure includes spatial and tabular information, which are indispensable for the oil spill disaster management process. All processed data resulting from disaster modeling and analysis is meticulously stored within the database, ensuring its availability for retrieval by authorized disaster players.

Disaster Models

Disaster models play a pivotal role in oil spill disaster management by providing essential information about oil spill locations, trajectory, risk areas, damaged areas, and emergency response. These models are primarily developed within the Geographic Information System (GIS) framework to generate accurate information and products for oil spill disaster scenarios [5]. Additionally, there are models that operate outside the GIS environment but are compatible with various GIS engines, such as OSIS, Oil Spill Risk Analysis (OSRA) model, and GNOME [6], [7]. Regardless of the specific application modules employed for oil spill modeling and analysis, the resulting products can be seamlessly integrated into an integrated oil spill disaster management, operation, and administration system database (Oracle 10g). This integration is facilitated by ESRI's ArcSDE and Feature Manipulation Engine (FME) software. ArcSDE serves as an advanced geographic application server for relational databases, enabling efficient management of geographic information within a database server and seamless data sharing across all ArcGIS applications. On the other hand, FME possesses the capability to integrate diverse geographic features with geographic information analysis software.

The integrated database is a critical component of the system that plays a pivotal role in situational analysis and disaster modeling. It serves as a central-

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ized repository for input data from various agencies and departments that act as custodians for essential information required for oil spill modeling, assessment, and emergency response. The database encompasses a wide range of information, including weather data, sea states, and other relevant parameters. While some of this information is linked to the database online and in real-time, other pre-existing data is readily available for analysis. The spatial and tabular information required for the oil spill disaster database is listed in Table 1 [8]. All processed data resulting from disaster modeling and analysis is meticulously stored within the database, ensuring its availability for retrieval by authorized disaster players.

Table 1. List of disaster products and functionalities

Disaster Products	Functionalities
Oil Spill Location Map	Shows Location Of The Disaster And Oil Spill Extents
Oil Spill Trajectory Map	Shows The Next Destinations Of Oil Spillage Based On Time Interval
Oil Spill Risk Map	Shows Area At Risk By Current Oil Spillage And Sensitivity Of The Area
Oil Spill Emergency Response Map	Shows Important Information For Disaster Mitigation Such As Location Of Disaster Support Centers, Settlements, Road Networks And Access Point To Disaster, Location Of Jetties, Etc.
Oil Spill Affected Area Map	Shows Affected Or Damaged Area By Oil Spill

Command and Control

The Command and Control System plays a pivotal role in facilitating disaster management, operation, and administration based on the output products generated by oil spill disaster models. It encompasses various components and functionalities that contribute to the seamless coordination of response efforts (Table 2).

To ensure effective disaster response, relevant disaster products can be conveniently loaded through the internet portal. These products serve as valuable references for disaster responders, enabling them to make informed decisions and take appropriate actions. The system further streamlines the process by providing relevant commands and tasks through forms, emails, or messages. Pre-designed forms are an integral part of the command and control system, ensuring that each authorized person receives customized forms tailored to their specific responsibilities and tasks.

Table 2. Command & Control System Components and Functionalities

Command & Control System Components	Functionalities; Provide Tasks or Information About:
Alert Messages	Disaster Event, Danger, And Warning Notification (SMS, Email, Portal)
Disaster Reports	Oil Spill Situational, Damage, Victim, Evacuation, Etc.
Human Resources	Contact Person, Officers On Duty, Role & Responsibilities, Task Assigned, Directive & Feedback, Designation, Etc.
Inventory	Availabilities, Request, Approval, Receive, Utilization, Allocation, Return, Etc
Support Center	Capacity, Location, Distribution, Type (Evacuation, Operation And Relief), Usage

The Command and Control System is designed to provide comprehensive support for disaster management, operation, and administration. It leverages the output products generated by oil spill disaster models to facilitate effective decision-making and response coordination. By offering a user-friendly internet portal, the system enables disaster responders to access relevant disaster products conveniently. These products serve as essential references, equipping responders with valuable insights into the situation at hand. Additionally, the system streamlines communication channels by providing commands and tasks through various mediums such as forms, emails, or messages. This ensures that authorized personnel receive clear instructions tailored to their specific responsibilities and tasks.

Communication System

The communication system's core infrastructure is an internet portal that effectively manages all incoming and outgoing transactions while enabling real-time communication among various disaster players. This portal also serves as a robust platform for distributing data to individuals such as fishermen and other stakeholders involved in coastal areas, including hotels, resorts, tourism areas, and villagers. These diverse groups have distinct requirements concerning details and response times related to oil spills.

To cater to emergency needs, a dedicated portal manager oversees the on-scene commander and personnel management in the field. Their primary responsibility revolves around organizing all field activities and providing comprehensive support for activity planning, logistics, and resource allocation. Portal managers can hail from different organizations, including control centers, civil protection agencies, local administrators, technical or scientific personnel, or operators in a call center.

The internet portal is designed to be highly intuitive and user-friendly, ensuring seamless navigation for all authorized users. It offers a wide array of features and functionalities that empower disaster players to effectively communicate and collaborate in real-time. The portal's robust architecture enables it to handle large volumes of data while ensuring optimal performance and reliability.

In addition to facilitating real-time communication, the internet portal also serves as a centralized repository for critical information related to oil spills. It leverages advanced data management techniques to store and organize vast amounts of data from various sources. This comprehensive database enables authorized users to access up-to-date information regarding oil spill locations, trajectory analysis, risk areas, damaged areas, and emergency response protocols.

Furthermore, the internet portal plays a crucial role in disseminating vital information to stakeholders involved in coastal areas. By leveraging its extensive network connectivity, the portal ensures that relevant data reaches individuals such as fishermen, hoteliers, resort owners, tourism operators, and villagers promptly. This timely information empowers these stakeholders to make informed decisions and take appropriate actions based on the specific requirements of their respective roles.

Overall, the internet portal represents a cornerstone of the communication system deployed for oil spill disaster management. Its robust infrastructure and comprehensive feature set enable seamless collaboration among disaster players while ensuring efficient data distribution across various stakeholders. By leveraging cutting-edge technologies and best practices in data management, the portal serves as a reliable platform for real-time communication and information exchange during critical situations.

2. SOFTWARE AND HARDWARE CONFIGURATION

To configure the proposed oil spill management, operation, and administration system, a wide array of software and hardware components are employed. These components play a crucial role in facilitating various aspects of the system, including disaster modeling, data processing, data storage, data interchange, data transfer, and decision support. Figure 3 provides an overview of the main software and hardware components proposed for the integrated oil spill disaster management, operation, and administration system.

a) Disaster Data Processing Modules:

One of the key components is the Disaster Data Processing Modules. These modules encompass all the software required for oil spill modeling and data processing. Among the most popular software utilized for GIS and spatial data processing and image analysis are ArcGIS and Geomatica. Depending on the source of early warning systems and oil spill detection devices, these software modules can be seamlessly integrated with other application development software.

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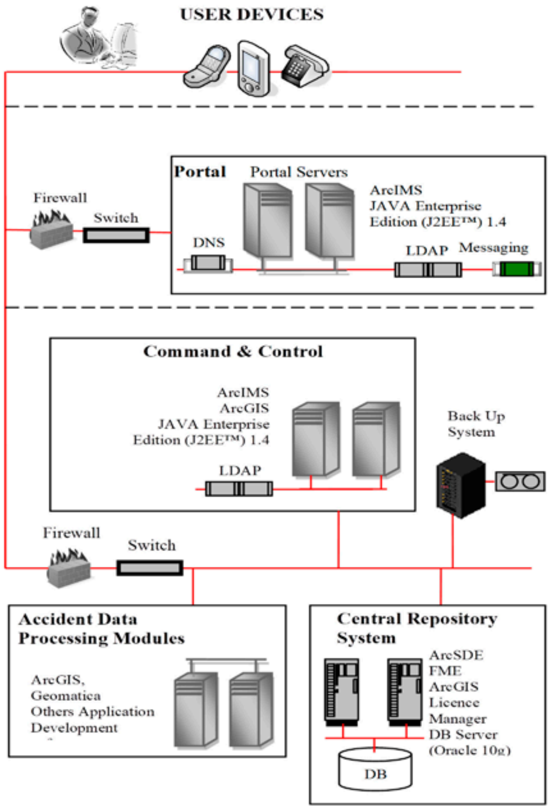

Figure 3. Oil spill management, operation and administration system configuration, Source: Authors.

b) Central Repository System:

The Central Repository System is a comprehensive infrastructure that encompasses computer servers and database storage servers. These servers are designed to store both geo-spatial data and non-spatial databases, ensuring the availability of essential information for oil spill disaster management. The Central Repository System is equipped with various software components, including the ArcGIS license manager, ArcSDE, and FME software. ArcSDE plays a crucial role in facilitating two-way data transition between application development and database servers within the ArcGIS environment. This seamless data exchange ensures optimal synchronization and accessibility of critical information. On the other hand, FME serves as a powerful data exchange system capable of extracting, translating, transforming, integrating, and distributing spatial data across more than 200 GIS, CAD, raster, and database formats.

The Central Repository System represents a cornerstone of the integrated oil spill disaster management, operation, and administration system. It provides a centralized storage solution for geo-spatial data and non-spatial databases, ensuring that all essential information is readily available for analysis and decision-making. By leveraging advanced software components such as ArcSDE and FME, the Central Repository System enables seamless data transition and exchange between various modules within the system. This efficient data flow enhances collaboration among different stakeholders involved in oil spill disaster management while ensuring optimal performance and reliability.

c) Command and Control System:

The Command and Control System plays a pivotal role in facilitating seamless communication and coordination between the portal system, data processing module, and central repository system. It serves as a vital bridge, enabling the smooth flow of spatial data and information across various components of the integrated oil spill disaster management, operation, and administration system.

To ensure efficient data exchange, the Command and Control System leverages ArcGIS and Internet-based GIS capabilities within the portal environment. This integration enables the seamless transfer of spatial data and information using ArcIMS. By harnessing these advanced technologies, the Command and Control System ensures that critical data is readily accessible to authorized personnel across different modules of the system.

Furthermore, the Command and Control System offers robust mechanisms for transmitting data through the portal. It leverages Domain Name Server (DNS) and Lightweight Directory Access Protocol (LDAP) to facilitate secure and reliable data transfer. These protocols ensure that data from the Command and Control System is seamlessly transmitted through the portal, enabling authorized users to access up-to-date information promptly.

d) The Portal system:

Manages all incoming and outgoing transactions. The Portal server structure is based on JAVA Enterprise Edition (J2EE™) 1.4, which defines the standard for developing multi-tier enterprise applications. J2EE simplifies enterprise applications by basing them on standardized, modular components, by providing a complete set of services to those components, and by handling many details of application behavior automatically. Portal systems are equipped with Messaging Server, DNS, and LDAP.

e) The Messaging Server

Is a high-performance and highly secure messaging platform that provides extensive security features to help ensure the integrity of communications through user authentication, session encryption, and appropriate content filtering to help prevent spam and viruses. The Messaging Server provides secure, reliable messaging services for entire oil spill players and command and control communities.

f) The DNS Server:

Provides fast, secure, high-speed, and high-bandwidth multiple Web transactions connectivity and networking.

g) The LDAP Server

Provides a central repository for storing and managing identity profiles, access privileges, application, and network resource information.

4. SYSTEM ANALYSIS

The system is designed to evaluate the capability of oil spill disaster players through a core operation and administration system at the disaster management center. It provides early warning, detection, monitoring, and mitigation functionalities in the event of an oil spill disaster. The system includes oil spill disaster models designed to produce situational information through thematic products required in oil spill management and emergency response. Figure 4 shows the data flow diagram through different system components.

In the Central Repository System, data collections have to be carried out based on the specification of thematic layers required for oil spill disaster through relevant agencies before a disaster happens. This will be prepared through downloading and uploading utilities. All of the gathered data requires pre-processing, which includes image pre-processing and enhancement, vectorization, interpretation, and extracting related features and converting them to an appropriate data format for modeling. Finally, all pre-pro-

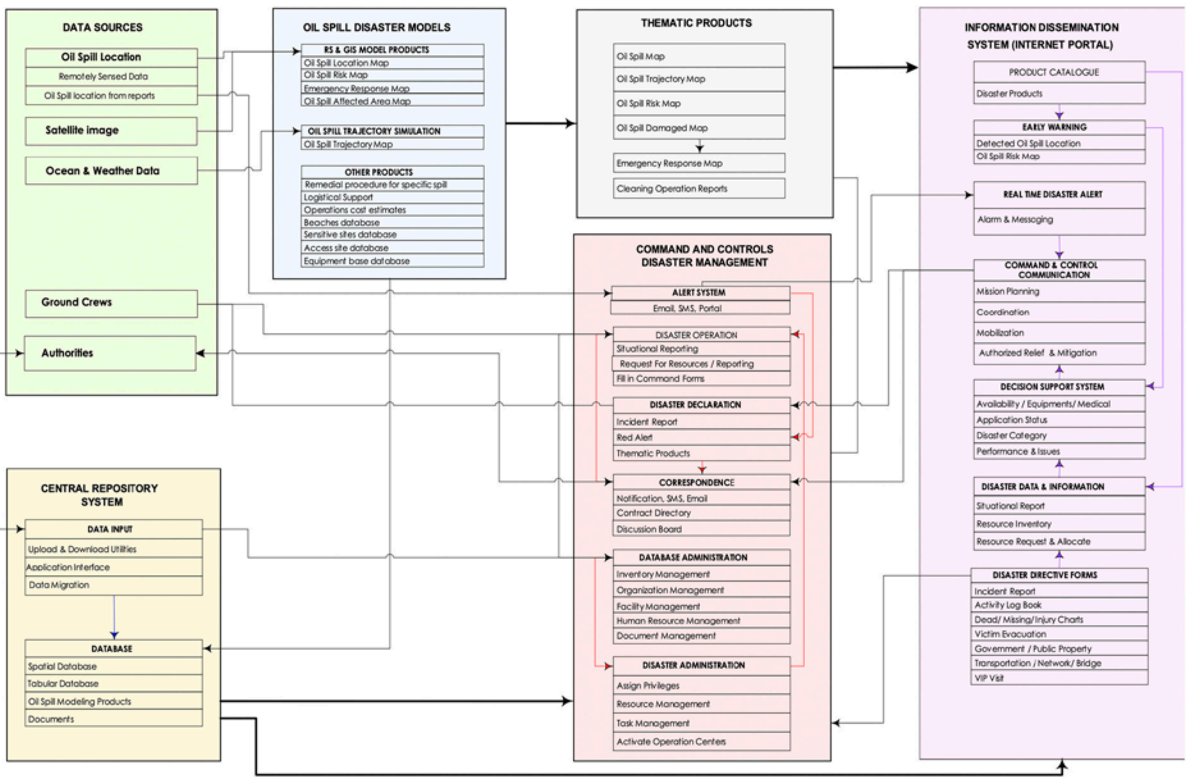

Figure 4. Integrated oil spill disaster management, operation and administration system data flow, Source: Authors.

ISSN:1390-5007
ASSILZADEH, H., TOGHROLI, E. - Interactive Oil Spill Management, Operation and Administration System. pp. 15-24

cessed data will be stored into a database and will be ready to get utilized by specific disaster models.

Oil spill disaster modeling and analysis will proceed by using available models to achieve disaster products immediately after an oil spill disaster happens. All the data stated will be modeled based on their particular models to generate various types of thematic products. The major models/systems for oil spill disaster are shown in Figures 2 and 4.

One of the major advantages of this system in comparison with other existing oil spill management systems is its command and control module for oil spill emergency response. The Command and Control System is like an oil spill operation and administration office that enables the disaster responders to have thematic products and information on the current oil spill event integrated with decision support. The system includes but is not limited to the following sub-components.

a) **Alert System**: The Alert System uses Email and SMS through Portal.

b) **Disaster Operation**: Disaster Operation includes Situational Reporting, Request for Resources, and Fill in Command Forms.

c) **Disaster Declaration**: Disaster Declaration includes Incident Report, Red Alert, and Thematic Products.

d) **Correspondence**: Correspondence includes Notification, SMS, Email, Contract Directory, and Discussion Board.

e) **Database Administration**: Database Administration includes Inventory Management, Organization Management, Facility Management, Human Resource Management, and Document Management.

f) **Disaster Administration**: Disaster Administration includes Assign Privileges, Resource Management, Task Management, and Activate Operation Centers.

One of the advantages of this system design is having a mutual communication through the internet portal. The system can also implement other communication infrastructures. Situational data from fields or disaster players can be sent to the disaster operation and administration office for evaluation, updating thematic products, and decision making. The portal system facilitates all functionalities described for the command and control system through forms, reports, emails, messages, and other utilities. It is simply a web page with several security levels that allows accessibility to different people on the ground like public, players, managers, and VIPs to different data related to the oil spill. The portal system is the core communication system between all mentioned parties involved with the disaster.

5. CONCLUSION

The system designed in this paper is a solution to incorporate the distinct systems currently used for oil spill management and make them a unique multi-functional oil spill management system. This makes the operational oil spill management real-time, more efficient, and systematic. It covers all aspects of oil spill management before, during, and after oil spill events, including disaster warning, mitigation, communication, assessments, documentation, and data repository. The system can reduce warning alert and emergency response time. The system can be easily integrated into all available systems currently used for oil spill monitoring and management like GNOME & CAMEO or other new technologies to facilitate robust real-time and interactive emergency response for oil spill accidents. Oil spill response agencies such as Canada-US Joint Marine Pollution Contingency Plan (CCG & USCG), Environment Canada (EC), and other organizations can easily join their system to this new web-based technology for better and efficient oil spill management and response. Finally, this architect design for oil spills can be used to develop other disaster applications. By linking all disaster applications like flood, landslide forest fire, and tsunami, the system can be converted into a centralized multi-disaster support system [9], [10]. The system design is flexible for adding any other functionality needed for supporting oil spill disasters.

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