Development of an object-oriented environmental impact assessment programme
C.-H. Orr & S.-F. Peng
Informatic Environmental Services, West Covina, CA 91791, USA

Abstract

Environmental impact assessment studies entail a series of activities including: information gathering, data acquisition, data analysis, project scope definition, system modelling, result interpretation, impact identification, result comparison, and compliance evaluation. The studies often extend to cover: different locations, multiple design alternatives, and planning for monitoring actions. The diversified environmental conditions and application needs warrant a systematic approach in the overall system planning. This paper highlights application of object-oriented techniques in analysis, design, and implementation of a computerisation programme for this problem.

1 Essential Considerations in Environmental Impact Assessment

Major human activities, actions, or projects, such as construction of harbour, ocean outfalls, etc., are likely to have a direct, indirect, and/or cumulative effect upon the immediate environment surrounding the activity location. The effect often leads to corresponding changes in the environmental characteristics. In order to evaluate these potential changes and to control and/or minimise potential detrimental effects upon the environment, an assessment programme is often conducted prior to starting of the project.

In many developed countries today, environmental impact assessment process has already become a pre-requisite requirement by law on many major human projects likely to have a significant effect upon the condition and quality of the surrounding environment. The actual process in the United States is driven by the federal law, regulations, state and the specific agency requirements, with the governing act National Environmental Policy Act (NEPA).
Environmental categorisation are relatively broad, typically including the following classes, each outlined with its respective areas of concern as:

- **water**: water quality change due to the project,
- **air**: air quality change due to the project,
- **land**: land resource availability and use,
- **ecosystem**: effect upon the surrounding ecosystem stability,
- **noise**: noise minimisation to improve living quality,
- **human and economic aspects**: human interaction with the environment and subsequent effect upon the economy due to the project.

Each of these elements has attracted intensive research efforts in the recent years, including: development of appropriate assessment methodologies, procedure in baseline data collection, formulation and identification of adequate numerical models and corresponding parameters, evaluation of the overall scenario, etc. For illustration purposes, this paper only focuses on the water quality related issues, where appropriate. In particular, discussions will be centered around discharge of human and industrial wastes into the open seas.

Major concerns in the evaluation of water quality include the changing conditions of following elements within the water environment: dissolved solids, suspended solids, temperature, water flow, toxic level, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), nutrients, and bacteria, all of which have direct impacts upon the surrounding aquatic life. Changes caused to these aquatic life will lead to an indirect effect upon human economy conditions, social activities and behaviour. Proper design and control of the discharge procedures, increase of treatment works, etc. often helps to limit the impact potential.

Environmental impact assessment studies typically include the following major steps:

- collection of background baseline information;
- definition of the scope of human activities, including what, where, and when;
- formulation of a study methodology in the evaluation of potential impacts, including necessary numerical models, project alternatives, monitoring plans, etc.;
- identification of potential impacts and comparison among alternatives;
- compliance with regulations and recommendations.

The process of environmental impact assessment has often been iterative in a typical ‘waterfall format’, as illustrated in Fig.1. The next phase of environmental assessment follows from the approval of the project planning and beginning of such a project implementation. A monitoring scheme has often been adopted to ensure and verify the impact levels are being controlled within the acceptable limits. The planning of such a monitoring programme has typically been integrated as part of the earlier stage environment assessment studies.
Baseline information is gathered prior to the introduction of the planned human activities. Gathered information can be used in two ways:

- elimination of irrelevant areas during the planning phase, and
- comparison with the projection for impact assessment during the evaluation stage.

Much of the necessary baseline data may be gathered from existing information, published reports/documentation and/or previous studies. In many cases, however, new data acquisition will be conducted to update or to supplement existing data. This information collection typically covers both the geographical and temporal dimensions. Geographical dimension is used to provide spatial coverage for the potential sites, impact zone, and reference locations. From the selected stations, water and sediment samples are collected at different water depths along the given water columns and on the sea bed, respectively. Temporal dimension is applied to cover the seasonal fluctuation. For comparison purposes, data should be collected with the consistent time frames.

Introduction of human activities often has essentially two stages for: introduction of the planned activities with corresponding construction works, and on-going operation of the introduced activities. Precise scopes of these intended activities need to be clearly defined in order to evaluate the potential impacts upon both the biophysical and socio-economic environments. Typically, these cover issues defining:

- the planned activities during their introduction and operation stages,
- the relevant materials and resources involved in the planned activities,
- the exact locations of the planned activities and their corresponding mixing zone boundaries, and
- the duration of the planned activities.
Necessary methodologies are developed for different assessment requirements. Often, they may involve use of selected numerical models for the prediction and projection of potential impacts caused by the planned activities. The modelled results can typically be used to establish overall cumulative effects, impacts upon individual environmental parameters of concern, and to evaluate causes and conditions for these effects. However, establishment of these models are often a difficult task due to a number of factors (Beck, et al):

- the environment is more involved than existing modelling resolution;
- identification of necessary model parameter values is subject to statistical analysis of data collected in a noisy environment; and
- the environment is dynamic and changes with time.

For a well designed environmental planning study, alternative schemes and their respective mitigation measures are also allowed for. Impact evaluation is performed for each of these alternatives for assessment and feasibility. Results from these evaluations are compared for recommendation. Parallel to the evaluation of the planned human activities, monitoring plans for both the construction and operation stages are also outlined based on the baseline data information and modelling results. Projected impacts will then be compared with the regulation requirements for compliance.

As outlined above, the overall planning studies in typical environmental impact assessment projects are characterised by a range of information activities including:

- information gathering and data acquisition,
- data analysis along both the spatial and temporal dimensions,
- project scope definitions in both qualitative and quantitative terms,
- numerical model formulation, identification and application,
- identification of potential impact levels, and
- multi-dimensional comparison among: different alternative schemes, monitoring conditions, and regulation requirements.

The diversified requirements for this whole range of activities have posed a challenging problem in the development of a computerised platform supporting these activities (Orr and Peng). In the following, discussions will be focused on a modern object-oriented approach to this problem.

2 Object-Oriented Analysis and Design

As discussed in the previous section, environmental impact assessment studies often involve a range of activities and applications. An integrated approach is necessary to provide a unified platform for its computerisation. Traditionally, structured approaches have been used extensively in the top-down hierarchical analysis and design to meet many organisation information needs. However, the inherent rigid frameworks within the structured approaches require a high degree of discipline throughout the system life cycle and often lack the flexibility to cater for the changing environment.
Object-oriented approaches have been gaining widespread popularity in the recent years due to its unique capabilities of:

- promotion of software engineering principles within the construct;
- high degree of encapsulation leading towards the much needed flexibility to support ever-changing requirements and conditions;
- improvement in the traceability from analysis phase to implementation;
- promotion and support for software reusability;
- support for specific object type implementation; and
- high degree of flexibility in object manipulation for system integration.

The above advantages of these modern approaches have enabled the rapid development in the integrated system applications. This paper presents an attempt of adopting these modern technologies in an integrated approach to a range of environmental problems.

Similar to conventional approaches, development of object-oriented applications also evolve through different phases for analysis, design, implementation, and maintenance. Principles for well analyzed and designed object-oriented software can be found in (Booch). Typical in the integrated environment, the range of activities are represented by a hierarchical structure with multi-level organisation. The top layer activities can be represented by a range of interacting application objects, which are supported at the lower levels with more detailed common and/or domain specific objects. Fig.1 can easily be viewed as a top level object representation for the overall requirements.

Major objectives and procedures during the analysis phase for object-oriented planning and implementation include:

- identification of essential application objects and object classes,
- identification of corresponding class responsibilities and attributes,
- identification of associating class operations,
- identification of scope of commonalties among given classes for potential abstraction,
- identification of relevant object use cases,
- analysis of individual use case behaviour with given class definitions,
- derivation of additional entity object classes to support the range of use case scenarios.

Following from Fig.1, some of the high level object classes and sub-classes in the studies of the aquatic environment are highlighted as:

- Baseline Class: include basic sub-classes for Water Quality, Ambient Conditions, Geological Conditions, Aquatic Life Conditions, Socio-Economic Conditions, etc.;
- Planning & Design Class: include basic sub-classes for Resources, Alternative Schemes, Schedules, and Monitoring Procedure;
- Modelling and Evaluation Class: include basic sub-classes for Near-Field Modelling, Intermediate Field Modelling, Far-Field Modelling, and Scaled Model Verification;
Impact Identification Class: include basic sub-classes for Modelling Projections, Baseline Condition Changes, and Impacted Domains;

Regulation Compliance Class: include basic sub-classes for Impact Summary, Criteria and Regulations, etc.

Details of individual classes are typically well wrapped within the classes' own implementation. Therefore, enhancing features within the Modelling class is not going to affect applications of other classes.

An illustrative sample class specification for an Ambient Temperature Condition sub-class is given as:

Name:
Ambient_Temperature_Condition

Responsibilities:
Provide analysis for ambient temperature reading

Operations:
Read_Data();
Mean_Value();
Maximum_Value();
Minimum_Value();

Attributes:
temperature;
time_period;
water_depth;

The illustrated sub-class above has its operations common to many other sub-classes within the Baseline::Ambient Current Condition class, such as conditions for Ambient Salinity, Current Speed, Current Direction, etc., which are typically obtained by the same current meter readings. A super-class can then be formulated. The common functionalities are shared and reused among other common sub-classes. Walking through the potential use cases may extend the applications of available classes to other applications and potentially new classes. For instance, a new class for Ambient Diffusivity characteristics can be derived from the current speed and direction.

Design stage follows from the analysis model with the following primary objectives:

- formulation of an implementation framework for the system architecture,
- formulation of the inter-object class relationships,
- formalising the class hierarchy, for inheritance, polymorphism, etc.,
- filling-in details of the class operations, state transition, and control,
- when necessary, introduction of control objects to bring individual entity objects together.

Both the analysis and design stages are carried out in an incremental and iterative manner from basic objects and minimal functionalities until a satisfactory design model is achieved to support the intended applications.

Based on the notations from (Booch\(^3\)), Fig.2 below gives a simple example of the class design and application of the Current Meter Monitoring class during the baseline study stage. Each monitoring station provides a series of readings, i.e. 1:N relationships for: current speed, current direction, temperature, salinity, etc. Mean values and, in some cases, extreme values,
can be extracted from these series of readings for further processing. Highlighted in the figure is also the Deployment Criteria class in support of and being used by the Monitoring class. One major advantage of object-oriented approach is that experience derived from the aquatic study can readily be adapted and reused in other areas, such as air, land, etc.

![Diagram of Current meter monitoring station class diagram]

Fig.2: Current meter monitoring station class diagram.

3 Object-Oriented Implementation

In the development of integrated applications, implementation inevitably takes on an incremental format. Typical steps include:

- for each domain top object area, start from minimal functionalities;
- establish the proper object hierarchy;
- develop preferred user interface;
- integrate with other top level objects.

Due to the inherent complexities with a diversified range of top level objects involved, many of the development steps in itself warrants a complete treatment for the planning, analysis and design processes. Typical examples include development of: numerical models, graphical user interface, etc.

An object based platform, including computer language and system tools, is recommended for the system implementation. Currently, the C++ language is enjoying tremendous popularity because of:

- C++ is a class-based object-oriented language providing the essential features of: data abstraction, inheritance, and polymorphism to support the object-oriented programming paradigm (Rao*);
- the needed persistence feature is available from many object-oriented databases as an extension to C++ for object database applications;
- C++ provides a more abstracted and better managed environment for the development of modern windows based graphical user interface, which is generally much preferred by the user community;
many class libraries, including graphical tools, numerical modules, etc., are already available commercially to support C++ development;

- the language is available in practically all platforms; and

- C++ interface to new system tools is often the first, if not the only, one being made available, easing a lot of development decisions.

A C++ implementation of Fig. 2 is illustrated below.

```cpp
class Measurement {
    private:
        double mean_value;
        Mean_Value();
    public:
        Measurement();
        ~Measurement();
        Get_MaxValue();
        Get_MinValue();
}

class Ambient_Temperature {
    private:
        Datum();
        ~Datum();
        Get_MaxValue();
        Get_MinValue();
    public:
        Measurement();
        ~Measurement();
        Read_Data();
        Get_Mean();
        Read_Data();
    }

//

class Datum : Measure {
    private:
        double max_value;
        double min_value;
        Maximum_Value();
        Minimum_Value();
    public:
        Datum();
        ~Datum();
        Get_MaxValue();
        Get_MinValue();
        Get_Mean();
        Get_Mean();
    }
```

4 Summary

Environmental impact assessment programmes are typically characterised by a range of activities, including: data analysis, numerical modelling, regulation compliance, etc. Experience from the recent object-oriented developments has demonstrated the object-oriented approach is well suited in the integrated development with a computerised system of these complexities. Works are continuing on its further design and implementation.

References


