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A multi-objective geographic information system for route selection of nuclear waste transport☆

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Abstract

Nuclear power is widely used throughout the world today. Functioning nuclear power plants produce large quantities of radioactive wastes needing to be transported to safe sites for proper management. With public emphasis on environmental protection and concern for safe transport of nuclear wastes, the problem of selecting an appropriate route for transporting nuclear wastes is a vitally important issue. The aforementioned route selection problem involves conflicting objectives among interested parties; therefore, we develop a multi-objective geographic information system (GIS) with ESRI ArcView GIS 3.x interface to practically support the involved parties for such a multi-objective route selection problem in engineering practices.

Keywords: Nuclear; Route; Geographic information system (GIS); Multi-objective

1. Introduction

Currently, nuclear power is generally used worldwide; however, radioactive wastes are inevitably combined with nuclear power benefits. If produced nuclear wastes are not properly transported to safe sites for strict management, the natural environment will be destroyed from pollution. Since the public is concerned with safe transport of nuclear wastes [1–6], the problem of choosing an appropriate route for nuclear waste transport should be handled with caution.

Route selection for nuclear waste transport becomes a decision for transporting hazardous materials [7,8]: the model developed by List and Mirchandani [9] is the most similar case to what we proposed in this study. They consider three objectives: total transportation cost, total risk, and equity of the risk imposed. Although many multi-objective models for transporting hazardous materials are proposed, the multi-objective transportation decision is not widely approved among practitioners so far. This is because: (a) these models are validated by a small road-network instead of an actual road-network, and the cost of collecting *actual* road-network attributes is very high; (b) most practitioners are not familiar with the complicated models; and (c) lack of an effective interface to integrate multi-objective programming and transportation planning in practice.

The geographic information system (GIS) is specially designed to assist in finding solutions to geographic problems by computer [10,11], e.g., location problems, shortest route problems, distribution patterns of people, etc. In short, the GIS allows both practitioners and

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theoreticians the opportunity to grab large chunks of earth's surface and explore them around in their hands. Since GIS can effectively storage actual road-network data, we can develop a customized application for an actual road-network with GIS assistance. As suggested by DeMers [12], the GIS encourages us to roll our world in much the same way that geographers, naturalists, and explorers have done, but with a much more precise set of tools. This paper successfully integrates the theoretical aspect (multi-objective shortest route problem), with the practical aspect (actual road-network attributes of GIS), to plan a multi-objective route for transporting nuclear wastes using a practical rather than simplified road-network. Our study is organized as follows: Section 2 illustrates the problem characteristics and the real transportation network for nuclear waste transport in Taiwan. In Section 3, the shortest route model with multiple objectives is established and the concept of multi-objective GIS for selecting such a route for transporting nuclear wastes is introduced. In Section 4, an actual case of Taiwan is used as a numerical example for resolution and discussion. Finally, conclusions and recommendations are presented in Section 5.

2. Problem characteristics

In this section, we focus on the problem characteristics for transporting nuclear wastes and illustrate the transportation network. These efforts are used to formulate our multi-objective shortest route model in Section 3.

2.1. Transportation stages

The Institute of Nuclear Energy Research (INER) of Taiwan was established early in 1968, specializing in nuclear technology R&D programs. INER is under the administration of the Atomic Energy Council of Taiwan (AECT), and is located in scenic Lungtan, Taoyuan, 45 km from Taipei, and occupies 120 acres of land. INER's primary R&D objectives are maintaining nuclear safety, innovating environment and energy technology, as well as promoting nuclear technologies in a civilian application.

The transportation program development strategy for radioactive waste management is to collaborate with the involved parties. Specifically, the transportation plan should present the INER's strategy and describe the management process used to work cooperatively with local governments, police, utilities, transportation carriers, and other public interests to refine the transportation planning as it is developed. The mission of INER is to manage and dispose of nuclear wastes in an open manner that protects public health, safety, and the environment, enhances national and energy security, and merits public confidence. INER is responsible for designing and developing a safe and efficient transportation plan with the capability to support waste acceptance.

The Taiwan Nuclear Waste Policy Act (TNWPA) established a stepwise approach, i.e., three stages for making decisions related to approval, licensing, operation, and eventual closure of the repository. These nuclear waste transportation stages can be summarized as: (a) application for transport; (b) in-plant operation and examination; and (c) road transport. These stages are strictly followed by Solid Waste Association of North America (SWANA) standards [13]. We use the third stage, road transport, to build our multi-objective GIS model.

When all transportation paperwork is approved, the Taiwan INER decides the date and timing of shipment. Nuclear wastes are often transported at midnight in order not to affect prevailing traffic or increase road transportation risk. INER sends personnel to inspect radiation dosage from each container, relevant staff, and equipment, prior to road transport [14]. Nuclear wastes must meet regulations before being released for total safety transport. Once INER personnel inspect and record a 2-m area depth for hourly waste dosage stipulated between 10 and 200 mR [14], these wastes are then permitted for road transport. When the container carrier from each branch waste producer passes inspection and undergoes application procedures, they are given a police escort to avoid unexpected accidents and ensure minimal radiation exposure risk to the population.

Based on operational practices cited earlier, nuclear waste transportation differs widely from general transportation issues: i.e., only minimizing travel time. On the contrary, conflicting objectives, e.g., avoiding accidents, minimizing travel distance, reducing exposure risk to population, etc., should be simultaneously considered to meet INER's mission goals. Thus, our problem is defined to finding an appropriate route with multiple objectives using an actual road-network. This route selection model formulated in Section 3 is eventually a multi-objective shortest route problem.

2.2. Network analysis

The detailed transportation network of nuclear wastes is very complicated, as shown in Fig. 1 by the GIS digital map. The nuclear power plant site is at the exact INER location, in an urban area within the mountains, while the storage site is located at a harbor near the sea,