# A Multi-objective optimization model for urban planning: the case of a very large floating structure

Yedidya Levi, Shlomo Bekhor, Yehiel Rosenfeld

Faculty of Civil an Environmental Engineering, Technion - Israel Institute of Technology, Technion City, Haifa, 32000, Israel.

## Introduction

Artificial islands were constructed in various locations around the world for different purposes, including urban expansion. Two conditions existed in most of those locations: shortage of land reserves and technological feasibility, in particular sand availability and shallow water. There are several alternatives to cope with these problems. One of the technologies that provide solution to the problem of fill-material shortage is the use of floating platforms (anchored or fixed to the seabed) in order to create the island. Given the high costs of such platforms, it is important to plan the land-use and transportation network allocation in order to maximize the benefits of of such artificial land.

The purpose of this paper is to develop an optimization model for urban planning in an artificial island composed of Very Large Floating Structures (VLFSs). The optimization model addresses the geometric shape of the island (the array of floating platforms), the land-use layout, and the transportation network. This subject is part of a vast research area dealing with urban development. The model developed in this paper considers the specific properties related to an artificial island made of multiple floating modules.

The combined land-use and transportation planning problem is very complex for modelling. Most of the optimization models in the professional literature considered separated models for either land-use or transportation. Relatively few models considered the combined land-use and transportation optimization problem.

Given a fixed land use configuration, the Network Design Problem (NDP) seeks to find the best transportation network for defined constraints. The problem has been continuously studied over the last five decades in the field of transportation planning. Note that most NDP models assume that the land-use layout is given, and consequently the total number of trips generated and destined in each zone is fixed. A more general problem, which is considered in this paper, accounts for different land-use layouts, in an attempt to find a better combination of land-use and transportation.

The Land-use Design Problem (LDP), sometimes called Multi-site Land-Use Allocation (MLUA), deals with optimizing of the land-use layout. The models differ from each other with respect to the objectives taken into account. The LDP generally does not explicitly include the transportation network. In addition, in most publications both LDP and NDP models considered only single-objective functions, such as maximizing land-use variables or minimizing travel times or costs.

<u>Methodology</u>

Three main objectives are simultaneously attempted in this paper: economic efficiency, maximum VLFS area utilization, and transportation efficiency.

In line with the literature, the approach of this paper is to formulate the optimization problem as “bi-level”. In the top-level problem, the decision-maker is required to decide the land-use layout and the road network structure, while taking into account the abovementioned objectives. The implementation of the transportation efficiency objective depends on the road users’ behavior. This behavior pattern is obtained by solving the lower level problem, which, in turn, is dependent on the decisions taken at the top-level.

The objective functions for the top-level problem are defined mathematically using integer programming approach. In this approach, the land-use decision variables are modeled in a spatial grid. Each cell in the grid represents a parcel of the area, to which a certain land-use type is assigned. Each cell (i, j) contains a vector of binary decision variables ($x_h^{i,j}$) as the number of land-uses' types (h).  In other words, the decision variable represents a particular land-use type assigned to a particular cell. The road network is defined as a directed graph with different characteristics. A binary decision variable is defined for each network segment ($x_g^a$), which indicates whether this segment is physically existing in the transportation network, or not.

The common approach to solve the overall problem consists of an iterative process of creating, examining and improving a set of scenarios. Heuristic algorithms, such as genetic algorithm, are suitable for this process. In this paper, every round of the iteration begins with a scenario set building. Each scenario consists of the following components: (a) spatial arrangement (geometric configuration) of the platforms comprising the island, (b) land-use layout, and (c) transportation network. At each round, the elements of the objective functions are evaluated.

<u>Case Study</u>

A case study was defined in order to illustrate and examine the model. A limited number of alternative scenarios were examined, and the group of non-dominated solutions was found, while examining every alternative scenario. For comparison between the different scenarios and detecting the "non-dominated" group, the values of the objective functions were calculated, as the results of the transportation model and the composition of the scenario.

The total area of the artificial island was divided into 24 cells (or traffic zones) representing 2,160,000 square meters. The scenarios were composed of the following possible configurations. First, four options for platforms arrangement and island geometric configuration were assumed. Second, two different transportation networks were created for each geometric configuration. The transportation network composed two types of links: highways and local roads. All networks were connected to the land by two highways, while all the external destinations were defined as one external traffic zone. Third, three different land-use compositions were defined. Each composition determined the number of assigned cells for the three different land use types. Finally, 20 different land-use layouts were tested for every combination of geometric configuration, transportation network and land-use composition. Some of the land-use layouts were randomly chosen, the others were logically constructed while addressing symmetry. A total number of 480 alternative scenarios $(20 \times 3 \times 2 \times 4)$ were tested in the case study.

The objective function values for each scenario were normalized to a 100% scale score to allow for results analysis. Only 4 results, out of the total 480 alternative scenarios, were found to be non-dominated, composing the “Pareto front”. Most of the tested scenarios received good transportation scores. One common feature in most of the scenarios with poor transportation scores was related to the location of the employment areas in the VLFS. In those problematic scenarios, all employment areas were concentrated together, which created congestion on the access roads to those areas. The results show significant correlation between the land-use components and their associated scenario-cost. This is primarily attributed to the relatively high platform cost that depends on the land-use type assumed (‘employment’, ‘low-density residential’, or ‘high-density residential’).

The extended paper will present detailed mathematical formulations along with vivid graphic presentations of the main scenarios, as well as outlay the next stages of the research.