A Simulation Model for Sea Space Planning

By

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Abstract

Any masterplan for coastal land use must be made with careful concern regarding environmental preservation.

In this study, a comprehensive assignment planning model for many kinds of activities in a coastal area was proposed.

The special features of this model are that the relation of sea water pollution caused by productive and living activities is analized quantitatively, and that some alternative plans useful for multi-objective planning will easily be found.

We applied this model to the Mikawa Bay area at the Pacific coast in central Japan, and examined the characteristics of the alternative sea space plans.

1. INTRODUCTION

We proposed a sea space† planning model[1] which allocates sites of several kinds of activities over a planning region to achieve a harmonious goal. We intended that the model represent the interaction of pollutants with activities in the sea space according to the requirements of multi-objective planning. The results of the model are an alternative sea space plan and an evaluation vector.

Decision makers of sea space planning select a masterplan from alternatives. An evaluation vector corresponding to the masterplan is the goal of their planning. They may consider which goal (or masterplan) they select with the aid of planners. If the planners know the characteristics of the model, they can greatly assist the decision makers. So, it is important for planners to know these characteristics before applying the model to actual planning.

However, the model in the preprint is fairly complex and rather conceptual. Therefore, we present a simpler model which is easy to operate. This simpler model has fewer kinds of activities and constraints, but the basic character of the model is maintained. In this paper we describe the simple model, its system characteristics and

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† We call the region of coastal land and sea along the coast, sea space.

computation results for the Mikawa bay area in Japan (see Fig. 3). From now on, we use the term ,the model' to refer to this simpler model.

2. THE OUTLINE OF THE MODEL

The model allocates sites for four kinds of activities over a planning region. These activities are environmental conservation, industrial, seaside resort recreation and fish cultivation.†

Figure 1 illustrates the outline of the model. The model is divided into three parts, the preliminary arrangement, the site allocation and the collection of the results. We describe these parts in order.

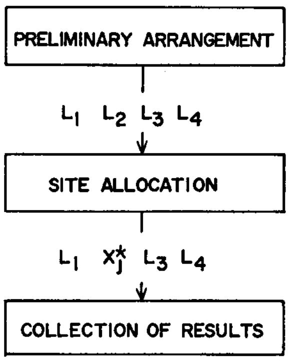


Figure 1. The Structure of Main Flow of the Model.

2.1 Preliminary Arrangement

A planning region is divided into many small tracts. Then, we select tracts suitable and available for each kind of activity. We call the set of the tracts selected for a kind of activity the tract set available for the activity, often simply called the available tract set. Four available tract sets are selected. They are as follows:

L_1 : tract set available for environmental conservation

L_2 : tract set available for industry

L_3 : tract set available for seaside resort

L_4 : tract set available for fish farm

2.2 Site Allocation

In this part, we allocate sites for the four activities. This part has three sub-models. The first sub-model is the allocation model for sites of environmental conser-

† Japanese fishermen cultivate many kinds of marine products. The fish cultivation site is the sea space necessary for farming these products.

vation. The second sub-model is for industrial sites. The third sub-model is for sites of seaside resorts and fish farming.

Tracts in which sites of an activity are allocated are selected from the available tract set.

The outputs of this part are as follows:

L_1 : allocated tract subset for environmental conservation

X_j^* : allocated industrial site area in tract j

L_3 : allocated tract subset for seaside resorts

L_4 : allocated tract subset for fish farming

where each subset is composed of tracts to which the activity has been allocated.

These three sub-models are termed the site allocation model. We describe the content of the site allocation model in section 3.

2.3 Collection of results

When we have allocated sites for all kinds of activities in the model, we collect the results of the allocation and present an alternative sea space plan. Then we evaluate the plan with evaluation indices of activities, denoted by Y_1, Y_2, Y_3 and Y_4 for environmental conservation, industry, seaside resorts and fish farms, respectively. These indices are as follows:

Y_1=number of tracts in L_1

$$Y_2=\sum_j C_j X_j^* \tag{2-1}$$

where, C_j is the industry location score in tract j

Y_3=number of tracts in L_3

$$Y_4=\sum_{i\epsilon L_4} A_i \tag{2-2}$$

where, A_i is the fish farm location score in tract i

The result of the evaluation is shown as a vector whose components are the values of the evaluation index of activities.

3. SITE ALLOCATION MODEL

Figure 2 shows the outline of the site allocation model, which is composed of three sub-models: (1) the environmental conservation site sub-model, (2) the industrial site sub-model and (3) the seaside resort and fish farming sub-model.

3.1 The Model Structure

In this model, the sites of the four activities are not allocated simultaneously but in an order previously determined. According to this order, the model is divided into three sub-models. The first sub-model is for environmental conservation, the second is for industry and the third is for seaside resorts and fish farms.

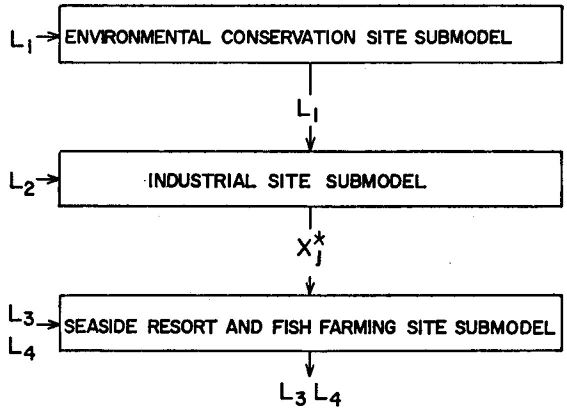


Figure 2. The Structure of Mail Flow of Site Allocation Model.

Before the contents of these sub-models are discussed, it is pertinent to show the reasons why we have adopted the method of an ordered site allocation, and why we have chosen such an order.

Regarding pollutants, we can divide the four kinds of activities into industry and the others. Industry discharges pollutants and they flow over the tracts in the region. Fresh water is required at the sites of the other activities. In this model, we deal with site allocation in such a way that the site of an activity can be allocated to a tract only if the water quality of the tract meets the standard for that activity. So, if we make up the site allocation model in terms of a simultaneous allocation model over all activities, we may then get such complicated water quality constraints that the location of suitable tracts would become very difficult to find.

Regarding exclusive or common use of a site for activities, we have adopted the rule that only one kind of activity can be allocated to a tract, except that seaside resorts and fish farms can use a common tract. The simultaneous allocation model would have complicated site use constraints which are quadratic in form.

Therefore, we separate the site allocation model for industry from the site allocation models for the other activities, and place them before or after the one for industry. This is the reason why we have adopted the method of an ordered site allocation.

Regarding the order, if we allocate the sites of environmental conservation, seaside resorts and fish farming before allocating the industrial sites, then water quality standards of these three activities result in constraints on the site allocation of industry. There may be many combinations of water quality constraints in the site allocation of industry, because of the many combinations of allocated sites for the three activities. It is also complicated to allocate sites of industry under the constraints corresponding to each combination of the above. Since the water quality standard for environmental conservation is the most strict among the three kinds of activities, if the results of the industrial site allocation model fit the water quality constraints of environmental conservation, then it should fit the constraints of seaside resorts and fish farming too.

Therefore, we allocate the sites of activities in the order of (1) environmental conservation, (2) industry, and (3) seaside resorts and fish farms.

3.2 Sub-models

Sub-model 1 Environmental conservation sites

We select tracts at which the sites of environmental conservation are allocated, from the ones in the available tract set L_1. It may be desirable that this work be done with the advice of ecologists. But otherwise, this work is done by trial and error. The output of this sub-model is an allocated environmental conservation tract subset $\boldsymbol{L}_1$.

Sub-model 2 Industrial sites

This sub-model, shown as follows, is a linear programing (LP) model.

$$\text{Max} \sum_j C_j X_j \tag{3-1}$$

subject to

$$\sum_j D_{ji} X_j + W_{0i} \leqq P_1 \quad (\text{for all } i,\ i \in \boldsymbol{L}_1) \tag{3-2}$$

$$0 \leqq X_j \leqq S_j \quad (\text{for all } j,\ j \in L_2 \text{ and } j \notin \boldsymbol{L}_1) \tag{3-3}$$

$$X_j = 0 \quad (j,\ \text{otherwise}) \tag{3-4}$$

where,

X_j : industrial site area at tract j

C_j : industry location store at tract j

D_{ji} : the amount of pollutants flowing into tract i from tract j per unit of industrial site area at the tract j (*C. O. D.* concentration)†

W_{0_i} : the original amount of pollutants at tract i (*C. O. D.* concentration)

P_1 : the upper limit amount of pollutants under the standard for environmental conservation (*C. O. D.* concentration)

S_j : available site area at tract j

X_j is the variable in this LP model, L_2 is the input from the preliminary arrangement part, $\boldsymbol{L}_1$ is the input variable from sub-model 1 and the others are external variables. The objective function(3-1) shows the total amount of location scores over the allocated sites. The first constraint(3-2) shows the water quality constraint at every tract where the site of environmental conservation is allocated. The water quality constraint is represented in terms of *C. O. D.* concentration. We give 1 p. p. m. as the value of P_1. The second constraint(3-3) is the available site area constraint for the case of j which belongs to L_2 and does not belong to $\boldsymbol{L}_1$. The third constraint(3-4) specifies that for any tract j not satisfying the first two constraints, $X_j=0$. The solution of this

† C. O. D. means chemical oxygen demand.

LP model is the allocated industry site area at each tract j, X_j^*. After solving this LP model we make the allocated industry tract subset L_2, as $L_2=\{j|X_j^*>0\}$. Sub-model 3 seaside resorts and fish farming sites.

When we have the solution of sub-model 2, we estimate the water quality at every tract by use of the next equation.

$$W_i=\sum_j D_{ji}X_j^*+W_{0_i} \qquad (3\text{-}5)$$

where, W_i is the amount of pollutants at tract i ($C.\ O.\ D.$ concentration)

The allocation of seaside resort sites is done as follows: if a tract meets two conditions, then we allocate a site for a seaside resort at the tract. The two conditions are:

$$i\in L_3,\ i\notin L_1 \text{ and } i\notin L_2 \qquad (3\text{-}6)$$

$$W_i\leq P_3 \qquad (3\text{-}7)$$

where, P_3 is the upper limit for the amount of pollutants under the standard for seaside resorts ($C.\ O.\ D.$ concentration)

We give 2 p. p. m. as the value of P_3. The result of this allocation is given as the allocated seaside resort tract subset L_3.

The allocation of fish farming sites is done in the same way as that of seaside resorts, but the conditions are different.
They are:

$$i\in L_4,\ i\notin L_1 \text{ and } i\notin L_2 \qquad (3\text{-}8)$$

$$W_i\leq P_4 \qquad (3\text{-}9)$$

where, P_4 is the upper limit for the amount of pollutants under the standard for fish farming ($C.\ O.\ D.$ concentration)

We give 3 p. p. m. as the value of P_4. The result of this allocation is given as the allocated fish farming tract subset L_4.

4. SYSTEM CHARACTER OF SITE ALLOCATION MODEL

The site allocation model is the ordered allocation model. In sub-model 1, we can select every combination of tracts where sites of environmental conservation are allocated; that is, every L_1. But we may not be able to make free selections for site allocations of industry, seaside resorts and fish farms. For industry, we can get every solution which is useful in sea space planning, because sub-model 2 can be solved for every L_1. The results of sub-model 3 are limited by the solution of sub-model 2. Therefore, the results of the site allocation model may be unprofitable for seaside resorts and fish farms. Planners in sea space planning may fear that the alternative plans obtained from this model do not cover every alternative which is worth examining. However, we think that perhaps we can get most, if not all, such alternative plans with this model. The water quality constraint in sub-model 2 is due to the result of sub-model 1. Since the standard of environmental conservation is most strict, if we select the L_1 profitable for environmental conservation, then the results of site allocations of seaside resorts and fish farms may be profitable for them also.

We can see the site allocation model as a simulation model in which the control variable is subset L_1. So, we can get various alternative sea space plans according to various subsets L_1 selected in submodel 1.

In selecting subset L_1, there is a great number of reasonable combination of tracts. If the number of tracts in L_1 is N, then the reasonable combinations are 2^N. It is tedious work to find the useful combinations from so many possibilities, but a systematic analysis of the site allocation model will help. The method to find them systematically is as follows:[2]

There are many steps in the method. Let us suppose we are in the *n-th* step and there are several subsets to be considered in the step. We denote the *m-th* of these subsets as L_1 (n, m). When we have the solution of sub-model 2 under the subset L_1 (n, m), some water quality constraints are active and others are inactive, at the solution. Then, we take the new subsets which are obtained by excluding any tracts corresponding to the active constraints from the tracts in subset $L_1(n, m)$. Such subsets are ones to be operated in the next step. They are subsets in the old subset $L_1(n, m)$. The solution of submodel 2 under each such new subset is different from the one under $L_1(n, m)$, but the ones under the other subsets in the old subset are the same as those under $L_1(n, m)$. Therefore, we need not operate sub-model 2 and 3 for the latter subsets. This is because the results of the site allocation model with the latter subsets are the same as the ones with subset $L_1(n, m)$, and we have already found them. At each step, we can find the subsets to be operated in the next step. The number of steps is not greater than the number of tracts in L_1. The first subset to be considered in this method is the one which is composed of every tract in L_1, that is L_1 itself. Planners can reduce the number of alternative plans to be examided by using this method.

5. COMPUTATION RESULTS IN THE MIKAWA BAY AREA

We applied this model to the Mikawa bey area in central Japan. Figure 3 shows the location of the Mikawa bay area and Figure 4 shows a more detailed figure of the area. In the latter figure, the dotted area is the sea, the thick line shows the planning region boundary and the fine line shows the tract boundary.

Figure 5 shows tracts available for the four kinds of activities in the model[3]. The

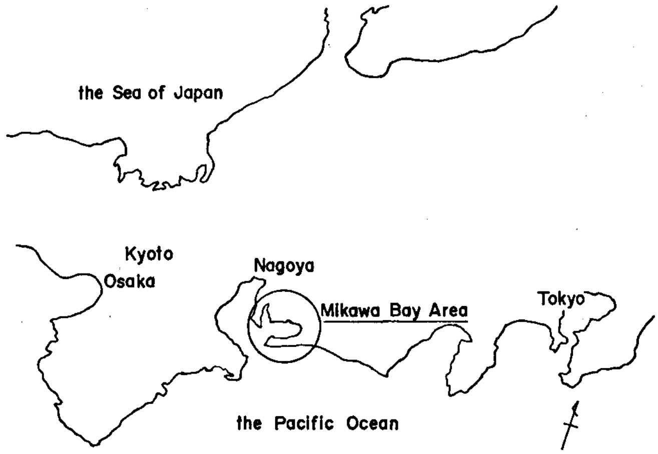


Figure 3. The Location of Mikawa Bay Area

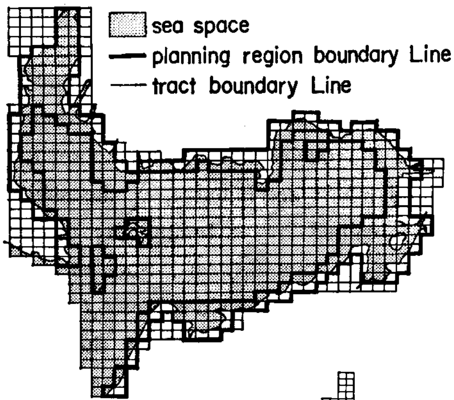


Figure 4. The Planning Region. (Mikawa Bay Area).

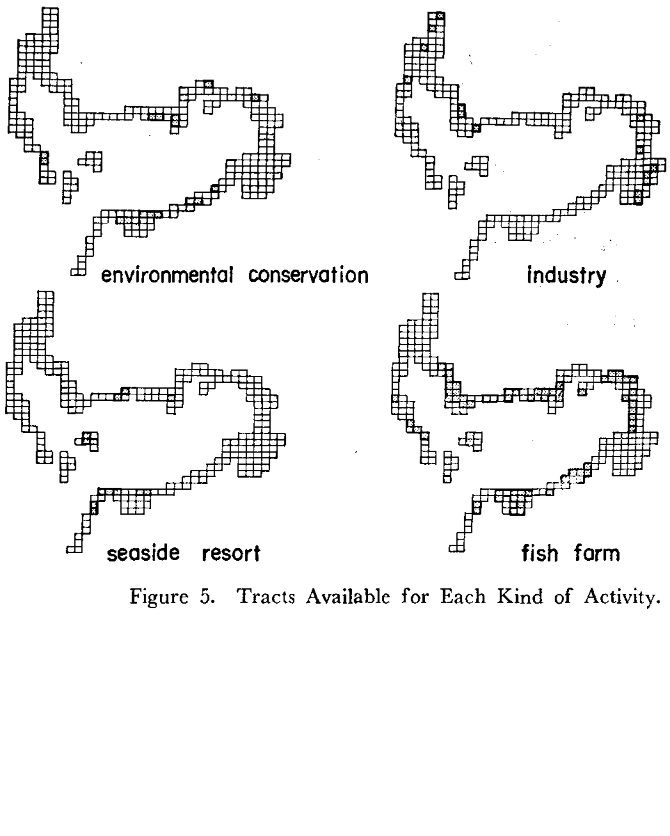


Figure 5. Tracts Available for Each Kind of Activity.

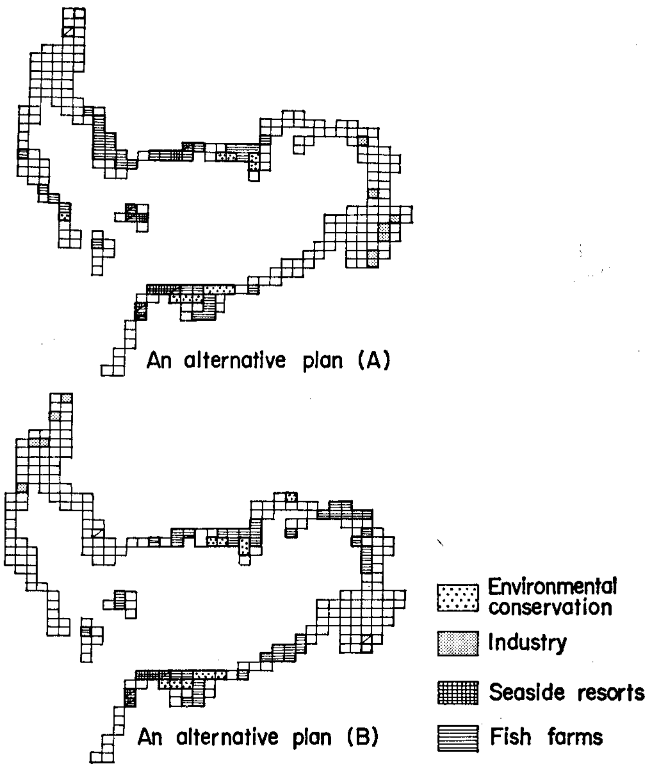
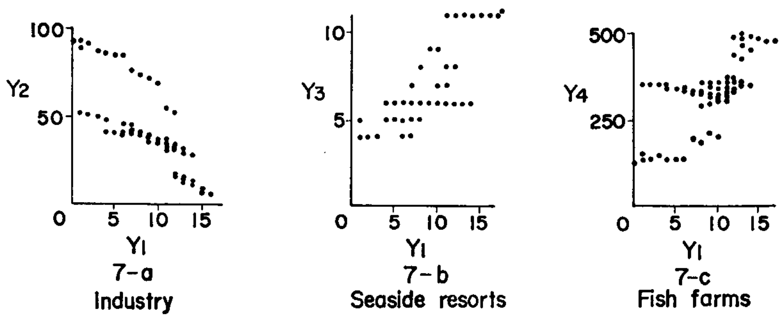


Figure 6. Two Alternative Plans of Activities Distribution Pattern.

numbers of the tracts in L_1, L_2, L_3 and L_4 are 17, 14, 13 and 68, respectively. In this case, the number of reasonable subsets $\boldsymbol{L}_1$ is about one hundred thousand. Using the method described in section 4, the number of subsets $\boldsymbol{L}_1$ to be operated was reduced to 73. The computing time to get one alternative plan was about 10 seconds with a FACOM 230-75.

Figure 6 shows two alternative plans. They have the same number of tracts where sites of environmental conservation are allocated. It is seen that the distribution pattern of the allocated sites of industry, seaside resorts and fish farms is very different for the two alternatives.

We show three figures in Figure 7. Each figure shows the value of the evaluation index for each activity in relation to the evaluation index for environmental conservation. One point in the figure represents one pair of values of evaluation indices for the activity and for the environmental conservation, and an alternative sea space plan. The figure shows the points for all alternatives obtained from the model. Figure 7-a is for industry. In general, we can see that the greater the value of Y_1, the less the



Note/ These figures are shown in relation to the value of evaluation index for environmental conservation.

Figure 7. The Value of Evaluation Index.

value of Y_2. We can find two groups of points in this figure. They show two distribution patterns of an industry site allocation for the same value of Y_1, the number of tracts in subset L_1. Figure 7-b is for seaside resorts. We can see that the greater the value of Y_1, the greater the value of Y_3. Figure 7-c is for fish farms. As a whole, we can also see that the greater the value of Y_1, the greater the value of Y_4. There are also two groups of points for the smaller values of Y_1. They correspond to the two groups of points in Figure 7-a. The group of points at the upper value of Y_4 in Figure 7-c corresponds to the lower values of Y_2 in Figure 7-a.

Let us suppose an evaluation space in which each coordinate shows the evaluation index for an activity in the model. One point in the space corresponds to one alternative plan. Some of these points are pareto optimum points. From Figure 7, we can reasonably suppose that the whole shape of pareto optimum points in the space is complex.

6. CONCLUSION

We have presented in this paper a simple model for sea space planning, with computational results in the Mikawa bay area.

The essential part of the model is the site allocation model. This model allocates the sites of four kinds of activities, environmental conservation, industrial, seaside resorts and fish farming, over a planning region. This model can be seen as a simulation model, in which the control variable is the allocated environmental conservation tract subset.

Planners can get various alternative sea space plans by changing the content of the control variable. The number of reasonable alternatives obtained from the model may be very great. But, using the method in this paper, we can systematically find alternatives which are worthy of examination in the planning process.

We applied the model to the Mikawa bay area. It was found that the method for finding useful alternatives was very effective and that the control variable affects the allocation results in two ways. One way is the number of tracts in which environmental conservation is allocated, and the other way is the distribution pattern of these tracts. From the computation results, we can suppose that the whole shape of pareto optimum points in the evaluation space is complex.

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