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AN OPTIMISATION MODEL FOR CORK HARBOUR INDUSTRIAL EXPANSION

a Research Paper presented by

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in partial fulfilment of the requirements for

obtaining the Diploma in

REGIONAL DEVELOPMENT PLANNING

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May, 1974

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ACKNOWLEDGEMENTS

I wish to thank Prof. J.G.M. Hilhorst for his constructive comments and criticisms during the elaboration of this paper. In addition I wish to thank the other members of the staff and my fellow participants.
Last but not least I express my thanks to Mr. J. Lanagan and Mr. M. Harrington, Industrial Development Authority, Cork, and John Quish, South-West Regional Development Organisation, for their assistance.

1. Introduction: Cork Harbour in the Development Context

Cork Harbour is destined to play an important role in the national and regional development of Ireland.

Buchanan calls Cork the Gateway to Europe; it therefore has a potentially wide hinterland (EEC) which should be developed fully (Cork as Growth Centre). The Industrial Development Authority in its regional strategy stated that owing to the good harbour facilities that are available, the industries needed to meet the target for the Greater Cork Area (4,900 jobs in 1971) will probably include waterside industries. The sub-regional strategy of the Regional Development Organisation includes similar statements:
'It is expected that the type of industrial development and employment envisaged in the city and environs and harbour area would not, in general, be at the expense of industrial growth elsewhere in the region. For the most part, the industries which would be attracted to Cork Harbour area would not come to the region and probably not to Ireland at all in the absence of such a suitable development centre. Rather should their establishment be seen as a transfer of industry which might otherwise have gone to other parts of the region. Having regard to the present state of infrastructure in order to achieve the scale of development proposed or even modest expansion, a large scale of investment is needed.'

After dealing with the Cork Harbour Development Plan (section 2), in which an area for future industrial expansion has been selected, an optimisation model will be developed (section 3) concerning the industrial activities to take place in this area, which then will be applied (section 4). The final section is devoted to the role of the model in industrial planning and promotion.

2. Harbour Development Plan

The Cork Harbour Development Plan (1972) basically used four arguments for infrastructural investments in the Harbour.

Firstly, after comparing Cork Harbour with other ports in Ireland and with ports in the United Kingdom and on the Continent in terms of their characteristics (navigation channels, berthage, depth), and after setting shipping trends,[1] it was concluded that at present no Irish port can berth and work the larger deepsea container vessels or medium or larger sized bulk carriers. This places Cork Harbour in a less favourable position since no advantages can be taken of the economies of scale to be expected of larger ships.[2]

If modern cargo handling facilities (including berth and jetties) are not available, this will relatively increase the days in port needed for (un)loading. For instance, compare the time needed for (un)loading a general cargoship by mobile crane with the (un)loading of a Roll on-Roll off ship or a Containership, both of the same size (dwt). Minimisation of days in port is important for larger as well as for smaller ships.

Not to allow for such advantages will make the exports less competitive as far as transport costs are concerned. If the planning of a port does not keep pace with developments in shipping, the port will as a result lose parts of its throughputs.

Finally, the plan concluded that Cork Harbour is the most suitable location for a deepwater port complex for general and bulk cargoes with provision for port industries.

Secondly the potential of Cork Harbour for port industries was considered. To a large extent this was based on a report produced by a firm of management consultants,[3] which identified the main potential competitive advantages of the port, such as availability of land, industrial water, labour, social amenities, financial incentives etc. The report listed classes of industries most likely to come to Cork Harbour, namely:

- primary metals industries
- agricultural processors and manufactures
- dry bulk handling facilities
- plastics and light chemicals.[4]

The third argument was the estimation of the port's contribution to employment in the Cork Area. It was found that over a period of 20 years Cork Harbour could provide some 20,000 jobs (primary and secondary port industries, service employment and other employment).

This forecast, first made with a 15-year time horizon, was based on the following assumptions:

- every two years a primary port industry will be attracted with an average site of 55 acres and an average employment/land ratio of 6 persons per acre.
  .: 7.55.6= 2,310 direct port employment (E^D)
- an induced secondary industry (E^E) of 1.5 E^D= 3,465.
  This inducement rate is derived from U.S.A. studies and adapted to the Cork context which is, however, difficult to assess.
- the service employment that is induced by manufacturing employment is based on a Foras Forbartha study which has estimated this inducement rate at 1.352.
  .: E^S= 1.352 (E^D + E^I) = 7.807

The total of 13,582 achieved in 15 years, was expected to grow to 20,000 after a further five years. Based on macro analysis the Cork Harbour Development Plan concludes that: 'Port industries therefore, will result in a considerable increase in employment in the Cork Area. The harbour represents the principal competitive advantage enjoyed by the Cork area and the potential represented by this advantage should be fully exploited if the area is to have full employment.'[5]

The final argument is based on a traffic forecast.
Berth requirements have been estimated and will play a role in the selection of the harbour area where the needed investment should be made.

Site Selection

Six areas were taken into consideration: Aghada, Cuskinny, Curlane Bank, Spit Bank, Ringaskiddy and Marino Point,[6] the selection being made on the basis of the following criteria:

- minimum depth requirements (35 feet)
- minimum length of sheltered berthage (4,000 ft)
- minimum land availability directly behind berths (200 acres)
- back-up area (preferable minimum 1,500 acres) and other site characteristics
- good road access and capability of high volume of water supply and provision of power
- technical criteria such as approach channels, swinging basins, berth construction, land reclamation, etc.
- finally, the cost of development.

Although the costs of development were lowest at Marine Point, Ringaskiddy was chosen on the basis of these criteria mainly because of its large back-up area, and the supply of water which can be provided at lower cost than in the Aghada area (to be developed after Ringaskiddy).[8]

Implementation of the proposals has been phased in two stages:

1. an initial, medium-term stage (3-5 years)
2. a long-term stage.

In the first stage the following is proposed

1. harbour facilities:
   - dredging of the basin
   - construction of a deepwater berth
   - reclamation works
   - deepening of the harbour entrance (120,000 DWT) and deepening of the Bar (up to 50,000 DWT)
2. other infrastructure:[9]
   - land acquisition 250 acres[10]
   - water supply 5 million gallons a day (mgd)
   - road improvements

In the second stage (1980s) a further expansion of the area is planned.

1. harbour facilities:
   - an additional deepwater berth
   - completion of dredging basin and reclamation works

2. other infrastructure:
- 12 mgd additional water supply
- land acquisition (1,100 acres)
- further road improvements

The proposed model does not explicitly refer to any timespan, but in practice this should be stated: firstly, because of the stages in the implementation of the harbour plan; secondly, for practical reasons, namely, information about possible industries and constraints. If the long-term timespan were chosen, difficulties would arise in estimating parameters and setting constraints because of technological changes. For instance, changing labour (qualitative and quantitative), land, water and power requirements of an industrial activity. Finally, changes may occur in the level of constraints, for example maximum pollution levels. For these reasons, we shall deal only with the medium-term stage of the implementation of the harbour plan.

3.1. The Model

The central question raised in this paper is, given the potentials and constraints of the harbour, what is the optimal combination of future economic activities, given also the various objectives of the development policies.

After examining the available literature a first solution was sought in linear programming[11] which is based on the same reasoning, namely, what are the optimum sizes of activities given the constraints and the objective. In general, the models have the following format:

Maximise $f = p_1 x_1 + p_2 x_2$ (1)

Subject to

$$a_{11} x_1 + a_{12} x_2 \leqslant R_1 \quad (2)$$

$$a_{21} x_1 + a_{22} x_2 \leqslant R_2 \quad (3)$$

$$x_1 \geqslant 0, \; x_2 \geqslant 0 \quad (4)$$

(1) is called the objective function which in this case should be maximised. In our context we could say, for instance, maximise port employment.

(2) and (3) are the constraint functions. The constraints are, for instance, the availability of land and water supply.

(4) The non-negativity requirement, saying that none of the activities can become negative.

With this model one has to face several problems. First, the assumption of linearity in the coefficients (p_i, a_{ij}). That is to say, they remain constant independent of the size of the activities. This can partly be overcome by means of programming with a parametic objective function.[12] That is to say, using coefficients in the objective function which are not fixed but are dependent on a parameter (λ) for which a range of values is considered. The objective function would then have the following form:

$$f = (p_1-\lambda)x_1+(p_2-\lambda)x_2 \qquad (5)$$

By replacing (1) by (5) the programme can be solved. Intervals for the value of λ can now be calculated for which a solution is still optimal.

However, the problem still remains for the other coefficients of the activities (a_{ij}).

A second problem is that production in a certain activity has a certain minimum size before it is profitable to produce. This can be solved by introducing minimum bounds of activity size. Maximum size could also be considered, for instance, depending on the size of the market.

Finally, we have the basic problem that due to indivisibility of factors of production, production in an activity cannot be increased continuously, but if the minimum size is exceeded a next minimum must be set.

This may be illustrated with a simple example. First it has to be decided whether or not to take up a certain activity. If the decision is in the affirmative, than due to indivisibilities a minimum size of 10 is necessary. Under the same reasoning, if we want to increase production then size 25 is necessary.

$x = 0$ (1)

$x > 0$ ______________ $x = 10$ (2)

$x > 10$ ______________ $x = 25$ (3)

$x > 25$ etc.

This method of reasoning leads to the methodology proposed here, which is based on a changed definition of activities. The activity previously defined as the production of output, is now defined as the production of an output of a certain size. This can be illustrated as follows: the previous definition implied one activity; according to the new definition we have two activities, $x = 10$, $x = 25$, which can be realised or not.[13]

The proposed methodology is called 'Zero One Integer Programming',[14] in which an activity is undertaken: yes (=1) or no (=0)

The model can be formulated as follows:

Maximise: $$f = p^1_1x^1_1 + p^1_2x^1_2 + p^2_3x^2_3 + p^2_4x^2_4 \quad (6)$$

Subject to:

$$a^1_{11}x^1_1 + a^1_{12}x^1_2 + a^2_{13}x^2_3 + a^2_{14}x^2_4 \leqslant R_1 \quad (7)$$

$$a^1_{21}x^1_1 + a^1_{22}x^1_2 + a^2_{23}x^2_1 + a^2_{24}x^2_4 \leqslant R_2 \quad (8)$$

$$x^1_1 \; x^1_2 \; x^2_3 \; x^2_4 = 0 \text{ or } 1 \quad (9)$$

x^1 is production of an output which can be produced at size x^1_1 and x^1_2.

Use of this methodology takes into account all problems mentioned above. Application of the proposed model requires the answers to three questions, namely: what are the objectives, the constraints and the activities.

3.2. Objectives

National as well as regional objectives have to be taken into account[15] and are summarised as follows:[16]

1. elimination of involuntary emigration (-) and (+)
2. reduction of unemployment or attainment of full employment (-) and (x)
3. maintenance of population dislocation at the minimum consistent with objectives 2,4 (-) and (+)
4. growth of output (+)
5. export promotion (+)
6. increase of personal living standards (-) and (+)
7. utilisation of resources with proper regard to their conservation (-).

In addition, the objectives of the Cork Harbour Commissioners might be considered. These are of a micro-economic nature, namely, that

8. port charges should cover the costs and provide a minimum reserve.

This objective is included because it might lead to conflict in the sense that running the model with this objective will yield a different combination of activities with a lower value than in the case of running the model with the other objectives listed.

Since we have only one objective function in our model, only one objective could be maximised. However, several solutions are feasible. For instance, an objective may be put as a minimum or maximum constraint. In principle this changes the nature of the model since an objective to be maximised is then bound to a specific level. Only in specific cases can an objective be put as a constraint. For instance, objective 7 can be interpreted as a constraint in that it establishes maximum pollution levels.

Another and more feasible solution is to run the model for each objective and to leave it to the decision maker to decide which combination of activities will be chosen.

A third approach could be a combination of the first two. In their present state most objectives cannot be incorporated in the models. Therefore we have to consider indicators which can be put into the objective function.

1. The objective of elimination of involuntary emigration is, as such, outside the scope of the model. It can only be included partially and indirectly if it is known what kind of people emigrate. For instance, are they high or low skilled, etc. If this kind of information is available it can be taken into account by maximising the employment of certain types of labour.
2. The employment objective can be incorporated by maximising port employment, either direct, or by including indirect employment, dependent on the available data.
3. The objective of minimising population dislocation is in our specific case less relevant; in our opinion, it refers to the necessary spread of the provision of jobs in the rural areas and smaller urban centers to avoid internal migration. Therefore, it is excluded from further consideration.
4. The objective of growth of output can be incorporated as a maximising output objective function.
5. The objective of export promotion can be included by maximising export values, or even more precisely, by maximising the net export value. Certain assumptions concerning price levels would then have to be made.
6. The objective of increasing personal living standards can be incorporated by maximising the wage bill.
7. The utilisation of resources with proper regard to their conservation. With regard to Cork Harbour, this can be interpreted and operationalised by putting maximum constraints on the disposal of industrial effluent. A major problem here is that it is impossible to estimate the effluent disposal of a potential activity. However: 'If actual analysis is not possible because the process is not actually in operation, analysis of effluents from similar processes carried on elsewhere which are usually available may be used.'[17]

   Effluents have been classified into four categories:

   1. non-toxic and not directly polluting but liable to disturb the physical nature of the receiving water,
   2. non-toxic but polluting by reason of organic content of high oxygen demand,
   3. toxic effluents containing directly poisonous material,
   4. polluting by 2 and 3.

It has been confirmed that constraints for effluent disposal can be established for the Ringaskiddy area.[18]

8. The objectives of the Cork Harbour Commissioners can be interpreted as to maximise revenues from port charges. A distinction has to be made between:
   - tonnage rates depending on the net registered tonnage of the measurement of the vessel
   - goods rates per metric ton. For the classification of the goods the Standard International Trade Classification Revised is used.[19]

     The rates on exports are in all classes 50% lower than import rates.

Whether this level of detail can be applied depends largely on the information available concerning imports and their origin and the exports of the potential industries.

To summarise: On the basis of the objection we arrived at the following operational objective functions:
- maximisation of employment of a certain skill
- maximisation of direct or total employment
- maximisation of output
- maximisation of net export value
- maximisation of wage bill
- maximisation of port revenues

Operational constraints derived from objectives:
- maximisation of pollution constraints.

3.3. Constraints

As could be seen from the previous section we have to deal with several types of constraints: constraints derived from objectives; and constraints derived from the Harbour plan, as follows:
- availability of land (400 acres). Of the total amount of available land a certain percentage has to be deducted for the construction of access roads. This percentage has been estimated at 3-5 per cent.[20]

There is no need to also deduct land for harbour facilities (berthing quays) since reclamation works will be undertaken for this purpose.

- water supply (5 mgd)
- power supply

It is difficult to establish an area of specific constraints in power supply since the cost of transmission (in terms of loss of electricity) is relatively low (National Grid System).[21]

A quantity constraint does not apply but there is a price constraint. The price per unit of power depends on the time pattern of industrial power demand. (Demand during peakloads incurs a high tariff.) Apart from the very detailed information this requires, it is difficult to incorporate this price constraint given the present state of the model.

3.4. Activities

Industrial activities which could be performed in the Ringaskiddy area depend basically on the industrial potential of Cork Harbour. In 1969, Arthur D. Little Ltd examined this potential and listed the requirements of potential port industries.[22] This study has to be rejected for two principal reasons. Firstly, because it is outdated.[23] Secondly, because the methodology used leaves open many questions and is as a whole unsatisfactory.[24]

A more realistic approach is that those activities are taken into account which either could be actively promoted by the Industrial Development Authority or which are based on planning proposals from industrialists who have shown interest in locating in Cork Harbour.

The first part of this approach is based on the following:

'Ireland is only one of many European countries which have programmes for attracting foreign industrial investment. Essentially, these programmes reflect the fact that national economies seeking to accelerate their overall or regional rates of industrial growth must look beyond their domestic sources of enterprise and technology to the growing volume of internationally mobile industrial investment. The result is an increasing level of competitive activity aimed at influencing industrial companies to direct projects to various locations within different countries. The attraction of new industrial investment to this country involves, therefore, the selecting, contacting and negotiating with industrial companies in what is actually a competitive international market for industrial projects.' [25]

This is to some extent also relevant for port investment, as the Arthur D. Little report confirms.[26]

In our opinion, the Industrial Development Authority should analyse this international market for port industrial projects. For the resulting projects, used as input for the model, the data might be taken from similar projects in operation elsewhere. Once a project is part of the chosen optimal combination, the IDA should actively promote this ready-made project (aggressive promotion policy).

4.1. Application of the model for Ringaskiddy area

The extent to which the model can be applied depends basically on the information available.

Table 1. Potential Industries Ringaskiddy Area

Type of Industry \ characteristics of Industry	Land acres	Water mgd	Employment persons	Port tonnage per annum	Symbol used
Chemical	15	1.5	65	22,400	x_1
Engineering	20	0.058	250	100,000	x_2
Engineering[a]	3-4	-	30	12,000	
Chemical	2	0.3	35	12,000	x_3
Engineering[b]	(37)-60	1.58	300	70,000	x_4
Chemical[c]	400	9	(150)200	915,000	x_5
Chemical	150	3	220	130,000	x_6
Engineering	60	0.95	1000	374,000	x_7

Source: IDA, Cork, June 24 1974.

(a) Is excluded from further consideration since no information is available on water supply.

(b) For x_4 the land requirement is set at 60 acres.[27]

(c) The employment of x_5 is arbitrarily chosen at 200.

As can be seen from the table, the amount of information available is rather limited. This is largely due to the fact that information on investment projects is mostly classified material. Whether one activity is larger than another given activity (see section 3.1.) cannot be concluded from the information available.

However, in a simplified format the model can be applied twice. Once with the objective of maximising direct port employment and land and water supply constraints; secondly, with port tonnage maximisation if it is assumed that this is an indicator of maximisation of revenue for the harbour commissioners. However, this is not necessarily the case since, first, tonnage rates are excluded and secondly, goods rates vary dependent on type of goods and whether they are exported or imported.

In addition, it must be stated as a working hypothesis that each activity represents a plant of a certain type of industry which is at full production capacity in the sense that the production can only be expanded by establishing a second plant of a certain production size (which can be included as a separate activity, see section 3). The two models can be formulated as follows.[28]

Model I. Employment maximisation

Maximise:

(1) $f = 0.65x_1 + 2.5x_2 + 0.35x_3 + 3x_4 + 10x_6 + 2x_7$

subject to:

(2) $1.5x_1 + 0.058x_2 + 0.3x_3 + 1.58x_4 + 3x_6 + 0.95x_7 \leqslant 5$

(3) $1.5x_1 + 2x_2 + 0.2x_3 + 6x_4 + 15x_6 + 6x_7 \leqslant 40$

(4) $x_n = 0$ or 1 $\quad n = 1.......7$

(1) in terms of 100 persons employed

(2) in terms of million gallons a day water

(3) in terms of 10 acres

Model II. Port tonnage maximisation

Maximise:

(5) $f = 2.24x_1 + 10x_2 + 1.2x_3 + 7x_4 + 13x_6 + 37.4x_7$

subject to:

(6) $1.5x_1 + 0.058x_2 + 0.3x_3 + 1.58x_4 + 3x_6 + 0.95x_7 \leqslant 5$

(7) $1.5x_1 + 2x_2 + 0.2x_3 + 6x_4 + 15x_6 + 6x_7 \leqslant 40$

(8) $x_n = 0$ or 1 $\quad n = 1.......7$

(5) in terms of 10,000 tons
(6) and (7) same as (2) resp. (3).

Both zero one integer programming models can be solved. One way of doing this is by means of the simplex method.[29] If the number of constraints and/or of activities is substantial, a computer run might be necessary. However, in our particular case with 6 activities and only 2 constraints, neither the first nor the second solution is practical. A more simple technique has been found in the decision tree (branching method).[30]

The decision trees of models I and II are given as appendix 4.

The results are summarised in the following table:

Table 2. Comparison of Results of Models I and II

	Employment	Port tonnage per Annum in 1000 ton	Unused Capacity		Activities in optimal Combination
			Water mgd	Land (acres)	
Model I	[1650]	578.4	0.512	243	x_1, x_2, x_3, x_4, x_7
Model II	1505	[616]	0.692	168	x_2, x_3, x_6, x_7
$x_5 = 1$	200	915	-4	0	

[ ] refers to objective maximised.

4.2. Marginal Analysis

As can be seen in the table, the optimisation of employment (model I) leads to unused capacity of land of more than 60 per cent. The water capacity is the real functioning constraint. The question which now can be raised is: if we increase the availability of land and/or water in the margin, what would be the effect on the objective to be maximised?

For example, if we introduce x_6 (which remained outside the optimal combination) this leads to an unused capacity of -2.488 mgd and 93 acres, indicating that if an additional capacity of 2.488 mgd would be made available, the marginal productivity in terms of employment would be $\frac{220}{2.488} = 88$. This marginal productivity might be compared with the alternative of introducing x_5. The needed additional watersupply would equal 3.488 mgd leading to marginal productivity of $\frac{\Delta E}{\Delta W} = \frac{200}{3.488} \simeq 57$. This is substantially lower than the first alternative, which might therefore be chosen.

In real terms, however, this marginal analysis does not hold for two reasons. Firstly, it might be the case that for introducing, say, alternative A, it could be done if the water supply is increased, whereas alternative B could be introduced when the availability of land is increased. Neither can be compared in real terms. Secondly, even if two marginal productivities of the same dimension are compared, say water supply, the marginal analysis in real terms would not hold because a small addition in water supply might require a higher investment than a larger increase, perhaps for economy of scale.

This marginal productivity analysis concerning constraint widening is therefore only applicable if information is available on the financial investments to be made. The role which marginal analysis could play is to equilibrate the supply of infrastructure with its demand, with reference to the objective function.

4.3. Conclusions on application

Given the potential activities, the optimal combination in terms of maximised employment differs from that in terms of maximised port tonnage as an indicator of the harbour commissioners' revenues. In other words, the objectives conflict.

It is now up to the decision maker, in our case Cork County Council which has to give final planning permission, to decide which combination of activities should be chosen.

The large capital intensive chemical industry x_5 appears neither in the optimal combination with regard to employment, nor in the optimum with regard to port tonnage. This is because it exceeded the water supply constraint by 80 per cent. If water constraint is widened to 9 mgd, ceteris paribus, then the chemical industry would be the only activity in the optimal solution with regard to port tonnage maximisation which then would conflict with the optimal combination in terms of maximisation of employment in which it will not appear.

It can therefore be concluded that, in view of the high priority of the national and regional objectives of employment, and given the assumptions (see sections 4 and 5) and conditions under which the model operates, the chemical industry should not be given planning permission. This conclusion brings us to the role of the model in industrial planning and promotion.

5. The role of the model in industrial planning and promotion

5.1. Its application context

In its present application, the role which the model can play is rather limited for several reasons.

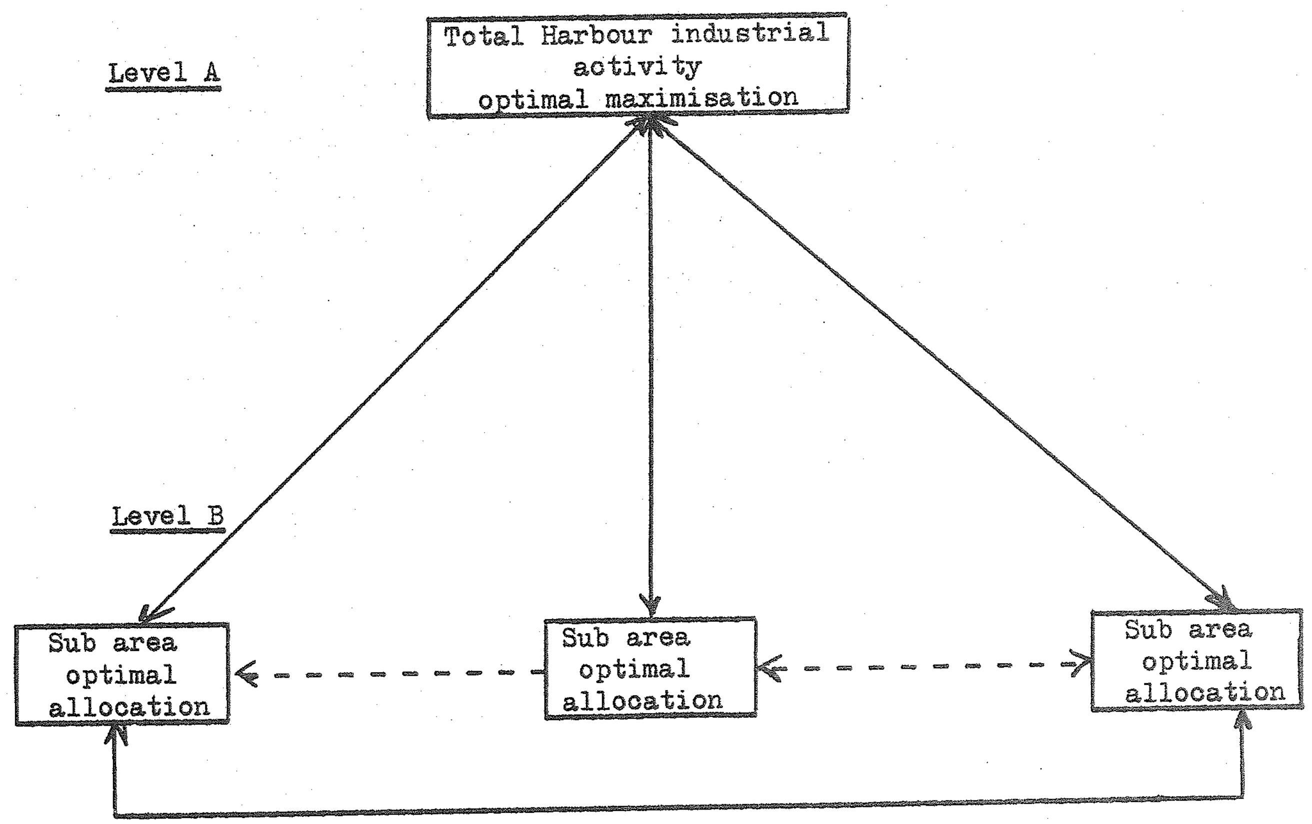
Firstly, owing to a poor data base only two objectives could be maximised, one of them only by using an indicator. Secondly, the model is applied marginally in the sense that it optimises only for one particular area of the total harbour area.[31] The role which it might play in the given application is as an aid in planning and decision-making since it is able to show conflicts between objectives and to show the trade-off between objectives, choosing one optimal combination over another.

Secondly, the model can be seen as an additional tool in evaluating industries in the sense that it counterbalances and complements the methodology used by IDA of evaluating industries in isolation.[32]

5.2. The potential role

The potential role of the model is twofold. Firstly, there is the obvious fact that if more data are available more objectives and more constraints can be imposed on potential activities, enabling the role outlined above to be more accurately done. Moreover, if sufficient data are available, the marginal analysis outlined in section 4.2. can be used to minimise the wastage of unused infrastructural capacity within the limits of the budget.

Secondly, if more areas are planned and developed simultaneously for future industrial expansion, the model can be used in a different way, as illustrated below.



At level A the model is initially used to give the optimal combination of industrial activities out of total potential activities for all areas, subject to constraints which are the sum total of constraints of the several areas. Thus, at level A, the emphasis is on maximising the objective function.

This stage being completed, the following stage (at level B) comprises the distribution of selected activities over the several areas. In fact this is trying out all combinations[33] of activities leading to optimal allocation of selected activities over the several areas. At this stage the emphasis is on minimising the unused infrastructural capacity.

Finally, a third stage (interaction between levels A and B) might be needed due to indivisibilities of industrial activities. That is to say, some industries might be eliminated because of the actual splitting-up of infrastructural capacities over the various areas. In this case a second run of the model at level A has to be made in which the eliminated activities are excluded and after which the second stage at level B is again executed. This would lead to an iterative process.

Finally, the marginal productivity analysis as outlined in section 4.2. might be used to equilibrate the demand and the supply of infrastructural capacity, and to indicate which potential industrial activities initially excluded may now enter the optimal solution.

The model developed in this paper can be an important tool in decision making and industrial planning and promotion in the sense that it considers industrial activities as a whole and quantifies the trade-off between objectives.

Taking marginal productivity analysis also into account, over-capacity of infrastructural localities can be minimised.

Once a combination of activities is chosen, the results can be an important input for other parts of the planning process. For instance, if the labour structures of the various activities chosen are known, this demand may be met by an adequate supply of the several labour skills needed. This is the function of manpower planning, and can also serve as an input in the planning of housing and social amenities. In connection with this, the results of the model can be an input in transport planning, especially if information is available concerning transport over land, i.e. the origin of domestically-produced raw materials to be used by port industries and the destination of their output for as far as it is intended for the domestic market.

The model is not necessarily connected with industrial expansion of a harbour but can in principle be used for other industrial areas, including industrial estates.

Appendix 1.

I Navigation restriction in the channel leading from the entrance of the Harbour to the City Berth

Location	Restricting depth of LWOST	Length Limitation	Equivalent dtw om H.W.
Eastern Entrance	37/38 ft	-	50,000
East Channel	20 ft	-	15,000
The Bar	27 ft	750 ft	25,000
Upper Harbour	18 ft	505 ft	15,000

Source Ch Dev. Plan 1972 p. 13.

II

Bulk Fleet in 1972 in DWT

Tankers		Bulkcarriers	
10- 60,000	2408	10- 18,000	606
60-100,000	432	18- 30,000	992
100-150,000	127	30- 40,000	300
150-200,000	38	40- 60,000	307
200-300,000	194	60- 80,000	93
300-400,000	7	80-100,000	11
	3206	100-150,000	33
		150- -	3
			2345

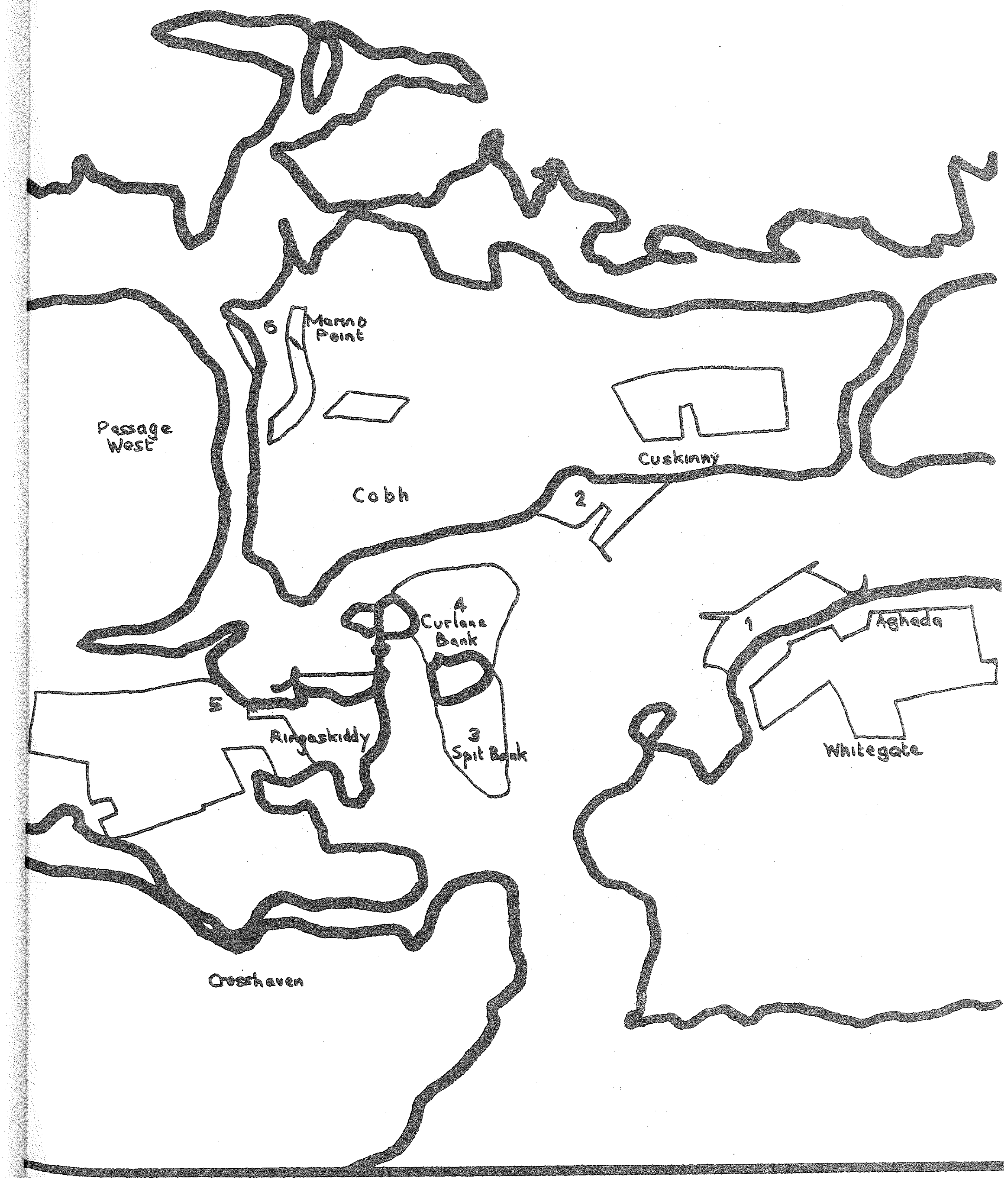
from: Cork H. Dev. Plan p. 25.

III

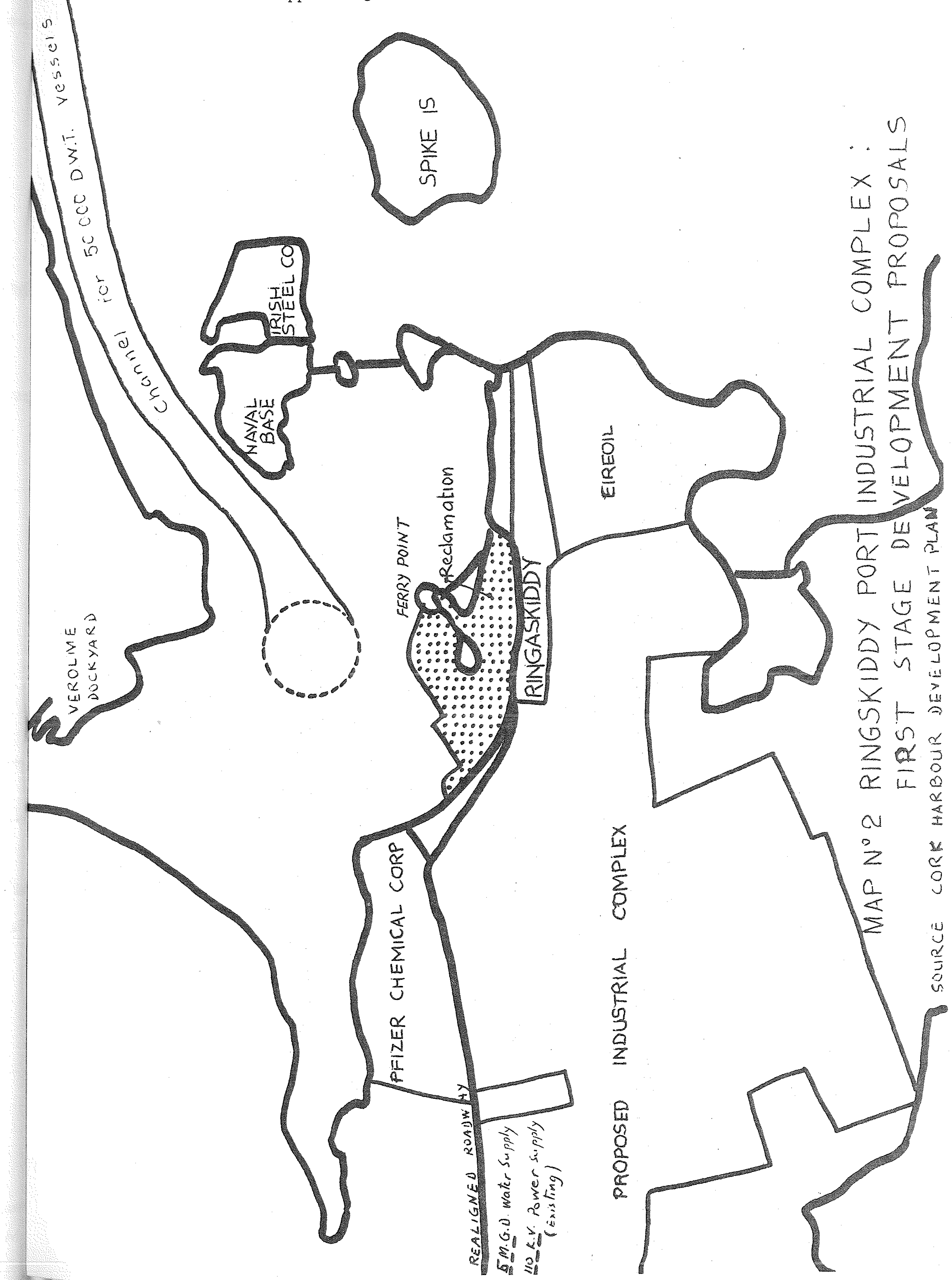
Employment Cork Harbour 1972

Employer	Number employed
Port	6,000
C.H.C. (including Pilots)	240
Dockers	300-500
Shipping Companies and Agents	200
Offshore Exploration	60

Source: Ch Dev. Plan 1972 p. 39.



MAP No 1 ALTERNATIVE AREAS CONSIDERED FOR ADVANCE FACILITIES SITES SOURCE CORK HARBOUR DEVELOPMENT PLAN



MAP No 2 RINGSKIDDY PORT INDUSTRIAL COMPLEX : FIRST STAGE DEVELOPMENT PROPOSALS

SOURCE CORK HARBOUR DEVELOPMENT PLAN

Appendix 4. Decision Trees

As stated in the main text, the decision tree or branching method is used.

An important aid in reducing the number of branches can be found in ranking activities according to their importance with regard to the objective to be maximised. In the first model, i.e. employment maximisation, activities have been ranked according to their labour context, as follows:

$$x_7, x_4, x_2, x_6, x_1, x_3$$

In the second model, i.e. port tonnage maximisation, the activities are accordingly ranked, which leads to the following picture:

$$x_7, x_6, x_2, x_4, x_1, x_3$$

In both models the activity symbolised by x_5 has been excluded since its realisation will always lead to exceeding the water supply constraint (see section 4.1.).

Symbols used in the model:

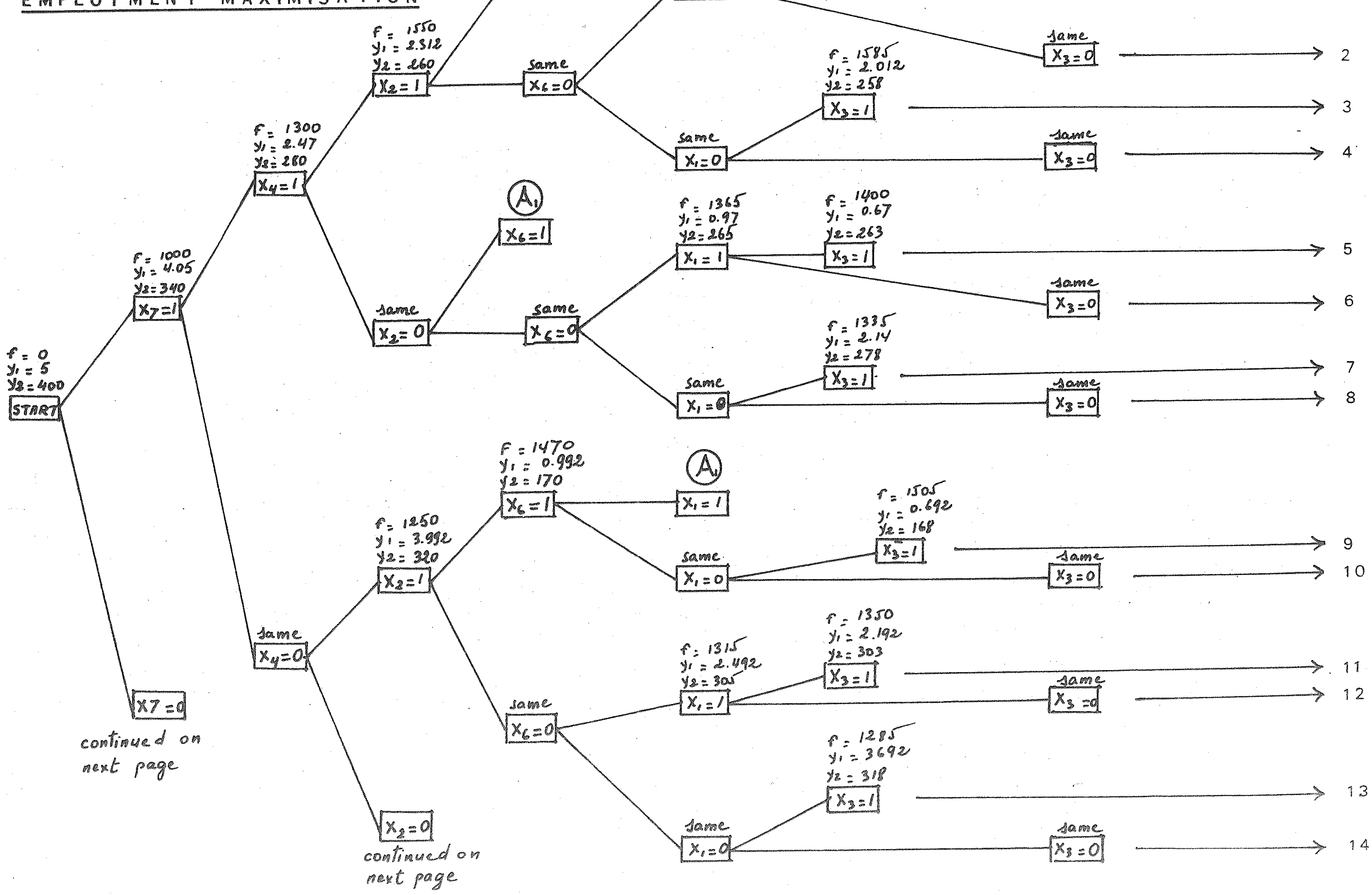
f The value of the objective function.
In model I, f is in terms of persons to be employed; in model II, f is in terms of thousand (1000) tons port tonnage.

(A_1) indicates that the activity concerned cannot be realised since it exceeds the first constraint. y_1 will become negative

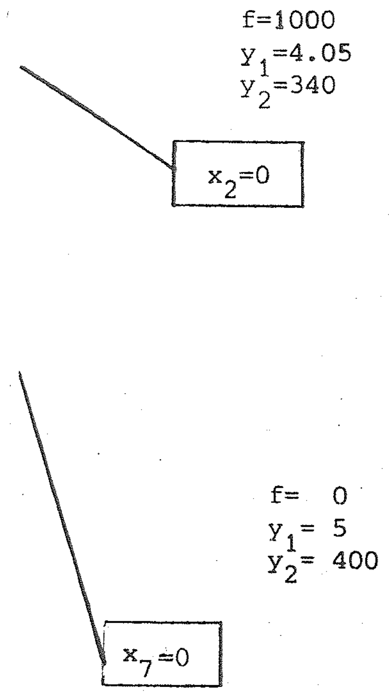
(A_2) same with regard to second constraint.

DECISION TREE MODEL I

EMPLOYMENT MAXIMISATION



Decision tree Model I Employment Maximisation (Continued)



in this case further branching will not yield any better results than with previous solutions. The value of the basic variable f is equal to 1000. If x_6, x_1 and x_3 would all be equal to 1 (indicating that they would be realised this would add to f: 220 + 65 + 35 = 320.

Thus the value of variable f in this solution will not exceed the solution numbered 11. $f \leqslant 1320$.

In this case the same reasoning can be adopted.

If the activity with the highest labour content (ad. 1000) is not realised (x_7=0) than all solutions which can be branched out from this position will be at maximimum 870. ($x_4 + x_2 + x_6 + x_1 + x_3 = 870$) Thus the value of the variable f can not exceed all other solutions branched out already. $f \leqslant 870$.

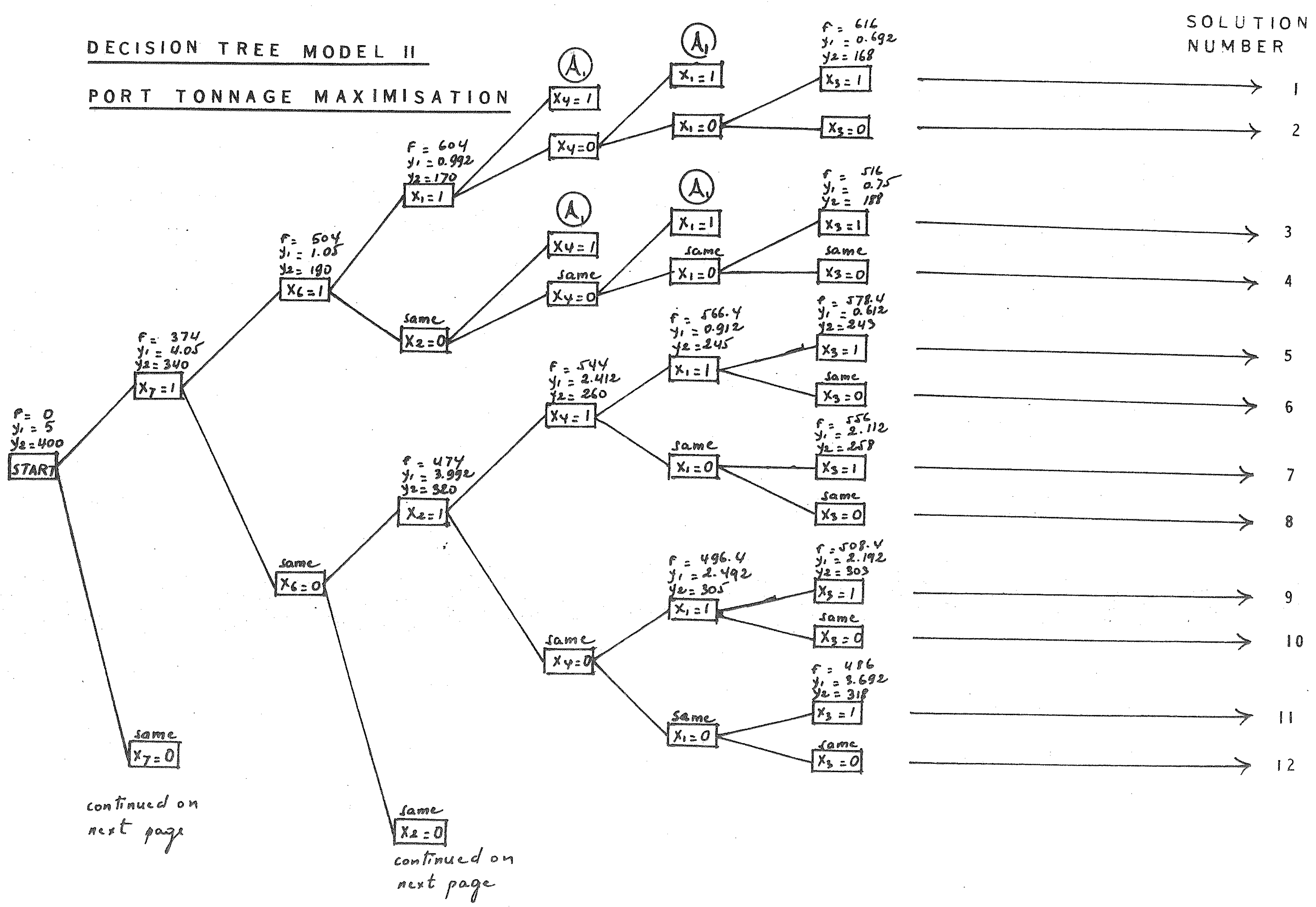
Results of Model I Employment Maximisation

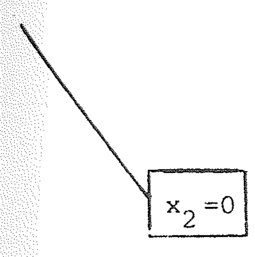
Solution Number	f	Values Y_1	Y_2	Activities in solution
1	1650	0.512	243	x_1, x_2, x_3, x_4, x_7
2	1615	0.821	245	x_1, x_2, x_3, x_7
3	1585	2.012	258	x_2, x_3, x_4, x_7
4	1550	2.312	260	x_2, x_4, x_7
5	1400	0.67	263	x_1, x_3, x_4, x_7
6	1365	0.97	265	x_1, x_4, x_7
7	1335	2.17	278	x_3, x_4, x_7
8	1300	2.47	280	x_4, x_7
9	1505	0.692	168	x_2, x_3, x_6, x_7
10	1470	0.992	170	x_2, x_6, x_7
11	1350	2.192	303	x_1, x_2, x_3, x_7
12	1315	2.492	305	x_1, x_2, x_7
13	1285	3.692	318	x_2, x_3, x_7
14	1250	3.992	320	x_2, x_7

First, second and third best solution are underlined.

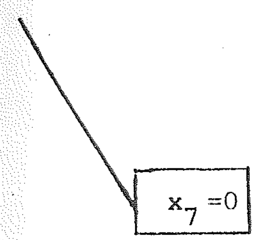
DECISION TREE MODEL II

PORT TONNAGE MAXIMISATION





From this position on further branching, is not necessary since if all reasoning (x_4, x_1, x_3) are realised, even then the value of the objective function will be 478.4 which is less than solution 11.



Some reasoning can be applied from this part of the tree. Without considering the constraints it can be said that if all remaining activities (x_6, x_2, x_1, x_1, x_3) are realised the value of the objective function would be 334.4. which is much less than the last solution branched out.

Results of Model II Porttonnage modernisation

Solution Number	Values f	y_1	y_2	Activities in solution
1	616	0.692	168	x_2, x_3, x_6, x_7
2	604	0.992	170	x_2, x_6, x_7
3	516	0.75	188	x_3, x_6, x_7
4	504	1.05	190	x_6, x_7
5	578.4	0.612	243	x_1, x_2, x_3, x_4, x_7
6	566.4	0.912	245	x_1, x_2, x_4, x_7
7	566.	2.112	258	x_2, x_3, x_4, x_7
8	544	2.412	260	x_2, x_4, x_7
9	508.4	2.192	303	x_1, x_2, x_3, x_7
10	496.4	2.492	305	x_1, x_2, x_7
11	486	3.692	318	x_2, x_3, x_7
12	474	3.992	320	x_2, x_7

First, second and third best solution in terms of porttonnage are undeclined.

Appendix 5. Arthur D. Little Ltd. Methodology

The methodology for analysing the industrial potential of Cork Harbour, used by ADL, has been called a screening methodology. It started with a list of 268 port industries and activities, including industries which require direct access to a port: those for which a waterside location is usual although direct access is not required; and finally, those industries which sometimes require port facilities although waterfront location is not essential. The following step consisted of ranking the manufacturing industries in the list according to their traffic generating capacity (using US census data), and secondly, port industries with the greatest employment potential were identified (without further specification). Then those industries were eliminated which seemed unsuitable to the Cork environment and those which require facilities which cannot be provided in the Cork Harbour region[1] (again both without specification).
Lastly they 'have kept in mind, but did not rigorously apply, eight criteria derived from the analysis of Cork's development potential' (pp. 30-31). These criteria were formulated as follows:

1. Not require very deep water
2. Require sites with economic effluent disposal
3. Not require excessive amounts of fresh water
4. Not require very large waterside industrial sites
5. Not rely on Irish domestic markets
6. Export to the UK primarily but not exclusively
7. Be companies or groups of companies from tax-agreement countries
8. Have, if possible, some interrelationship with industry existing in the Harbour Region.

From this screening 15 industry groups were retained for further examination, of which 9 industries had a 'likely' potential.

However, the application of this methodology and the final results are very difficult (if not impossible) to connect with each other, especially since several steps described in the methodology are not specified or further elaborated upon.

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1. Harbour Region defined as: Cork Cobh, the urban district of Cork, Fermoy, Kinsale, Midleton and Youghal and the rural districts of Cork, Bandon, Fermoy, Kinsale, Midleton and Youghal, all within commuting distance of Cork Harbour.

FOOTNOTES

1. See Appendix 1.
2. Harbour plans of about the same period have emphasised this point. For example, Scottish Council, Oceanspan (1970: Appendix A), and the Clyde Estuary Development Group, Report on Possible Industrial Developments in the Clyde Estuary (1969), p. 9.
3. Arthur D. Little Ltd., 'The Industrial Potential of Cork Harbour' (1970). Report and appendices.
4. Ibidem, p. 5.
5. Cork Harbour Development Plan (1972), p. 43.
6. See map, appendices.
7. Cork Harbour Development Plan, op.cit., p. 54.
8. Summary Cork Harbour Development Plan (1973), p. 9.
9. The Cork Harbour Commissioners have no competence concerning this part. Their domain extends to the high water mark whilst the County Council covers the mainland.
10. More recently it appeared that land acquisition is planned to be extended up to 400 acres. Interview with J. Quish, Regional Development Organisation.
11. C. van de Panne, Linear Programming and Related Techniques (North Holland Publishing Company, Amsterdam, 1971).
12. Ibidem, p. 104.
13. x=0 is not regarded as an activity since the question of realisation has no implication for the model.
14. C. van de Panne, op.cit., p. 347.
15. Sources: T.M. O'Connor, Regional Industrial Planning, in Administration, 20, 1 (1970).
    Cork Harbour Development Plan (1972)
    Regional Development Organisation, Regional Development Strategy (1972).
16. Regional Objectives are marked (-), National Objectives (+).
17. Dublin Institute for Industrial Research and Standards, Recommendations for disposal of Industrial effluent waters' (1970), p. 3.
18. Interview with Mrs. M. Wheelan, Cork County Environment officer.
19. Schedule of Tonnage and Goods rates, 1973 Cork Harbour Commissioners (Exemptions and exceptional rates are not dealt with in this paper).
20. According to interview with J. Quish.

21. Interview with Mr. Fahy, District Manager Electricity Supply Board, Cork, April 1974. The generation of power seems not to be a problem.

22. Arthur D. Little Report, op.cit., p. 47.

23. The study was started in 1969 and published in 1970. Two specific proposals have already been carried out elsewhere in the Harbour (Steelmill), or elsewhere in the country (Alumina plant Shannon Estuary).

24. Interview with Mr. O'Sullivan, Planning and Development Manager, Cork Harbour Commissioners. For a summary description of this methodology, see appendices.

25. T. O'Neill, 'Industrial Development in Ireland', Administration, 20, 1,(1972) p. 39.

26. Arthur D. Little, op.cit. pp. 34 and 41 of report, p. 14 of appendices. In all three cases incentives are decisive in attacting industrial projects.

27. If land requirement turns out to be 37 then the difference is about the same as the percentage which has to be deducted from the total available area for road construction.

28. Activity x_5 is excluded from these models since it cannot be realised within present water constraints. See also section 4.5.

29. C. van de Panne, op.cit., p. 349.

30. Ibidem, p. 351.

31. Presently industrial expansion is in progress at Little Island and Great Island, for instance.

32. T.M. O'Neill, op.cit., p. 42.

33. That the number of combinations might become too large to handle can be avoided by considering the preferences of the planners and industrialists. For example, industries with a high labour content should be sited in the sub-area which is closest to the labour pool. On the other hand actual constraints limit the choice of area; for example, the depth of the upper harbour does not allow the location of industries using large-size bulk carriers.