Operations Research Techniques in Regional Planning

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Abstract

Though there are some evidences that regional disparities of economic development are lessening rather than increasing because of the adoption of certain regional policies, a full-scale regional/locational planning which would optimize the productivity in the background of regional and national goals together is not yet in operation in India. This is not because of the lack of techniques, but because of the non-availability of full informations and statistical materials needed for making the techniques operational.

The present paper reviews the operations research techniques that have the promise of application in the context of developing the national economy through regional/locational planning and also examines the possibilities and limitations of using these theoretically developed techniques for regional planning operations of India.

1. INTRODUCTION

1·1. Indian national planning began in 1951. The basic objectives of the planning as set forth under "The Directive Principles of State Policy" in the Constitution are really in concordance with the broad principles of regional planning.[1] There are also some evidences that regional disparities are lessening rather than increasing, because of the adoption of certain regional policies such as the policy of dispersal industrial production. Mahalanobis has stated that "this policy would include geographical dispersal, that is locating units of production in such a way that the different regions of India can share equitably in the programme of production. Specialised regional resources and economy of transport must receive proper consideration ; but planning should be deliberately aimed at achieving a broad parity in the level of production and of living in the different regions of India and preventing the formation of depressed areas."[2] Again the Planning Commission and the Central and State Governments have conducted or are conducting various special studies in different regions/States for the purpose of identifying and developing the backward areas or have financed various academic institutions and organisations to help surveys concerning the regional aspects of development [3] But a full-scale regional/locational planning is not yet in operation, not because of the lack of techniques, but for the lack of full informations and data needed.[2·4] This is, however, not very unlikely at the initial phases of development in an under-developed country.

1·2. There might have been the uses of operations research techniques in solving certain localised and partial regional planning problems in India. For instance, the Indian Statistical Institute and the Operations Research Association, Bangalore, undertook a special survey in May-July 1958 to estimate the capacity of the Karwar-Hubli road in the transport of iron ore from Bellary to Karwar (upto Hubli by meter gauge railway and then to Karwar by five-ton lorries.)[5] The background of the problem was that some 5 million tons of iron ore would have to be exported from Bellary to Japan and to Europe, and it would be convenient to export most of it from West Coast ports and, in particular to develop to the maximum extent the route to Karwar, then carrying 0·2 million tons per year. Our findings were that the transport of iron ore through Karwar—Hubli road could be increased from 0·2 million tons to 2·52 million tons per year based on a mathematical model, or to 3·45 million tons using military experience based on convoys of lorries. In view of the difficulties in applying the discipline of a military column to a civilian transport problem, we suggested the interin solution of 2·52 million tons ; but the final solution might give a lesser value, since we believed that the mathematical model was simplified to the extent of ignoring the probabilities of the occurrence together with different combinations of obstacles, and the delays caused under various postulated traffic densities. We suggested that these probabilities could be worked out by using a graphical model of each section of road of relatively homogeneous traffic characteristics, and applying to each group in turn the Monte Carlo technique of forecasting.* There might be similar instances of the use of operations research techniques. But a greater promise of application of such techniques is in sight in the field of regional/locational planning in India. The aim of this paper is to extend the use of operations research techniques in regional planning and also to examine the possibilities and limitations of using these theoretically developed techniques for regional planning operations in India.

2. REVIEW OF INDIAN EXPERIMENTS

2·1. Regional Input-output Model :

Some preliminary attempts were made by the author to explore the possibilities of using input-output techniques at regional level. Similar experiments have been going on at national level conducted by various persons like Ragner Frish [6], Sandee [7], Chakraverty [8], Ashok Rudra [9] in the Indian Statistical Institute and also by some research workers in the Indian Planning Commission for last fifteen years or so. An input-output (or inter-industry) analysis at regional level differs a little from an input-output analysis at national level, because of an added complexity of inter-regional movement of products. For a nation, we have the relation.

$$X=C+G+K+M+U,$$

with $M=E-I$

or $X=Y+U,$

with $Y=C+G+K+M$

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*Assuming graphs representing section of road of differing traffic characteristics and also representing ore traffic by lorry on a given scale, the Monte Carlo technique would consist of feeding obstacles and delays (first established by field work) in various combination and permutations. The various forms of delay would be arranged in numbered tables, an particular delay being represented in proportion similar to those encountered on the road. The combinations of delays would then be fed into the graphs by selecting delays by means of tables of random nnmbers, and the effects on the new or postulated traffic density would be estimated.

wherein, X=gross national product, C=private consumption, G=government expenditure, K=capital formation, M=net national export, U=intermediate consumption or the consumption for productions, E=national export total, I=national import total and Y=final product.

At regional level,

$$X^r = Y^r + U^r,$$

but here, $$Y^r = C^r + G^r + K^r + M^r + S^r$$

with an additional component of S^r. The index r is used here to indicate the regional estimates of rth region to our earlier scheme of notations except for S^r and M^r. Here,

S^r=export of rth region to other regions of the nation

and $$M^r = E^r - I^r,$$

where E^r=regional contribution in national export total from rth region ;

$$\sum E^r = E,$$

and I^r=share of the regional requirement of national import total in rth region ;

$$\sum I^r = I.$$

If S^{rl}=the import of lth region from rth region,

then $$\sum_l S^{rl} = S^r$$

and $\sum_r S^{rl} = D^l$=import of lth region from other regions of the nation.

As $$\sum_r S^r = \sum_l D^l$$

or $$\sum_r (S^r - D^r) = 0,$$

the final product of the nation Y is free from any term of the form S. But it should be clearly understood that

$$Y \leqslant \sum_r Y^r.$$

Introducing the input-output coefficients, a^r_{ij} (input coefficients of ith product in producing the jth product in rth region), we have

$$X^r = B^r Y^r,$$

where B^r = Inverse of (unit matrix minus matrix A^r), where A^r contains elements a^r_{ij}'s. If A^r is known and Y^r is predetermined, X^r is soluble and thus planning measures can be taken for each of gross outputs for each region.

The determination of regional input-output matrix A^r requires the knowledge of technology at specific region for specific industry. Dhar (10) made a preliminary attempt to construct a seventeen sector input-output table for West Bengal and the Calcutta Metropolitan District. Simplification due to gaps in data could not be avoided in this experimental study and hence improvements are necessary before its application in planning. Similar conclusion has been drawn by the author himself in his very preliminary attempt to construct such a matrix for South India (States of Andhra, Kerala, Madras and Mysore). Again, at national level, we may have certain norms of increasing Y in view of the perspectives accepted in our national planning framework. But because of the inequality $Y \leqslant \sum_r Y^r$, it is not easy to determine the regional norms of growth for a given pattern of growth of national economy unless we have very precise knowledge of inter-regional export and import situation at a point of perspective time-horizon. It is very difficult to have a precise idea of export and import situation by regions from the currently available data on transport. Moreover, it is difficult to estimate the regional share of capital formation and government expenditure in view of overlaps in regional estimates. Pal and Subramanian [11] have, however, made an attempt to estimate the demand for regional private consumption in 1970-71 and 1975-76 for four major regions of India from the data collected by the National Sample Survey (*NSS*). But the projection was limited to only very few sectors of consumption of the *NSS*.

2.2. Regional Allocation of Planning Investment through Mahalanobis Model.

It is a truism that the level of development of a nation is directly related to the nature and precision of data made available by the Statistical Organisations of the nation. We have already discussed on the meagre availability of precise data needed in the regional input-output table. Certain simplifications are naturally evident for immediate operational purpose. Under similar circumstances, Mahalanobis used the data on incremental output-investment ratios only for two sectors, the sectors of investment goods and consumption goods (later, splitting the consumption goods into three sectors for a four-sector model) to arrive at the allocation of planning investments in two sectors for the Second Five Year Plan of India. (2.12.13.) This is an optimizing model, but has the limitations of using very limited number of sectors without showing explicitly the inter-industrial relation and naturally is much behind the actual implementation stage. Granting these limitations and also accepting the fact that the detailed locational data like the data on interregional transport are not readily accessible at the initial stages in a developing economy, we can think of a simple generalisation of Mahalanobis model to have the quick estimates of allocation of planning investment by a sector of a region. It can be shown that

$$Y_t = Y_0 \left[1 + \frac{\alpha_0 \sum_r \left(\lambda_{ir} \beta_{ir} + \lambda_{cr} \beta_{cr} \right)}{\sum_r \lambda_{ir} \beta_{ir}} \left\{ \left(1 + \sum_r \lambda_{ir} \beta_{ir} \right)^t - 1 \right\} \right]$$

where, Y_t = national income in t th year ;

Y_0 = national income in the base year ;

α_0 = proportion of net investment to national income.

β_{ir}, β_{cr} = incremental output—investment ratios in the sectors of investment goods, i, and consumption goods, c, for r th region; these values are assumed to be constant for a planning time-horizon of short length, T, years ; $0 \leq t \leq T$,

$\lambda_{ir}, \lambda_{cr}$ = proportionate allocation of total national investment in the sectors i and c respectively for r th region in a particular planning time-horizon.

If we put $Z_T = \sum_{t=0}^{T-1} Y_t$, we have

$$Z_T = Y_0 \left[Y \left\{ 1 - \frac{\alpha_0 \sum_r \left(\lambda_{ir}\beta_{ir} + \lambda_{cr}\beta_{cr} \right)}{\sum_r \lambda_{ir}\beta_{ir}} \right\} + \frac{\alpha_0 \sum_r \left(\lambda_{ir}\beta_{ir} + \lambda_{cr}\beta_{cr} \right)}{\left(\sum_r \lambda_{ir}\beta_{ir} \right)^2} \left\{ \left(1 + \sum_r \lambda_{ir}\beta_{ir} \right)^T - 1 \right\} \right]$$

Having known the values of Y_0, α_0, β_{ir}'s and β_{cr}'s and also the preassigned value of T, we may seek an allocation which maximizes Z_T satisfying $\sum_{r=1}^{R} \left(\lambda_{ir} + \lambda_{cr} \right) = 1$. Attempts are being made to estimate β_{ir} and β_{cr} from the data of Annual Survey of Industries and also from the reports on Plan-Projects.

3. INTER-REGIONAL LINEAR PROGRAMMING

3·1. A Static Model :

I shall now discuss a static model worked out by Stevens (14) to give an impression about the nature of basic statistical materials needed at the minimum even in a simple inter-regional programming model which treats inter-regional transport and natural resource endowments in explicit form. In this model for U regions and n goods, the goods may exist in resource, intermediate and final forms. The notations $h(r)$, $h(i)$ $h(f)$, where h ranges over 1 to n, would signify the resources, intermidiate and final forms of goods h respectively. At any given point of time, each region is assumed to possess fixed and non-augmentable endowments of natural capital and human resources. All resources are, however, immobile. Whenever the resources can be made mobile by some suitable productive processes, they will be treated as intermediate goods. The intermediate and final goods are mobile. "Services" are treated here as goods, such as transport services (in ton-miles or similar unit) or labour services (in mandays or similar unit) and so forth. The objective function, Z, which has been maximized in this model is effectively the gross final products of the nation, given by the expression (1) :

$$(1) \quad \ldots\ldots\ldots\ldots Z = \sum_{L=1}^{U} \sum_{e=1}^{n} P^{L}_{e(t)} \sum_{J=1}^{U} {}^{J}T^{L}_{e(t)}$$

Subjected to the constraints (2) to (5) :

$$(2) \quad \ldots\ldots\ldots\ldots\ldots \sum_{J=1}^{U} \sum_{d=1}^{n} {}_{e(r)}A^{L}_{d(t)} \; {}^{L}T^{J}_{d(t)} \leqslant E^{L}_{r(r)}$$

(resource constraints)

$$(3) \quad \ldots\ldots\ldots\ldots\ldots \sum_{J=1}^{U} \sum_{h=1}^{n} {}_{d(t)}A^{L}_{h(t)} \; {}^{L}T^{J}_{h(t)}$$

$$+ \sum_{J=1}^{U} \sum_{e=1}^{n} {}_{d(t)}A^{L}_{e(t)} \; {}^{L}T^{J}_{e(t)}$$

$$= \sum_{J=1}^{U} {}^{J}T^{L}_{d(t)} \; ; \quad d \neq m$$

(pool of intermediate goods d other than transport services m).

$$(4) \ldots\ldots\ldots\ldots \sum_{J=1}^{U} \sum_{h=1}^{n} {}_{m(l)}^{L}A^{J}_{h(l)} \quad {}^{L}T^{J}_{h(l)}$$

$$+\sum_{J=1}^{U} \sum_{e=1}^{n} {}_{m(l)}^{L}A^{J}_{e(f)} \quad {}^{L}T^{J}_{e(f)}$$

$$=\sum_{J=1}^{U} {}^{J}T^{L}_{m(t)}$$

(pool of intermediate transport service m).

$$(5) \ldots\ldots\ldots\ldots \sum_{J=1}^{U} {}^{J}T^{L}_{e(f)} \geqslant C^{L}_{e(f)}$$

(final demand constraints),

where,

(6) ......$P^{r}_{e(f)}$=the given "market" prices of final goods e in region L (in Rs. per unit),

(7) ${}^{L}T^{J}_{e(f)}$, ${}^{L}T^{J}_{(dt)}$=the number of units of *final goods e/intermediate goods d* produced in region L to be transported to region J,

(8) .. ${}_{e(r)}A^{L}_{d(t)}$, ${}_{d(t)}A^{L}_{h(t)}$, ${}_{d(t)}A^{L}_{e(f)}$=the number of units of *resource e/intermediate goods* $d(\neq m)$/*intermediote goods* $d(\neq m)$ required to produce a unit of output of *intermediate goods d/intermediate goods h/final goods e in region L,*

(9) ....${}_{m(t)}^{L}A^{J}_{d(t)}$ ${}_{m(t)}^{L}A^{J}_{e(f)}$=the number of units of transport services m required to transport a unit of *intermediate goods d/final goods e* from region L to regon J,

(10) ......$E^L_{c(r)}$=the endowment of maximum locally available supply of resource c in region L, and

(11) ......$C^L_{e(f)}$=the minimum level of the demand of final goods e in region L.

Here, instead of solving for the outputs of processes, we are solving for the transportation of goods, given by (7). The total production for any process in any region can always be found by summing the transportations made from this process to all regions including itself.

The model is very simply presented in that the breakdowns of final product in terms of consumption, investment etc ; are not shown at all. The minimum level, of demand of these breakdowns together *i.e.*, of final product is exogeneously determined which enter in the constraint (5). Naturally certain external methods are involved for their determination which are not discussed in the present model. On the other hand, the model has expande on the evaluation of the roles of inter-regonal transportation and regional natural resource endowment, which are very important in regional analyses. All constraints of regional importance have not, however, been entered in this model, but they can be easily incorporated.

The constant parameters given by (8) are very similar to regional input-output coefficients but with added complexity of three types of inputs. The determination of these parameters requires specific knowledge of technology in specific region/location. At least a part of these data my be obtained from the returns of the Annual Survey of Industries.

The statistical materials relating to the inter-regional transport coefficients defined in (9) are available only in partial form, *e.g.*, railway trade matrix by States. The data on the endowment of maximum locally available supply of resources defined in (10) are again partially known ; we can think of determining them only very tentatively, at the moment, from quantitative indices, direct where available—otherwise indirect, and/or direct qualitatative informations together with the knowledge of aggregate national figures. The data on private consumption, a part of item defined in (11), can be determined, by broad sectors atleast, by an elasticity analysis alongwith a consideration of parities in distributive aspects. (11) Finally it would not be, perhaps, very difficult to determine the regional price data (6) from the available informations. But much of operational research works have yet to be attempted before the successful applications of regional models.

3·2. **Dynamic Programming**. As the temporal interdependence is brought in view in a dynamic programming through the relations of capital capacities, like the relation (12) stated below, the investment sector should better be introduced in a static model, if it has not already been done as in Steven's model, and its relation with activity level be seen through certain new set of coefficients, like the capital-output coefficients or the coefficients of an investment matrix by receiving and delivery sectors, etc , as in Frisch's experimental national model (6). So, there is an additional complexity of determining regional values of such coefficients.

(12)...... ${}^{t}{}^{K}i=(t-1)^{K}i+(t-s_i-1)^{J}i-(t-1)^{D}\ i,$

where ${}^{t}{}^{K}i$ = capital capacity of *i*th sector in *t* th year,

${}^{t}{}^{J}i$ = gross investment of *i*th sector in *t* th year,

${}^{t}{}^{D}i$ = depreciation of *i*th sector in *t*th year,

s_i = investment gestation lag in number of years of *i*th sector ; this is characterized by the average length of time that can be expected to pass beeween the point of time where an investment is made in sector *i* and the point of time where the resulting capital goods are in operating order and can be used in the production sector. (15)

At national level experiments, both Frisch (6) and Sandee (7) have maximised consumption as target objective for the terminal year of a planning time-horizon. But Frisch has gone a step further in optimising the immediate objective relating to employment, investment and foreign assets in the coming year (*i.e.*, the year next to the base year) problem. We may, however, think of optimizing a preference function of aggregated values over all years in the planning time-horizon instead of a single year. Again both Frisch and Sandee simplified the dynamic aspect of the problem, the investment flow over time, by certain assumption so that the investment in tth year is dependent on the activity level of **tth year alone** and on certain known time-independent parameters and values. Frisch has assumed that the production and consumption activities increase at exactly the same constant rate (or some suitably inflated constant rate) so that the economy grows in a balanced state. While Sandee has assumed that every investment flow increases (or decreases) linearly with time in the planning time-horizon and in that the considerations of investment gestation lag and depreciation have been ignored. Obviously, these assumptions are very restricted, even though they simplify the computational load. This **Static Way** of handling the dynamic models can be eliminated, provided we can extrapolate, by some method, the activity level just beyond the planning time-horizon for a period dependent on the length of gestation lags, for which investments are to be made without any yield in the planning time-horizon paper.

Bhatia has actually developed theoretically a similar kind of model wherein the gestation lag/ period has been assumed to be same for all sectors and the length of such lag coincides with the period (of length five years in his very simplified and tentative illustration) that has been chosen instead of a year in his analyses (16). Thus he provided the capital inputs in period $(p-1)$ for the new capacity

$$\Delta_p^L X_i = {}_{(p+1)}^{\;\;L} X_i - {}_p^L X_i \,, \text{ where } {}_p^L X_i$$

is the output of i in region L for period p—to be created in period p. So, if the planning time-horizon is of length P periods, the capital inputs made in Pth period really goes for the creation of the new capacity of $(P+1)$th period which does not occur in his objective function Z,

$$Z = \sum_{i=1}^{n} a_i \sum_{L=1}^{U} \sum_{J=1}^{U} \sum_{p=1}^{P} \Delta_p^L X_i^J ,$$

where a_i is the "value added" for rupee worth of product based on the use of new capacity created in the planning time-horizon and

$\Delta_{p}^{L\ J}X_i$ is the increase in flow from region L to region J of i th product made possible in the $(p+1)$th period because of new capacity created in the pth period. He has eliminated this difficulty by the introduction of a set of terminal conditions that

$$\Delta_{(P+1)}{}^{L}X_i \geqslant \Delta_{P}{}^{L}X_i$$

This terminal condition, however, can suitably be changed, say

$$\Delta_{(P+1)}{}^{L}X_i = (1+{}^{L}M_i)\,(\Delta_{P}{}^{L}X_i)$$

where ${}^{L}M_i$ is a known constant indicating an expected proportionate rate of growth per period for ith input in Lth region.

In this model the national income has been maximized for whole of the planning time-horizon of length P periods. The capital has been considered mobile between regions, while labour immobile. Naturally regional labour requirement is limited by the maximum locally available labour. Like Steves, Bhatia visualised the output in terms of flow or transportation variables. But Bhatia has gone a step further in estimating the product of transportation sector, that are needed in view of the increase of flow during the planning time-horizon, by means of transport co-efficients ${}^{L\ J}t_i$, the amount of transportation product required to effect the flow of an unit of product from regional L to J

$$\left(\sum_{i=1}^{n} {}^{L\ J}t_i = {}^{L\ J}t\right)$$

and corresponding input coefficients ${}^{L}A_{ti}$, $(i=1), \ldots\ldots \ldots, n)$, assuming that the transportation facilities have to be provided at the point of origin of the flow. Because of the assumption of one way utilisation of transportation product, the actual capacity needed in practice might be less than the value under theoretical assumption. But a correction factor can always be introduced. The special treatment of transport has led Bhatia to introduce an additional column for transport in the matrices of input-output coefficients and capital-output coefficients. He has also distinguished between the output generated by old and new technologies.

Naturally he had to introduce matrices of input-output coefficients characterizing both the technologies. The regional variation has, however, been ignored in the old technology, but the initial capacities under old technology, by products and by regions are known constants. The consumption patterns by products, by regions and by periods are known and determined exogeneously.

This model has not yet been illustrated with full Indian data. As in the static model some experimental research has to be done before successful application of a dynamic programming model.

4. CONCLUSION

From the foregoing analyses, it is clear that the application of certain operations research techniques are yet experimental even at the national level. Perhaps some kind of non-optimizing input-output technique, based on iterative computations, may be applied very soon in our national planning framework. But it will take some time to apply an optimizing programming model, which takes into account the interdependence of sectors, regions and periods, because of the limitations of data and computational facilities. Even if this problem is solved, there remains still the problem of determining actual location of production ; solution at regional level simply narrows down the problem of locational decision of production, but certain micro-analyses of economic activity need for locational decision cannot yet be incorporated at the micro-level programming.

The classical location theories involving the comparative cost doctrine, the economy of scale of production, etc., are essentially the study at micro-level. It is almost impossible to introduce directly micro-level location theories into a national or regional model, particularly when the decision of each firm is not influenced by or does not influence the location decision of other firms under the assumption of traditional location theories. But the optimizing techniques of operations research may possibly be applied at **another stage** to make the locational decision of a **particular industry** when the upper limiting value of its aggregate production can be obtained from the macro-regional programming model and also when the suitable discrete locations for that industry are predetermined by traditional location theories or by some other techniques, such as, the industrial complex analysis or the analysis of locational production functions. Pal [17] has demonstrated theoretically a similar kind of model forcement industry, which links up the macro-regional/national production targets with the choice of location of production.

There may be many other methods yielding some kind of partial locational solutions (18, 19, 20), which need to be incorporated in a **holistic** national/macro-regional planning framework. But it is very necessary to examine all such partial locational solutions together for a balanced type of final decision-making. This task is very difficult. The macro-regional programming models, however, yield certain control figures. But enough researches and experiments are yet necessary to yield satisfactory results in full-scale and balanced locational planning.

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