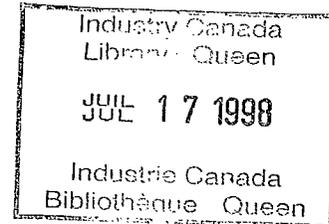


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A National Telecommunications Planning
and Policy Simulation Model ^{*(1)}

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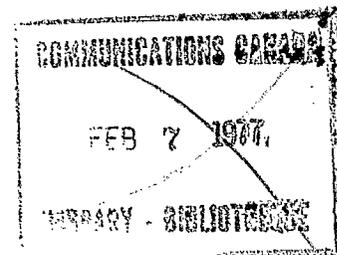


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77-01-T

* Paper presented at the 2nd International Conference on Dynamic Modelling and Control of National Economics, January 24-27, 1977, Palais Auersperg, Vienna, Austria.

- (1) This project has been financed by the Canadian Department of Communications. It is a tripartite effort of the following organizations: the Canadian Department of Communications, Sorès Inc. of Montréal and the Laboratoire d'économétrie, Université Laval. Mr. G. Henter from the Department of Communications has been the project manager of the project. Professor T. Matuszewski from the Laboratoire has contributed to the conceptualization of the model. Mr. J.-P. Schaak from Sorès Inc., has been responsible for the software developments. Those persons can be seen as co-authors of the present paper. However the present authors are sole responsible of the interpretations given here and, in particular, do not pretend to reflect the view of the Department in this domain under study.



PLAN

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Summary

The paper describes a national telecommunication planning and policy simulation model, constructed for the canadian network. Its main aims is to evaluate the financial consequences on the carriers of the modifications of some control variables like depreciation rate, rate of return, etc, variables which are under the control of a regulatory agency. It also computes the cost of the various services in order to test for possible cross-subsidies. The main characteristics of the model are: a) it is very disaggregated in order to be as close as possible to the service producing activities of the firm; b) it contains 4 blocks: Operating, Costing, Sharing and Accounting. This construction by block allows simulation using any block or using all blocks together as an integrated unit; c) it is completely operational in the sense that it is runned with a part of the canadian network containing 60 nodes and 250 links.

1. Introduction

The main purposes of the present paper are threefold:

- a) to describe in an explicit manner the planning and policy simulation model so far developed for the industry of telecommunications;
- b) to report on some empirical experiments performed with the model;
- c) to suggest some extensions mainly in view of taking the dynamic aspects of the problems. However, in view of motivating the way the model described below is articulated, a brief review of the institutional setting in which the industry of telecommunications operates seems to be worthwhile.

In Canada, the radiocommunications activities, including broadcasting, transmitting and receiving undertakings, are under the legislative authority of the Parliament of Canada. Moreover, most of the important telecommunications carriers (which account in total for more than 75 per cent of all telephone and telegraph services in Canada) are federally regulated. This includes, among others, Bell Canada, British Columbia Telephone, Telesat Canada and the Canadian Overseas Telecommunication Corporation (now Teleglobe). All other telephone and telegraph undertakings are provincially regulated.

The regulation is done by performing the following two steps. The first one is the determination of what is called the Total Revenue Requirement (TRR) which is the aggregate amount of money each carrier wishes to recuperate each year. It is calculated in view of obtaining the levels of the tariffs. It is obtained as follows:

$$\text{TRR} = \text{Operating expenses} + (\text{rate base} \times \text{rate of return}) \quad (1)$$

The rate base is of course the net plant value which is the gross plant value minus the accumulated depreciation. Most of the time, the historical (or book) cost is taken instead of the reproduction one. In so far as the rate of return is concerned, the regulated agency imposes an upper bound which is strongly related to the cost of capital⁽¹⁾.

The second step in the regulated process is the determination of a tariff structure. In other words, taking the estimated future demand for each service supplied by each carrier into account, the regulated agency (but many times it is the carriers) has to decide some tariffs in order that the TRR be recuperated; that is to say

$$\sum_{t=1}^k \sum_{i=1}^m p_{it} q_{it}(\cdot) + \lambda = \text{TRR} \quad (2)$$

Here, p_{it} refers to the rates applied to the various services i , t refers to the different periods, say the day, where for each one the tariffs are different⁽²⁾. Finally, the net result of the intercarriers activities is denoted by λ .

In the institutional context peculiar in Canada, a brief comment is an order concerning the inter-carriers activities. We said previously that there has been a divided authority over telecommunications carriers. In consequence, the recognition of a "national dimension" in the network as a whole has been left largely to the discretion of the Trans-Canada Telephone System (TCTS) which is a non-incorporated association and as such, has not been subjected to any regulation whatsoever. In other words, the inter-carriers activities are not formally regulated by a central agency.

This last aspect motivated, in July 1973, the Department of Communications in Ottawa to elaborate a desaggregated simulation model in view of evaluating the financial impact of various sharing schemes which can be applied for splitting the revenues and costs, consequent to the supplying of some interregional activities by the carriers. Since that time, this initial objective has been displaced by more ambitious ones. Even if those objectives are described more fully in the next section, they can be summarized by saying that the model so far constructed aims at developing tools which respond to some policy questions in the domain of telecommunications.

2. Objectives of the model

The basic features of the industry of telecommunications are very well-known, so this is not the place for reviewing them. However, it is also known that various policy questions can be raised in relation both to equations (1) and (2) appearing in the Introduction. Among the most important ones, one can mention the following ones.

In the equation (1), the main problems are the financial consequences of various methods of accounting and in particular:

- i) which item can be expensed and which one can be capitalized?
- ii) which method(s) of depreciation used: the ELG and/or the ASL ones?
- iii) how to value the assets of the carriers: at their historical or reproduction costs?
- iv) which rate of return to allow, how strong must it be related to the cost of capital and to the book value of the assets?
- v) is there any optimal financing structure for the regulated carriers?

Strongly related to these questions are the next ones which are present mostly due to the importance of the variations of the demand for telecommunications during a same period of time and also from the fact that the carriers try to manage the network as a whole.

- vi) which are the impacts of varying the routing of the messages and their relationship with the existing capacities of the Canadian interregional network?
- vii) which are the financing consequences of varying the quality of the various offered services?
- viii) is there any important excess capacity in the Canadian network?
- ix) how to guarantee the "survival" of the network?

Central to equation (2) is the problem of determining the cost of each service supplied by each carrier (each carrier offering more than one service) in view of evaluating empirically the possible cross-subsidization among services, among peak and off-peak customers, among generations. For achieving this objective, a lot of questions must be answered:

- x) which cost associate with each service: marginal and/or average one?
- xi) which time dimension for the costing purposes must we uses: retrospective, current or the prospective ones?
- xii) in view of the lot of common and joint costs present in the industry of telecommunications, which costing separation procedure must be utilized?
- xiii) in practice, is there any relationship between the tariffs and the costs (however defined) of the services? Or, to say the least, does the taking into account of some "social considerations" disturb this relation?
- xiv) is it possible to find a tariff structure which is subsidy-free?
- xv) what are the impacts of various revenue sharing schemes concerning the interregional telecommunication service?

Needless to say the National Telecommunications Planning and Policy Simulation model does not pretend to provide automatically "optimal" solution for the carriers and for the regulatory agencies to these various questions. However, it was constructed in order to evaluate the financial as well as the economic impact, both on the real operations of the telecommunications system and on the financial consequences for the carriers and for the system as a whole of some various policy options and alternatives in the domain of telecommunications in Canada. This aim is reached by formulating, processing and evaluating some scenarios, two scenarios being different once some technical, accounting and/or economic variables are modified.

Finally, it is obvious that the NTPPS model can also be viewed in a wider setting as a contribution towards the formulation of policies aiming at having an even more efficient telecommunications system in

keeping with the broad social, economic and political objectives in Canada as formulated by the government in its Proposals for a Communications Policy for Canada: a Position Paper of the Government of Canada [6].

3: Logical structure and software system of the model

3.1 Logical structure

The objectives of the model have been stated in the previous section. It can be reminded that these objectives mainly concern the various operations of the carriers, the costing of the various services they provide, the different settlement schemes for splitting the revenues and/or the costs of their interregional activities and finally their methods of accounting. Consequently the logical apparatus of the model has been designed in such a way as to be able to take these main activities of the telecommunications carriers, and their interrelationships, into account. For each of them a block is constructed within which the necessary computations are performed and output are generated. It is the purpose of this section to briefly describe these blocks, show their interrelations and give an idea of the software. The next section will be more explicit on each block.

The general structuring of the model, the various blocks and their interrelations are indicated by the Flowchart, figure 1. The purposes of each of these four blocks can be summarized as follows.

a) The Operating Block takes the structure and the operations of the Canadian network into account and the types of traffic it carries. Its main purposes are to transform the traffic patterns at peak demands into usage on the particular links contained in the physical network and to compute the presettlement gross operating revenues. The usages of the facilities provide an input for the Costing Block and the presettlement gross operating revenues, a component input for the revenue division process dealt with in the Sharing Block.

b) The Costing Block has for main functions to associate costs, whichever defined, with the physical facilities of the network and to allocate costs to various services and streams of messages, using different basis (for example, under the present utilization of the network or assuming its full utilization). The cost by stream and service is fed into the Sharing Block.

The Costing Block permits also to produce the plant assets by categories of plant by carrier in terms of both the gross investment and net investment, i.e. gross investment minus accumulated depreciation. This output is fed into the Accounting Block.

c) The Sharing Block contains a set of sharing schemes between carriers which aim at remunerating the owners for usages of their system by service streams passing through more than one system. In consequence, the output of this block will be, once a particular scheme is used, the determination of the postsettlement operating revenues by carrier. This provides an input for the Accounting Block.

d) The last block is the Accounting Block. It contains the accounting algorithms required to produce the financial statements, for each carrier, as the result of say some particular operating and/or sharing scenarios. In addition to the financial statements, a number of ratios are also produced, like the rates of return under various bases and the debt/equity capital ratio. Of course, these outputs reflect the financial impacts of a particular simulation.

Finally a goal programming model is incorporated in the Accounting Block. This model permits to measure the impacts on some key variables once some constraints (for example, an upper bound on the rate of return) are imposed by a regulatory agency.

From the foregoing, the reader has surely noticed that the model has been shaped to utilize and maintain information, both exogenous and endogeneous, at a fine level of disaggregation. Also, by virtue of the "building block" concept and the structuring of the model

in four main blocks, a very great flexibility in simulation capability has been provided. As indicated by the dotted line on the flowchart (figure 1), simulation scenarios may be constructed through accessing and changing some control variables or parameters in any one, in more than one or in all of the four main blocks. It follows that the various scenarios and their impact can be evaluated by running the model end-to-end, or for intermediate output from any one of the blocks.

It is important to notice, and the reader can verify by himself by looking in the section "Experiments with the model", that although the model has been designed to deal with the national network as a whole, it is capable of dealing with scenarios pertaining to individual carriers or region.

3.2 Software system

A few words concerning the software system of the NTPPS model will close the present section. It can be said immediately that the series of programs which constitute the NTPPS model are first, written in FORTRAN and second, are incorporated into a conversational computer software system designed to permit a user with little knowledge of computer systems to rapidly perform a series of analyses or scenarios, with minimal prior instruction. The conversational characteristic of the programs works as follows. Once the appropriate keywords for the desired function(s) are entered, the system responds with a certain number of messages and instructions in such a way that when a decision is required, the user will be answered by a list of possible answers or by a question mark appearing on the terminal, question which must be answered before allowing processing to continue. At the end of each simulation run or updating function, the user is asked if he wants to terminate or repeat with revised inputs. The user then has the option of repeating, proceeding to a new block by entering another keyword, or of signing off.

The two key components of the software system of the NTPPS model are data blocks, and software blocks. The interaction of these blocks, and the logic flow of the model are illustrated schematically in Figure 2.

i) The data blocks of Figure 2 consist of a permanent data base component, connected to a temporary data base component via "intervention programs" shown as inverted triangles in this figure.

The permanent data base components (identified as parallelograms) consist of base data items used in the NTPPS system, such as description of the initial state of the switching network, rate information, accounting and cost ratios. The role of the permanent data base is to provide a benchmark for users of the system.

The temporary data base components (shown as hexagons) serve as intermediate "scratch" storage space in which the user can incorporate modifications to the permanent data, for purposes of a particular simulation scenario.

The conversational intervention programs (shown as inverted triangle) represent for the user the main control points on the system. The use of these programs permits the user to define a particular simulation scenario by modifying elements of the permanent data base and transferring these modifications to the temporary data base.

ii) The software blocks of Figure 2 consist of the main processing programs, the auxiliary processing programs and endogenously generated data base components.

The main processing programs (shown as rectangles perform the principle calculations of the model and are usually organized around one particular algorithm or process. Due to data handling and computer memory constraints, the processing programs do not necessarily conform to the compartmentalization "Operating Block", Costing Block" etc, used to describe the model elsewhere in this paper.

The auxiliary processing programs (represented as squares) serve as "housekeeping" links between main programs, generally transforming endogenously generated data into an appropriate form for subsequent computations.

The endogenously generated data base components (the circles with tail) contain results of calculations of one processing program which must be stored for use by subsequent programs. In certain cases the contents of these endogenous components can be printed on the users' terminal for examination and analysis before proceeding to subsequent calculations.

4. Finer description of the Blocks

4.1 Operating Block

4.1.1 Data base

Operating Block tends to reflect the structure and the operating rules of the national telecommunication network. The data bases for this block is as follows:

a) Traffic data base

i) For the non-switched traffic, point to point circuit requirements for a base period are given. Television and private lines are the only non-switched services considered so far.

ii) For switched traffic, point to point offered traffic profiles are provided in Erlangs or C.C.S. for typical days. Although the profiles can be modulated along 24 hours, oftentimes only the load for the peak hour is retained with factors of proportionality to convert in loads for other slices of the day. The model is intended for directly observed traffic patterns, but for development purpose a gravity type model can generate traffic. This type of traffic can be split in U.S. traffic, adjacent province traffic, and non-adjacent province traffic.

b) Switching network (S.N.) data base

The S.N. is given with its configuration, its hierarchical structure and the rules of overflowing, its quality of service parameters (probability of loss on the ultimate trunk), the number of circuits on each link, the location of the switching machines, an ownership tag for each facility.

c) Transmission network (T.N.) data base

The T.N. is given with its configuration, the link capacities (actual and ultimate), the ownership tags.

d) Tariffs data base

For that experimental phase, the rates are those of the Trans Canada Telecommunication System.

4.1.2 Algorithms

a) An algorithm which estimates the traffic carried on the links of the S.N. given the data mentioned in 4.1.1a) and 4.1.1b); the expected traffic on a given link is decomposed according to the origin-destination streams. This is done by using the well-known Erlang formula for overflow probabilities and Poisson's formula for loss probabilities on the ultimate links. A carefully sequence of choices of links, ascending and descending the node hierarchy, permits the building-up of loads from different streams on each link. This can be computed for any typical desired time period.

b) An algorithm which allocate on the T.N. the circuit requirements for switched and non-switched traffic. All nodes of the S.N. are nodes of the T.N. but the reverse is not true. Given the circuits requirements for the adjacent nodes of the S.N. and the circuits requirements for the origin-destination pairs of the non-switched traffic, a linear programming model allocate those requirements to chains (routes) subject to capacity constraints on transmission facilities. The chains are not enumerated but chosen with the help of the dual variables associated to the capacity constraints at each iteration. With problems of the size treated in NTPPS, the enumeration would forbid any computation.

The ideal objective function to be minimized for the allocation should be a linear combination of variable operating costs associated to the facilities. Unfortunately these costs are negligible. Two alternate criteria are:

i) minimize the allocated circuit-miles; this is equivalent to maximize the excess capacity measured in circuit-miles. The interpretation being that it is rational to put aside the greatest possible capacity for the future.

ii) minimize the "cost" of the allocated circuits, the unit cost for each facility being drawn from the embedded cost (average or incremental). This idea looks like a posteriori costing of the excess capacity since the above minimizing is equivalent to the maximizing of the excess capacity cost under the hypothesis that there is enough capacity for the given requirements.

The following notation is used in the allocation model:

$s = (s_1, \dots, s_1, \dots, s_m)$: the spare capacity vector, i referring to the i -th transmission link.

$x_k = (x_{1k}, \dots, x_{jk}, \dots, x_{n_k k})$: the number of circuits carried on the j -th chain for the k -th origin-destination pair, ($k = 1, 2, \dots, L$).

$\alpha = (\alpha_1, \alpha_1, \dots, \alpha_m)$: the weight (unit cost, length, etc.) vector associated with the spare capacity vector.

$u = (u_1, \dots, u_1, \dots, u_m)$: the capacity of the links in the transmission network.

v_k : the circuit requirement of the k -th origin-destination pair ($k=1, \dots, L$).

I_m : an identity matrix of order m .

A_k : a boolean matrix of link-in-chain membership, for k -th origin-destination built from the entire transmission network configuration corrected for routing restrictions if any.

$e_k = (e_{1k}, \dots, e_{n_k k})$, a vector composed of 1.

Formally, the allocation model can be formulated as follows

$$\text{Max } z = cs$$

$$\text{Subject to: } I_m s + \sum A_k x_k = u$$

$$e_k x_k = v_k \quad (k = 1, \dots, L)$$

$$x_k \geq 0 \quad (k = 1, \dots, L)$$

c) For the expansion of the S.N. an algorithm computes the dimensioning of high usage and ultimate trunks for the new total traffic; then it compares the result to the existing available circuits and it derives hereof the necessary addition in term of circuit requirements and switching facilities. The dimensioning is done through the application of a version of the economic C.C.S. rule which says that the number of circuits to handle a given volume of switched traffic should be allocated between the direct and alternate route so that the ratio of the respective marginal costs equals the ratio of the corresponding marginal efficiency. Most of the software of the algorithms mentioned in 4.1.2a) has been reutilized once some parameters have been reinterpreted as variables.

d) For the expansion of the T.N. the model described in 4.1.2b) can be modified as follows:

Notation:

The same as for 4.1.2b); plus the following ones

Δu : the vector of expansion on the links

$\overline{\Delta u}$: the vector of upper bounds on the components of Δu

c : the incremental unit cost coefficient vector

Δv_k : the additions to the circuit requirements for origin-destination pair k

Formally, the model of expansion-allocation is the following

$$\text{Min } z = c\Delta u$$

$$\text{subject to: } -I_m \Delta u + \sum_k A_k x_k + I_m s = u_0$$

$$e_k x_k = v_k + \Delta v_k \quad (k = 1, \dots, L)$$

$$0 \leq \Delta u \leq \overline{\Delta u}$$

$$x_k \geq 0$$

Some comments are needed. The asset valuation functions from which the cost coefficients are derived (see the Costing Block) would permit easily more sophisticated models with mixed integer linear program features; the huge size of real problems motivates the choice of the present model. Moreover, if one is ready to accept the same "cost" coefficient for a unit of excess capacity as for a new unit on the same link, the expansion model has almost the same form as the pure allocation one, namely:

$$\text{Max } z = cs$$

$$\text{subject to: } I_m s + \sum_k A_k x_k = u + \overline{\Delta u}$$

$$e_k x_k = v_k + \Delta v_k \quad (k = 1, \dots, L)$$

Therefore the software of the former model is readily available and the cost and capacity expansion is retrieved by the following simple transformations: if $s_i \geq \overline{\Delta u}_i$, then $\Delta u_i = 0$; if $s_i < \overline{\Delta u}_i$; then $\overline{\Delta u}_i = \overline{\Delta u}_i = s_i$; and in any case $\Delta c = c\Delta u$.

e) Another algorithm compiles the usage of facilities by traffic streams. This compilation is needed for certain sharing schemes which use the notion of stream cost (see Sharing Block), for certain stream survivability preoccupations, and for identification of cost responsibility during peak period. With the results of the algorithm which estimates the average offered and carried traffics on each link of a given S.N. for any period, some separation rules based on the pro-

portions of different traffic streams can be elaborated for the composite traffic between adjacent nodes of the S.N. and by extension for the cost of switching equipments. Moreover, through the circuit requirements, the circuit allocation on the T.N. can be related to that composite traffic, the relative composition of which being used for splitting the cost of any transmission facility.

4.2 Costing Block

Recall that the main purposes of the Costing Block are 1) to associate different costing concepts with the physical facilities of the carriers and 2) to allocate costs to the various services. The process for achieving each of these two objectives will now be examined.

4.2.1 Incurred costs of the facilities

The incurred cost of each facility is the summation of the following components: depreciation, cost of capital, operating costs and finally the non-income tax. The incurred costs have been calculated both on a gross asset basis and net asset one, for each carrier and for the following accounting types of plant: switching, transmission, general equipment, building and land. The general logic for calculating these costs is shown by the Costing Flowchart, (figure 3). We will now reviewed the important steps appearing in this diagram.

As can be seen in the figure 3, the starting point for calculating the incurred costs is the assets valuation of the assets, some at their reproduction costs and some at their historical ones. The Asset Valuation module provides, beginning-of-a-(particular)-year values for the aforementioned types of plant. The values for general equipment, building and land are taken directly from the financial statements of the carriers. However, such is not the case for switching and transmission equipments. For these elements, the assets valuation operation is performed by using some assets valuation functions: these functions are step ones in order to capture the economies of scale in the industry of telecommunications. Since in the NTPPS model we are

primarily concerned with the TCTS transmission network which consists essentially of microwave repeaters, multiplexing equipment and towers, these assets only will be evaluated for that network. For that purpose, all repeaters in the TCTS system have been classified, according to their function, into three categories: regular repeaters⁽³⁾, branching or junction repeaters⁽⁴⁾, terminal repeaters⁽⁵⁾. For each of them, a cost function was established, the costs varying with the installed capacity (in RF channels). Up to now, we are conscious that our treatment of the multiplexing equipment has to be improved.

In view of calculating the first component of the incurred costs, i.e. the depreciation, once the reproduction costs functions are available, the following steps must be performed. First, the growth rate of gross additions to the plants is required both in the Aging and Indexing Module and also in the Deferred Tax Module (the result of which being an input for the computation of the cost of capital). It is obtained as follows.

$$GA(y) = GA(0) \times R^y,$$

where $GA(y)$ is the gross addition in year y ; $GA(0)$ is the gross addition in the initial base year and R^x is the compounded growth for y years. R is obtained by first transforming this equation in logarithm, second, by making a regression.

Up to now, the Asset Valuation Module which provides reproduction asset values, applies current cost functions and current technology to assets evaluated in the Operating Block. However these reproduction asset values must be transformed into historical asset values which are the ones which appear in company's books and also which are needed for regulatory purposes. In order to do this, we have to calculate the dollars surviving from the vintages, which we call the aging procedure, and to construct price indices relative to such vintages, which we call the indexing procedure. In consequence, the Aging Module applies various methods of depreciation, survival characteristics and growth rates. In the Aging and Indexing Module, the indexing factors are

- a) pricing which reflects dollar inflation over time;
- b) changes in technology which reflects differing real costs for the same capacity due to varying states of technology.

Two methods of depreciation are programmed in Depreciation Module. The first is the Average Service life (ASL), which depreciates on a straight line basis the whole of the vintage group. The second is Equal Life Groups (ELG) which depreciates the smaller equal life groups within the vintage group. However, for simulation purposes, it is possible to modify various parameters like the survival curve, the average life of the equipments, the maximum life, the inflation rate, the growth rate and finally the reproduction value.

The cost of capital is the second component for evaluating the incurred costs. It is calculated by using the following equation:

$$\text{Cost of capital} = \frac{1}{(1 - t)} [\text{RORE} \times (1 - \text{DCR})] + (i \times \text{DCR})$$

where t = tax rate, RORE = rate of return on equity: DCR = debt/capitalization; i = average interest rate on debt.

Finally, the last component is the operating costs which include among others the following elements:

- Maintenance: repairs to plant, station equipment, transmission power, buildings and grounds, etc.
- Marketing and commercial: advertising, sale expenses, salaries and wages, directory expenses;
- Traffic: mainly operators wages in the handling of messages;
- Provision for pensions and other employees benefits;

- Accounting: salaries and wages of Accounting and Statistical Departments;
- Engineering: principally expenses incurred in connection with planning for plant additions and changes and for equipment design for customer requirements and special projects;
- Other expenses: general office salaries and expenses, operating rental and miscellaneous expenses.

Up to now, these operating costs are estimated by applying particular ratios to the asset costs.

4.2.2 Costing of services

We now come to a brief review of the costing procedures applied in the NTPPS model for costing the particular services. It can immediately be said that for a switched service, say the public message, any (marginal or average) cost is the summation of the costs in the switching network plus the costs in the transmission one⁽⁶⁾.

The computation of the supplementary switching cost is strongly related to the problem of dimensioning the switching network. By dimensioning we simply refer in this context to the process of estimating the necessary minimum size of switching facilities (in terms of switched trunks) to handle a given level of traffic respecting a minimum quality of service constraint at peaking conditions. Given two traffic demand configurations, D_1 and D_2 , one determines for each configuration the dimension of the switching network, using the C.C.S. rule (technique extensively used in the literature as well as in the industry). (This rule has already been explained in sub-section 4.1.2c)). Once this dimensioning is performed, by comparing the assets required for D_1 and D_2 , it is possible to obtain the change in investment required to move from one traffic configuration to another.

The computation of the supplementary transmission cost for a service is done as follows. First we use the asset valuation step functions (taken from the Costing Block) associate with the links in the transmission network and, depending of the types of costs we are interested in (say average or marginal, historical, current or prospective), some slopes are retained. These slopes are then introduced in the objective function in the allocation model as described in 4.1.2b). The transmission cost of a service is then calculated by running twice this allocation model; first, taking all the services into account and second, after eliminating the requirement constraints peculiar to the service under study. The difference between the values of the objective function, (i.e. the gain in terms of investment costs) will be the cost attributable to the service in question. This approach permits great flexibility in the sense, for example, that the costs coefficients can be revised before the second run is performed, and also avoids the very difficult problem of explicitly separating the facilities costs among the services according to their relative usage.

4.3 Sharing Block

The basic inputs consist of the pre-settlement gross operating revenues by stream of traffic, the facility usages and the facility costs. The output is the post-settlement revenues which are fed into the Accounting Block.

In Canada, revenue settlements occur in five cases:

- 1) Trans Canada Telecommunication System (TCTS) settlement. It applies to traffic originated and/or terminated in Canada and involving three or more carriers;
- 2) Adjacent members settlements;
- 3) Canada-United States settlement (TCTS versus ATT and CN-CP versus Western Union);
- 4) Teleglobe - CTO (Commonwealth Telecommunication Organization) settlement;
- 5) Teleglobe - Domestic carriers (TCTS and CN/CP) settlements.

For our experimental model, only three settlement schemes are retained:

- 1) The "Full Division Plan of Settlement" (TCTS): it starts by pooling all common system revenues; then each member receives from the pool an amount equal to the expenses it assigned to the provision of the revenue generating services. The balance of the pool revenues is shared according to the member's contribution in the provision of the service, this contribution being measured in terms of its share of the assigned plant value. Most separations during the cost assignment are made from relative use measures, and even the excess capacities are allocated.
- 2) The Old Commonwealth Scheme: it distributes the pooled revenues in the same proportion as the incurred expenses (operating expenses, depreciation and cost of capital).
- 3) The New Commonwealth Scheme: it equally divides the revenues of each stream between the terminal partners as well as the costs associated with the particular stream. Nodes and links unit costs are computed including capital and operating costs, then route unit costs are derived and stream costs are obtained by multiplying those route unit costs by the respective stream usages and summing for all routes of a stream. The carriers are terminal partners for certain streams and transit partners for others so that a kind of equilibrium is reached between the partners in sharing the revenues.

4.4 Accounting Block

The financial statements for each carrier, and possibly for all the carriers if desired, are the major outputs of the accounting block and also of the NTPPS model. These financial statements basically consist of the following:

- a) the Balance Sheet which consists of two main parts: assets and liabilities. The format specifically shows, in great details the changes that take place during the current year and, in consequence the situation of the carriers at the beginning of the year, the changes during the year and finally the situation at the end of the year of each carrier is printed.

b) the Income Statement which illustrates the operating revenues, operating expenses, other expenses, income taxes, debt service charges, extraordinary items and finally net income available for dividends and retained earnings.

c) the Sources and Uses of Funds Statement which shows how various funds are collected and from what sources. It also shows how these funds have been deployed, such as in gross construction expenditures, investments, miscellaneous and increase in working capital. It should be noted that the sources and uses of funds algebraically equal the changes to the Balance Sheet.

Moreover some financial ratios are also automatically computed. Among them, one can mention the debt/capital ratio, the common dividend pay-out ratio, and the ratio of return for equity components.

Essentially these financial statements and ratios are obtained by utilizing a simultaneous equation system approach, system which contains as relations the main accounting definitions. Among them, one can mention the following: net income, net income available for common equity, equity, realized earnings, long term debt, accumulated depreciation, gross telephone plant, capital cost allowance, current differed taxes, etc. Some of the variables used in the simultaneous equations system are exogeneously given (some being purely exogeneous and some coming from the other blocks): there are 74 variables in this category of variables; and, the system generates 43 endogeneous variables. It can be noticed first, that the program is so constructed that there is no constraint on the choice of the variables which will appear as exogeneous and second, that the result of a particular simulation is printed in a format similar to the published financial statements in order to facilitate the understanding among the regulating agents and the carriers, since the financial results are the main yardsticks in many regulation issues.

5. Experiments with the model

5.1 General considerations

The model is modular, therefore several blocks have been used separately, given their inputs coming from other parts of the model or coming from exogenous sources. For instance, if one is concerned by the composition in terms of origin-destination of the traffic carried during a given period on a particular switching link, the usage of switching network algorithm can be run. If somebody is looking for an allocation of circuits to satisfy a given increase for a private line requirement between two points, the transmission allocation algorithm can be used alone given a specified initial state. As a matter of fact, it is the Accounting Block which is used the more often independently for the analysis of the consequences of various financial sourcing strategies, the determination of revenue requirements and/or the analysis of the consequences of different rate levels when carrier's rate applications are submitted to the regulating agency.

5.2 The Maritimes region experiment

In order to test the model operationally in both its conceptual and software aspects, we tackled the problem of costing the "incremental" cost of private line service in the Maritimes region. It has been possible to test the logic of the model, prove out the software, test all the various linkages between the blocks and compare the results to known data. It was a sixty node switching network, down to level four in the hierarchy, with many high usage trunks. The transmission network gives rise to 172 nodes, 189 links, 215 demand requirements. Three objective functions were tested for the transmission allocation model (minimizing the circuit-miles, the total cost with average unit cost, the total cost with incremental unit cost). The computer cost of the experiment was around a few hundreds dollars, but the problem involves considering several hundreds of million dollars in diverse facilities. The Maritimes experiment has been very encouraging and it led to several improvements in the data base and in the logic.

5.3 The cross-subsidy among services.

Based on game theoretic approaches⁽⁷⁾, several tests have been run. All tests involve the computation of incremental costs of some sort for subsets of services under the hypothesis of sub-additivity for the total cost function. For instance, if $R(S)$ is the revenue from the set S in the best coalition N (the greatest coalition), and $C(A)$ the total cost of set A , the generalized incremental cost test is:

$$R(S) \geq C(N) - C(N - S), \text{ for all subsets } S \text{ of } N.$$

The theory does not specify how to compute $C(-)$; the regulating agencies can consider embedded, current and/or prospective costs. We made some computations with the embedded costs for public messages, private lines and program transmission; no cross-subsidy has been detected. Other scenarios are presently run; let mention the possible cross-subsidies between transit traffic versus regional and adjacent traffic and also, the cross-subsidies between the peak and off-peak consumers of the public.

6. Extensions and improvements

The encouraging results obtained with that rather big model permit to envisage several improvements and extensions.

1^o The data base should be ameliorated particularly on the circuits requirements side and on the cost side where multiplexing costs and metropolitan node costs should be ameliorated.

2^o A Demand Block showing the reaction to tariff changes would also be of great value, but it requires the access to the wealth of carrier's data.

3^o The size of problems capable of being treated is too small and software improvements should relax such a constraint, for instance a generalized upperbound method is quite advisable for the transmission allocation-expansion algorithm; also, when the networks reach a greater level of detail up to level 5 in the switching hierarchy - some decomposition devices are a must.

4° The prospective cost approaches will require a limit horizon multiperiod model which has been already outlined (some kind of branch and bound algorithm along time paths). Also the allocation-expansion model should be transformed in some kind of mixed-integer algorithm to account for major cost function jumps or for the introduction of new technologies. An operational model for one period marginal expansion is presently available but is not so far link with the present one. For more details about this model, see [1].

5° Finally a Policy Block could be dreamed of where the main trade-offs could orient the searching for satisfying solutions. This last undertaking should be conduct with regular confrontations with the carriers and provincial planners.

Notes

- (1) There is a lot of problems which can be discussed in relation with the equation(1). For an excellent summary, the reader is referred to Kahn, A. [3], chapter 2.
- (2) It is rather surprising that there has been little reconsideration of the fundamental principles of determining total revenue requirements. But "the reconsideration of basic principles has been directed primary at rate structures, the conception being that if particular rates could be brought more closely into conformity with incumental costs, the purposes of economizing and of damping the upward spiral of costs and rates could be achieved". See Kahn, A. and Zielinski, C. in [4].
- (3) At a regular repeater, the microwave signal is simply received, amplified and retransmitted. These repeaters occur, on average, every 25 or 30 miles troughout the network.
- (4) At a branching or junction repeater, long-haul signals are received and then retransmitted in several directions.
- (5) At a terminal repeater, all signals are demodulated (or modulated for outgoing signals) and demultiplexed to the voice band. This type of installation is normally located in a large metropolitan node and is usually linked to a long-haul (toll) switching of office.
- (6) This approach cannot calculate some trade-offs between switching and transmission costs.
- (7) See, for example Faulhaber, G. [2]; also Loehman, F. and Whinston, A. [5].

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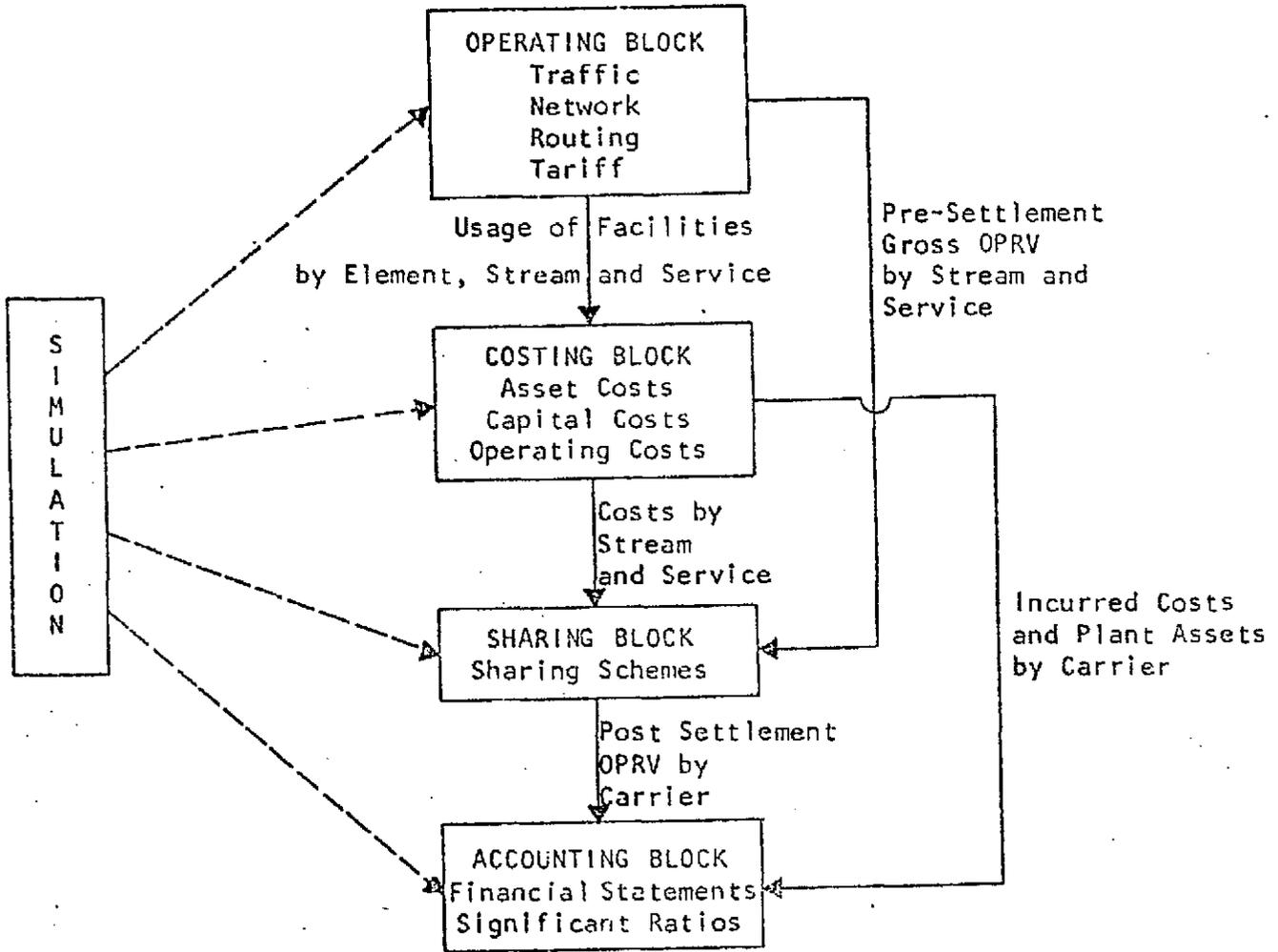
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A NATIONAL TELECOMMUNICATIONS PLANNING

AND POLICY SIMULATION MODEL

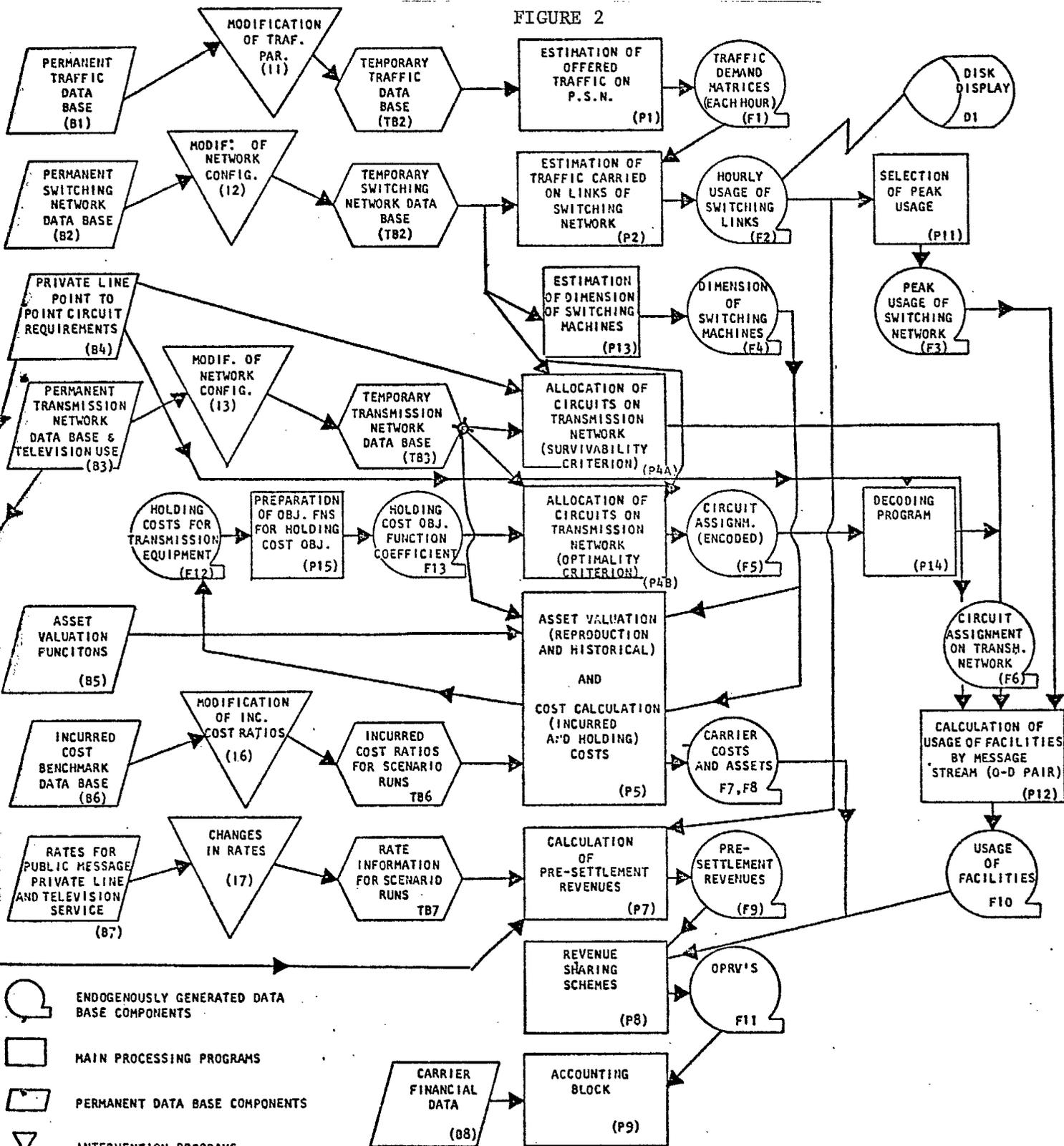
CONCEPTUAL STRUCTURE

FIGURE 1



**NTPPS MODEL
SYSTEM FLOWCHART**

FIGURE 2



Note: ADDITIONAL DECISION POINTS OCCUR IN P4B, P5, P8 and P9 WHERE THE USER MAY SELECT THE PROCESS DESIRED

OPERATING BLOCK FLOWCHART

FIGURE 3

