FORECASTING AND MODELLING OF RADIO SPECTRUM ALLOCATION[1]

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Introduction

This report contains the results of a pilot study, carried out for the Department of Communication, Economic Analysis Branch, on the possibility and desireability of developing a model to assist in the formulation of spectrum policy. The study had two aims:

a) To conceptualize the policy formulation problems in terms which identify the scope and importance of the problem to the Department of Communications, and which identify the data needed to approach the problem, and

b) To assess the potential value of some of the techniques of systems analysis in the policy formulation problem.

This report is in three sections: a formulation and conceptualization of the problem of spectrum allocation; a description of those data which are required for spectrum policy analysis and of those which are available; and a discussion of alternative forms of models for policy analysis. The report concludes with some recommendations for future

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activity on the problem. This is a pilot study, so any conclusions are preliminary and subject to further exploration and analysis and to validation when data become available. A major concern in the work reported herein is the impact of technology on the utilization of the radio spectrum, because technological developments are likely to be of increasing importance.

For the sake of specificity, this report focusses on the task of allocating spectrum for use in land mobile communications, although it is recognized that all decisions regarding allocation of parts of the electro-magnetic spectrum are interdependent. The allocation of part of the spectrum to a class of users affects all other current and potential future users, although frequently in an indirect and sometimes remote way. It should also be noted at the out-set that, although it might be desireable, perhaps even in some sense optimal, to completely reallocate the entire available spectrum on the basis of detailed analysis and careful costing, this sort of action is impossible. There are so many rigidities present because of the large investments in production facilities and equipment in use that any major change in allocations of spectrum could have disastrous effects. Any new policies must produce gradual change tied to, or at least in step with, new technological innovations.

The Spectrum Allocation Problem

The radio spectrum, as a valuable and limited resource, must be allocated among competing uses and users on the basis of governmental policies. These policies must be developed and evaluated in a climate of explosive growth in some areas of the user group, at a time when technological change can have very significant impact on the users and the types of use of the spectrum and in explicit cognizance of loosely defined social goals, changing international agreements and the fundamental fact that any user has the potential through interference to devalue the resource for other users.

A number of groups (largely industrial) in Canada and the United States of America have made forecasts which lead to the conclusion that serious over-crowding of parts of the spectrum, especially in large urban areas, is imminent. These forecasts are very simplistic, typically based on projections of historical growth rates in sales and on population projections. Important aspects of the problem such as market and technological effects are left out of most of these models, but the fundamental issues are clear and the conclusions are essentially valid. The main purpose of this study is to discuss the feasibility of modelling the policy formulation and analysis process so that reasonable and effective responses to these problems may be formulated.

The problem is important, not only because over-crowding of the radio spectrum leads to interference and inconvenience for some users, but also because of the very significant contribution which widespread use of mobile communications can make to society and to the economy. Land mobile radio, used commercially, can substitute efficiently for capital and for labour and can lead to reduced costs and increased responsiveness to consumer demand. In the public sector emergency police and ambulance services depend heavily on mobile radio communications to carry out their duties effectively. Steady growth in these services as well as the development and expansion of services such as mobile telephone, automatic vehicle monitoring, paging, automatic beacons and general radio service will contribute to the growing pressure to revise allocation policies.

Data Requirements

The central role of spectrum policy analysts consists of anticipating and solving problems of increasing demand for portions of a limited resource. This task is very complex because it involves consideration of social, political, economic and technological factors, many of which are not readily quantifiable. However, the task of the body charged with making the allocation decisions can certainly be assisted by reliable hard data. The data which are most useful in the ultimate model can, of course, only be determined after a class of models has been selected and the important variables estimated. It is necessary to postulate as many variables as possible, to collect reliable data on these variables and finally to assess their utility in the context of the type of model ultimately constructed.

Those variables which should be considered as a minimal set can be classified into five groups: demographic, economic, social, technological and spectrum useage variables. Demographic variables are needed to characterize the age distribution, income distribution and locational distribution of the population. These variables will be useful in assessing the contribution of population changes, rural/urban differences and age to the utilization of radio spectrum. Economic variables should include equipment costs, measures of substitutability among alternatives (such as CATV for broadcast TV), measures of utility for various types of service to various users, national economic indicators and regional economic indicators. Social variables which may be useful as predictors would include measures of population mobility and indicators of social conditions. The latter variables may be even more useful than economic variables if lead/lag relationships with economic activity can be established. Technological data should include technological forecasts of possible new developments, together with estimates of time spans for implementation. Finally, spectrum useage data, which are clearly very important, should relate to numbers of users per channel, numbers of channels per megahertz and the frequency and duration of transmission by licence holders. It would also be very useful to have estimate of the numbers of unlicensed sets in operation. This variable could be crudely estimated by comparing numbers of units produced by all manufacturers to numbers of licences issued and adjusting appropriately.

The above list of types of variables is long, but it is still not exhaustive. We must recognize that an important goal in modelling should be parsimony. The final model should have as few variables as possible, consistent with the generation of behaviour in the model which is faithful to the observed behaviour in the actual system. The choice, from among all possible variables, of those variables to be used in the analysis, must await a detailed study using actual data and the methodology to be proposed. Such a study will eliminate those variables for which the cost of collection is too large relative to their contribution to the model.

Data Availability

A number of demographic, social, and economic variables are available in the publications of Statistics Canada, although they are not always timely, and the frequency of computation of some measures is unsuitable. Because the rapid growth in land mobile radio is a relatively recent phenomenon, it will almost certainly be necessary to look at monthly data in order to have series which are long enough to establish trends. It may be necessary to disaggregate some of the series, with all the attendent problems. Some of the variables, such as equipment costs, will have to be sought from industry sources such as Electronic Industries Association of Canada or the American counterparts. It is, however, unlikely that these industry groups have data in sufficient quantity, at a sufficient level of detail and quality, and available for public consumption. One must anticipate that much of the interesting data (for example, future technological plans) will be considered secret.

Data on technological futures might have to be collected de novo by means of personal interview or by use of a Delphi study. Some data can be gleaned from the testimony of the carriers at regulatory hearings, in Canada and in the United States of America, but these business plans must be treated with requisite scepticism. It may be that some data can be constructed by analogy with similar phenomena, or the same phenomenon in other countries. It is clear, for example, that the countries of Western Europe have faced the problems of spectrum crowding and are making efforts to solve them.

Spectrum useage data and World data should be available from the Department of Communications, but, as has been persuasively argued[1,2] prior to and during the work of the S.M.S., this is not the case. The major sources of data are, D.F.L., I.R.L.S., F.C.C. and I.R.A.C. and, although these files are adequate for the frequency assignment and licensing functions for which they were designed, they are inadequate for analysis of spectrum policy options. The structure of the data files, their lack of accuracy and completeness, and the fact that some vital elements are missing, makes these files unsuitable. These problems have been well recognized within D.O.C. and it is hoped that the new S.M.S. will provide data in useable form. The proposed Spectrum Surveillance System, which

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1. Data and Statistics for Spectrum Policy Purposes, an internal working paper by G.R. Begley, March 12, 1976; D.O.C.

2. Identification and Analysis of Data Items for Assignment Licensing of the Spectrum Management System, Spectrum Management System task force, internal report, December 1975, D.O.C.

will provide land mobile channel loading information will be an important part of the S.M.S.. Until the S.M.S. project Master database is fully operational, data will have to be obtained from the existent files, with careful attention being paid to the shortcomings. On a regional basis it may be desireable to access the databanks maintained in the Regions, to obtain timely data.

Methodological Options

In all phases of government there has been an ongoing search for systems of improving the general welfare through better decision making. The only solution which has been found has been to select the wisest possible human judges or commissioners to make the decisions. The problems are too complex and the various "publics" to be served have interests which are too divergent and often conflicting to base the decisions on other than human judgement. However, such judgement processes can be augmented and assisted by careful analysis. A report in 1970 to the United States Director of Telecommunications Management by the Committee on Telecommunications of the National Academy of Engineering[3] suggests that there are four areas in which it is practical to improve spectrum management:

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3. The Application of Social and Economic Value to Spectrum Management. Final Report to the Director of Telecommunications Management under contract OEP-SE-69-101, June 1970, pp. 2,3.

1) Enrich the processes of judgement with social and economic evaluations of the impact of potential spectrum decisions.

2) Develop procedures whereby the interest and counsel of other than adversaries in particular spectrum management issues could be brought into the total process of evaluation.

3) Be concerned for balance and diversity in background of training and experience among the judges, and

4) Stimulate and encourage further research into procedures for evaluating technical, economic and social factors.

The present work can be viewed as a response to the need expressed in (4) and a specific attempt at the task set out in (1) above.

The problem of spectrum allocation policy can be viewed simplisticly as one of forecasting future demand for licences in a number of categories of service and a number of geographic regions, forecasting the amount of available spectrum on the basis of existing licences and possible cancellations and then incorporating technological forecasts. These technological forecasts may involve substitution among existing and new technologies (and forecasts of the rate and extent of substitution), or development of new equipment,or the utilization of new methods of transmission of signals. An example of this latter phenomenon is CATV, which has the potential to essentially eliminate the broadcast of airborne television (and to some extent radio) signals, especially in congested urban areas.[4] There is also virtue in attempting to assess the extent to which technological innovation is largely a response to the problems of over-crowding of the spectrum, rather than the natural technical change in an industry

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4. George, D.A. Telecommunications Technology, in H. Edward English, ed. Telecommunications for Canada, Metheun, Toronto, 1973, pp. 257-300.

with a high level of technological expertise[5]. Technological innovation of the former type may be expected to be self limiting as new policies (and other breakthroughs) reduce the congestion, and this reduces the pressure to seek alternative solutions.

A further aspect is that technological innovation or spectrum allocation decisions may lead to significant changes in the utilization of the spectrum and in prompting further technological developments. A current example of this phenomenon involves the recent American decision[6] to reallocate spectrum from UHF television to land mobile in the 900 MHz band. This major decision was, to a large extent, made possible by the development of the cellular system whereby a large service area is broken up into small cells with automatic switching among cells as mobile users move from cell to cell. This decision will prompt more research and development into the cellular and alternative systems and will undoubtedly lead to better technologies, reduced costs and increased demand for services.

Some of the methodological tools which can be brought to bear on the present problem include: econometric modelling, scenario construction, simulation, sensitivity analysis and dynamic modelling. These approaches are not, of course mutually exclusive, nor are they exhaustive, and virtually

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5. An interesting aside in this regard is the fact, cited by Rose, J.C. in "Baby Dinosaur and Antitrust Policy", Communications, April 1976, that, after the famous Carterfone decision in the U.S.A. which permitted the attachment to telephones of equipment not supplied by the telephone companies, AT&T has introduced three new switchboards, each of which took approximately one year of Research and Development, whereas, prior to the decision, Research and Development time was almost six years.

6. F.C.C., Docket 18262, United States Federal Communications Commission.

all of them must rest on a solid basis of sound statistical data analysis. We will now briefly describe some of the characteristics of these approaches and their utility in the problem of spectrum allocation. It should be noted here that some researchers have argued that spectrum should be allocated as any marketable good; that is that governments take a purely economic approach and allow the marketplace to ration the good among potential customers using purely market mechanisms.[7] This concept is in direct opposition to the view that government should use public goods in ways which help to achieve social goals, and cannot be the sole basis of an allocation system. This does not preclude the right (perhaps even the responsibility) of government to price (via licence fees) the use of the spectrum in ways which reflect, to a greater or lesser degree, the value of the spectrum in the hands of the licensee nor to effect some rationing in this way. The point is, simply, that non-economic factors must also enter into the allocation decisions in non-trivial ways.

Econometric Modelling

The science of econometrics is based on the premise that changes in economic activity can be explained by a set of relationships among economic variables. These simultaneous equation models are useful for conceptualizing a set of hypothesized inter-relationships among the economic variables and for judging the extent to which these hypothese are supported by available data. They are not, however, very useful for incorporating

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7. An interesting sidelight here is the fact that, since spectrum use is not priced, the normal market process of reducing inefficient use of a scarce resource through a high price is not present.

non-economic data or qualitative variables, nor for assessing the impact on the important variables of allocation decisions. In the present context an econometric model of the amenable aspects of the subject system will permit the testing of some structural hypothesis about the demand/supply characteristics of the system which will have a bearing on the determination of which types of policies are likely to be effective.

Scenario Construction

Researchers interested in technology assessment and 'futures' studies make heavy use of scenarios. These scenarios can then be subjected to discussion and analysis by experts to search for consensus on possible economic and social impact. For example, a scenario might specify that, by the year 1985, "pocket-size, two-way, multi-channel transcievers with high service quality and range of 20 miles are widely available at $100. each". The analysis can then focus on the impact of this event on relevant social, economic, and political variables, and also assess the sequence of occurrences between the present and 1985 necessary to move to that point. These occurrences could include technological developments, financial investments and policy decisions in the public and private sectors.

A major difficulty in this approach lies in obtaining a reasonable consensus on possible scenarios. The Delphi approach and modifications thereto[8] has found wide use in the development and partial assessment

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8. Pill, Juri, "The Delphi Method: Substance, context, a critique and an annotated bibliography," Socio Economic Planning Science, Vol. 5, 1971, pp. 57-71.

of scenarios. Delphi is a controversial methodology, not without very serious detractors[9], but it does hold promise in problems such as the present one.

Simulation Models

The role of simulation as a tool in the analysis of complex systems is well known. The principal benefit of a simulation model is that it permits the introduction of random events into the evaluation of the system. These events, such as the occurrence of a technological breakthrough in miniaturization or in switching, or in television hardware, can be caused to occur in the model and their effects observed. The virtue of a computerized simulation model is that large numbers of events can be simulated under various situations and with various assumptions regarding distribution of events and the nature of their impacts on the system, all without disturbing the actual system, and in greatly compressed time spans. Any method of evaluating policy alternatives must use some aspects of simulation modelling, if only because the actual system has so many complex inter-relationships which must be left out in order to have a model of workable size.

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9. Goodman, Joel M. "Delphi and the Law of Diminishing Returns," Technological Forecasting and Social Change 2, 1970, p. 225.

Sensitivity Analysis

We mention this topic here to emphasize its importance in the modelling of complex systems, and to indicate that it is, in fact, the principal means of formulating and evaluating policies. As we have indicated elsewhere[10], a carefully formulated and scientifically rigorous sensitivity analysis of a complex system can point up the kinds of policies which will be likely to yield desireable outcomes. This is an important task because of the counterintuitive behaviour of complex systems, as described by Forrester and his colleagues at M.I.T.. In his ground-breaking work[11], Forrester lists four reasonss that intuitively obvious "solutions" to complex problems are often seriously wrong: an attempt to relieve one set of symptoms may create a mode of system behaviour that also has unpleasant consequences; the attempt to produce short-term improvement often sets the stage for long-term degradation; the local goals of a part of the system often conflict with the objectives of the larger system; and finally, planners are often led to intervene at points in a system where little leverage exists and where effort and money have little effect. The object of sensitivity analysis on a complex model is to determine precisely what sorts of intervention will achieve desireable systems results, and further to assess the global effects of such interventions.

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10. West, E.N. Some Statistical Aspects of Sensitivity Analysis. Sixth Annual Pittsburgh Conference on Modelling and Simulation, Proceedings, 1975, pp. 1277-1281.

11. Forrester, Jay W. World Dynamics. Wright-Allen Press, Cambridge, Massachusetts, 1971.

A serious problem which arises in the context of sensitivity analysis and the evaluation of policy alternatives is the definition of systems response. It is desireable to have a response variable defined for the system so that the performance of the system after an intervention can be readily monitored. For the system currently under discussion, one could focus on an economic variable such as estimated total contribution to the Gross National Product which results under a possible allocation of spectrum. Conversely, it is possible to develop a measure which incorporates social benefits (such as wide access to the spectrum, moderate licence fees, efficient response of emergency services, etc.) as a response variable but the sensitivity analysis can then become very complicated. With respect to the details of sensitivity analysis, it suffices here to remark that the technique of crossed factorial experiments is a useful way to examine a wide range of possible values for the many variables which characterize the system.

Systems Dynamics

This approach to the modelling and analysis of complex systems arises out of the work at M.I.T. by Forrester, Meadows and their colleagues on the feedback-loop structure of systems and their consequent dynamic behaviour. The essential features of systems dynamics models are the feedback relationships which allow the modeller to adapt the structure of the model more closely to the sort of behaviour actually observed in complex systems, and the fact that they are designed to be iterated through time, presenting

discrete glimpses of the inter-relationships of the variables as they evolve. In the M.I.T. work, and most subsequent attempts in the same vein, researchers are studying problems faced by systems in which some of the crucial variables have been growing over time and appear to be approaching immutable limits; this is precisely one of the critical aspects of the present problem of allocation of the very limited available spectrum.
In the next section we present a preliminary formulation of a systems dynamics model of the land mobile spectrum demand system. As emphasized by Forrester in World Dynamics[12], model development must be a gradual, iterative procedure, with the model constantly subject to re-structuring as better insight is gained into the inter-relationships among the variables.

A Model for Analysis

The proposed model for the analysis of the impact of spectrum allocation policies employs a philosophy which can be characterized as cross-impact forecasting. This model incorporates cross-impact analysis and trend extrapolation in the medium of a systems dynamics simulation. The primary aim is to produce scenarios of alternative future trends which are simultaneously extrapolated on the basis of past data, and which interact with each other. There is an underlying assumption that any social system has a great deal of inertia, and thus the most likely future will lie close to a simple extrapolation of past trends of key variables. It is further implicit that any deviation of a variable from its historical trend

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12. Forrester, op. cit., pp. 15, 32.

will have an impact on other variables in the system. The purpose of the feedback (systems dynamics) model is to track all system trends as they are impacted by and react to changes in other trends. As will be seen, candidate new policies and technological events can be characterized by changes in historical trends and in cross-impacts among variables. In this preliminary exposition, we discuss briefly how trends may be extrapolated, give some ideas on the estimation of cross-impacts and devote considerable space to the dynamic modelling problem.

Enzer[13] has defined cross-impact analysis as: "...a generic name for a family of techniques that try to evaluate changes in likelihood of occurrence among an entire set of possible future events and trends in light of limited changes in probability for some of the items in that set." In the Enzer formulation, and in the present model, interaction are defined only for pairs of events or trends. Higher order cross-impacts pose very difficult conceptual and estimation problems. According to Helmer[14], the general situation can be described as a game composed of trends (time series data on key systems variables, e.g. G.N.P., demand) and events (unexpected occurrences such as technological breakthroughs, crises, major policy decisions) which cause trends to deviate from their naive projections. Between each pair of events or trends (or mixed event-trend pair) there is

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13. Enzer, S., Cross-Impact Techniques in Technology Assessment, Futures 4 (1) pp. 30-51, March 1972.

14. Helmer, H.O., Cross-Impact Gaming, Futures 4 (2) pp. 149-167, June 1972.

a cross-impact, which may be zero, of course. The situation may be described as in Table I.

Table I - Cross-Impact Matrix for Trend-Event System *

	T_1	T_2	T_n	E_1	E_2 . . .	E_m
T_1	—	$X_{T_1T_2}$ . . .	$X_{T_1T_n}$	$X_{T_1E_1}$	. . .	$X_{T_1E_m}$
T_2	$X_{T_2T_1}$	—	$X_{T_2T_n}$	$X_{T_2E_1}$	. . .	$X_{T_2E_m}$
⋮						
T_n		etc	—			
E_1				—		
E_2					—	
⋮						
E_m	$X_{E_mT_1}$	$X_{E_mT_2}$ . . .				—

* $T_1, T_2, \ldots, T_n$ are trends

$E_1, E_2, \ldots, E_m$ are events

$X_{T_iE_j}$ = cross-impact of trend T_i on event E_j.

Helmer categorizes the four kinds of cross-impacts possible in this context as[15]:

1) Trend-upon-trend cross-impacts: depend upon the difference of the trend from its initial projection multiplied by a constant and activated after a predetermined delay.

2) Event-upon-event cross-impacts: influence the odds of occurrence of the impacted events by a multiplicative factor and is activated after a time delay. Whether the impacting event occurs or does not occur, the impacted event has its odds of occurrence altered.

3) Event-upon-trend cross-impacts: cause a predetermined amount to be added to the trend if the event occurs, or subtracted from the trend if the event fails to occur. It is activated after a predetermined time delay.

4) Trend-upon-event cross-impacts: multiply odds of impacted event by an exponential term, $\exp(-\Delta T \cdot \text{constant})$, in which ΔT represents the deviation of the trend from its initially prescribed value at that time. The impact is activated after a predetermined delay.

In order to keep the initial model as simple as possible, we consider a system containing only trends and trend-trend impacts. The occurrence of surprises (events) can be incorporated later if the model appears to be unresponsive to changes in the trends of key variables. Figure I, which uses the system dynamics nomenclature, illustrates the feedback nature of the system, for the case of two trends.

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15. Helmer, H.O., op. cit. pp. 152-153.

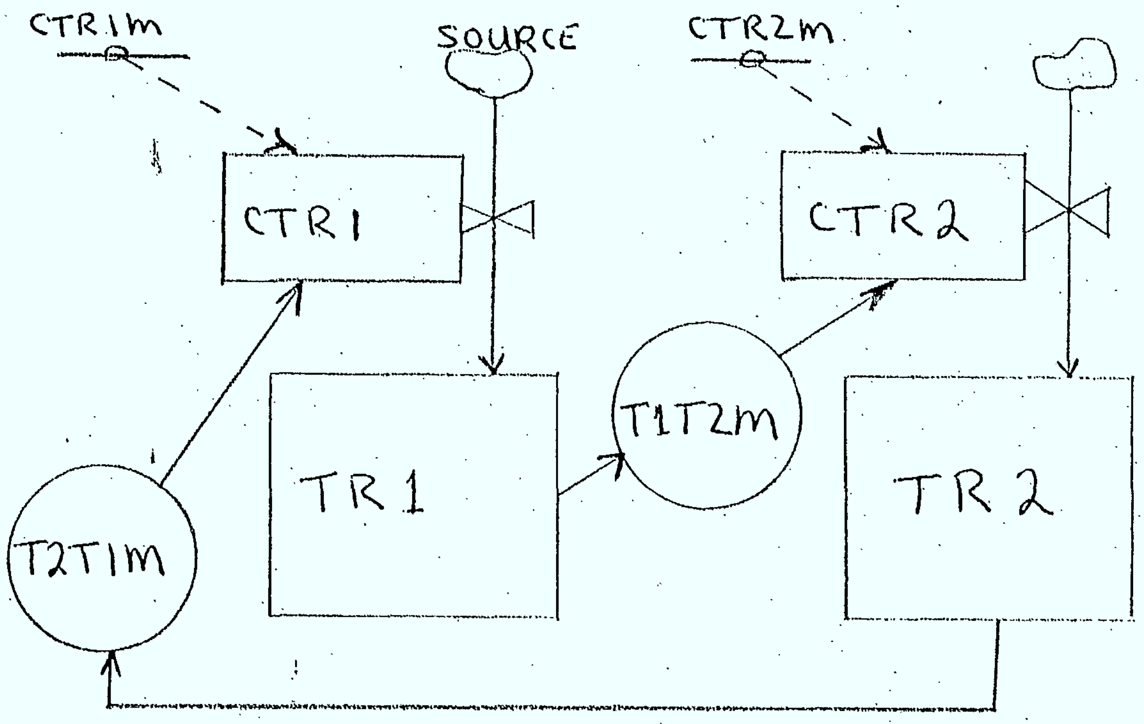

FIGURE I - Systems Dynamics Model of Trend-Trend Cross-Impact System.

As can be seen, there is a closed-loop feedback system: the current level of trend 1 (TR1) leads to a cross-impact (via T1T2m table) on CTR2, the control rate for trend 2 and leads to a new trend level (TR2), which, through table T2T1m (the cross-impact of trend 2 on trend 1) varies the rate of change of trend 1, leading to a new value of TR1, and so on. This system can then be simulated through time to forecast the likely behaviour of the relevant trend variables.

A major problem (and really the only one) in this methodology is the estimation of the values of the cross-impacts. In the systems dynamics formulation these are tabular(functional) relationships which describe how the impacted variable will react (in terms of changes in its normal rate of change) to a deviation of the impacting trend away from its naive extrapolated value. Concretely, the relationships may be described by two equations:

[Deviation in change in trend i over time period K to K + 1]	=	[Naive increments in trend i at time K]	X	[Cross-impact of trend i′ on trend i]

This deviation is then used to determine the level of trend at the end of period K:

[Trend i at the end of period K]	=	[Trend i at the beginning of period K]	+	[Change in trend i which occurred during period K = sum of naive increment plus deviation caused by cross-impact.]

or, in the DYNAMO notation used in systems dynamics simulations:

$$TRI \cdot K = TRI \cdot J + DT * CTRI \cdot JK \qquad (1)$$

$$CTRI \cdot KL = CTRIM * (TI'TIM \cdot K + 1 \cdot 0) \qquad (2)$$

In this notation we write a variable name (e.g. TRI - trend or CTRI - change in trend i) followed by a subscript (·K , ·J) with the convention that K is the current time period, J is the previous period, and L is the next time period. Thus ·JK refers to the interval just preceding the current instant, and ·KL refers to the coming interval.

The length of each interval is constant (DT time units) and rates are expressed in amounts per time unit. For example, G.N.P. may be forecast to change a number of dollars per day and a time period may be 365 days (DT = 365). The model can thus be incremented ahead one year at a time or using a smaller DT. The variable CTRIM is the naive per-period change in the value of the trend as time passes, and the table TI′TIM gives the cross-impact of trend I′ on trend I due to the deviation of trend I′ from its projected value in the time cycle ending at K. This assumption that the cross-impact depends only on the deviation of the impacting trend in the previous time cycle is not crucial. The cross-impacts can also be related to time, to some exogenous variable or to prior rates of change of the other trends. The cross-impacts are defined to lie in the interval (-1, 1) - one possible tabular function is shown in Figure II.

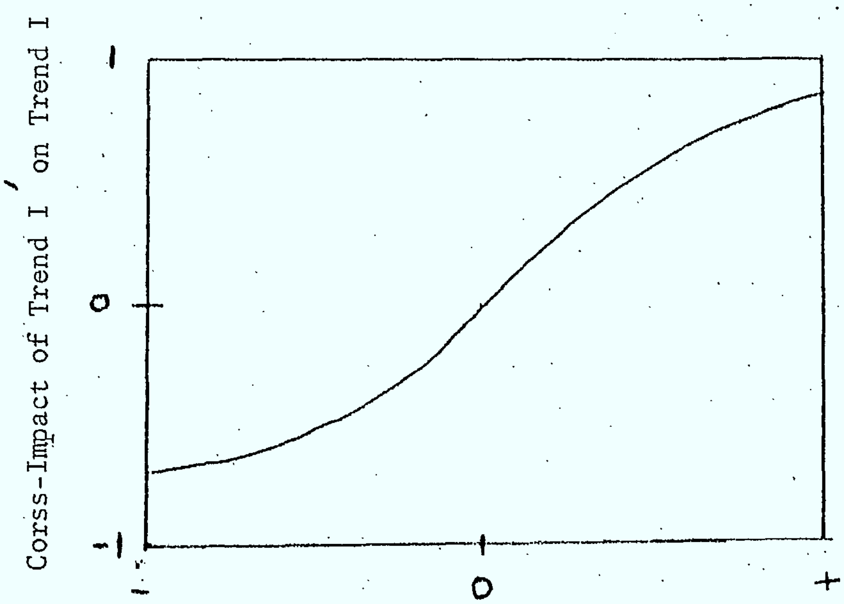

FIGURE II - Cross-Impact of Trend I′ on Trend I

This figure indicates, for example that if the impacting variable (I′) is above its naively projected value, then the impact on variable I will be positive. The tabular value lies between -1 and 1 so we can see from equation (2) above that the effect can range from total cancellation of the change in variable I (TI′TIM = -1 so the right hand side becomes 0) to a doubling of the projected rate of change in variable I. The no-impact case (TI′TIM = 0) applies the normal per-period change (CTRIM) to the current level of the trend.

Assuming that the naive projection of the trends can be carried out without difficulty, let us focus on the task of estimating the cross-impacts. This can be done in two ways. Firstly, a study of historical relationships by means of multiple regression can yield estimates of the impact of each of a set of trends on a given trend. This is an automated procedure and assumes that the cross-impacts will not change over time. Subjective judgement about likely changes could be incorporated into the resulting estimates to alter the shape of the tabular functions. The second approach is to obtain subjective estimates initially using a Delphi or Modified Delphi scheme. This scheme could be implemented by assembling a panel of experts to discuss which variables are likely to be important in analyzing the system. After a list had been prepared (and trends estimated) the cross-impacts could be estimated using the experts' responses to questions such as:

> "If the actual value of G.N.P. at some future time were 100 units below the projected value, what impact would that have on the projected level of demand for radio channels."

Respondents could be asked to estimate the strength of the cross-impact (none, weak, moderate, strong) and the direction (positive or negative) and, once consensus had been reached, these could be translated into numerical values. The well known techniques of estimating utility functions involving hypothetical lotteries would also be useful in the Delphi study.

After the trends and cross-impacts have been estimated and the systems dynamics model has been programmed in DYNAMO it is only necessary to initialize the trends and run the model. The output will consist of the time traces of the trends and can be plotted for rapid visual evaluation. The model can be used initially to obtain an unperturbed (surprise-free) view of the system to depict what will happen in the absence of policy intervention. After this baseline has been established, policies can be tested by applying them to the relevant trends at a chosen instant and then resuming the simulation. For example, the impact of a technological breakthrough could be assessed by intervening with an instantaneous jump in the technological change variable and then continuing the simulation. A policy decision which would reallocate a block of spectrum (as in the F.C.C. decision at 900 MHz) could be assessed by reducing the users per channel variable the appropriate amount and then allowing the simulation to proceed. Finally, a change in fee structure could be allowed to change the relevant economic variable before restarting the run. After each of these interventions the behaviour of the trend variables in successive time periods will permit evaluation of the likely behaviour of the system.

After a model has been built and calibrated it may be found to be relatively insensitive to reasonable changes (interventions) in the variables used above to test policy options. This stable behaviour may be caused by too small values of the cross-impacts used in the model, or may arise because the system itself has a great deal of inertia. In order to observe the sort of erratic behaviour which would normally follow a serious policy change (and so that actions can be chosen to reduce the wide fluctuations) it may prove useful to introduce some events (surprises) into the model, together with event-event and event-trend impacts. These events can be caused to occur (and to impact the system) in prechosen, random ways to simulate such things as technological breakthroughs or in deterministic fashion to simulate deliberate policy changes. This step of complicating the model by the incorporation of events should not be taken unless the nature of the trend variables and their associated cross-impacts lead to too highly deterministic a system.

Finally, as has been indicated above, technology can be incorporated in the model as a trend variable, measuring, for example, channels per MHz or users per channel and can then be allowed to impact on other variables and be impacted by them. Alternatively, it may be possible to develop a technological progress function[16] appropriate to the system and

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16. Fusfeld, A.R., Technological Progress Function: A New Technique for Forecasting, Technological Forecasting 1 (3), pp. 301-312, 1970.

to use it as a trend variable. This aspect requires further development. In this same veing the capacity to forecast the substitution of one technology for another will have to be developed and included in the model. Stern, Ayres and Shapanka[17] present an interesting case study and develop some useful methodology for forecasting the course of market penetration as a new product or technology competes with and gradually supplants an older one. This phenomenon is of importance in the present system and the methodology should be adapted.

Future Activity

The problem of allocation of radio spectrum for land mobile users is economically, socially and politically important and must be attacked with vigour. This report proposes the construction of a systems dynamics model incorporating elements of cross-impact analysis and trend forecasting. The next stage should be to conduct a Delphi study to determine a short list of variables for which trends can be projected on the basis of reasonably accurate data. This study should also seek consensus on relevant cross-impacts and on possible events for inclusion in the model. The model should be constructed and calibrated using a small number of variables having high reliability. Simultaneously, research should continue on the development of technological progress functions for the technology-driven aspects of the supply of radio spectrum and on the forecasting of

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17. Stern, M.O., Ayres, R.U., Shapanka, A., A Model for Forecasting the Substitution of one Technology for Another, Technological Forecasting and Social Change 7 (1), pp. 57-79, 1975.

substitution because this aspect will be important in evaluating the effects of technological change.

The available demand data should be examined to determine what level of aggregation is appropriate for the model. If there are significant regional effects, it will be necessary to construct a number of models. To the extent possible, the structure of these models should be the same, although, for example, the estimates of cross-impacts may vary widely. To assist in comparisons, models should, to the extent possible, use the same set of variables although different policies may be evaluated in the various regions.

Finally, it would seem desireable, although this pilot study has not considered the problem, to simulate the effects of de-regulation of part of the presently regulated system, in order to examine the likely impact of some of the current Provincial demands regarding CATV.

Summary

This pilot study has focussed on the problem of allocation of radio spectrum for land mobile users. We have formulated the problem in detail, discussed data required for an analysis of policy options, and described alternative methodologies for evaluating the impact of policy changes, especially considering the effects of technological change on the system. We have proposed a method of analysis based on trend cross-impact forecasting and have expounded in some depth the details of this novel approach.

Finally we have suggested what future activity follows naturally from this study. In our judgement the model proposed is feasible and potentially very valuable in generating and assessing policy options for amelioration of the problem of improved allocation of the radio spectrum.