交通誘發에 의한 地域開發 評價方法論

안승범(교통개발연구원 도시교통실)

Methodology for Evaluating Transportation-Induced Regional Development

Seungbum Ahn

Abstract

In this paper a modeling paradigm is described for answering the following questions: What would be the economic impact A, the social impact B, the demographic impact C, the land-use impact D, the environmental impact E and the user benefit F, over geographic scale G for a transport investment H at time T. The paradigm is illustrated for two ITS technologies: Advanced Transportation Management Systems (ATMS) and Advanced Vehicle Control Systems (AVCS).

Introduction

The total benefits and impacts that result from a transport improvement are never realized immediately. In other words, there is a stream of benefits flowing over time and the economic effects are not fully felt in the region until any production-marketing economies and cost savings resulting from the improvement manifest themselves in the forms of freight rates, pricing structure, land values, production levels, etc. Therefore, a subtle but important distinction exists between transportation user benefit and the nonuser economic impacts of a transport improvement.

Transport benefits accruing to road users, in terms of time savings, cost savings and savings due to accident reduction, are the primary effects of transportation improvements. These transportation user benefits are the main components of benefit-cost analysis, which provide a quantitative assessment of the relative benefits of different alternatives in terms of a common monetary measure. Nonuser economic impacts measure the secondary effects of capital expenditures on the regional economy. They affect income, employment, and production. An example of an user impact is the effect of a new highway on the amount of time that it takes to make certain trips. Nonuser impacts include such effects as increased employment opportunities and lower prices on goods for which transportation costs are reduced.

There has long been a recognition that efficient transport plays a key role in supporting a dynamic economy and a high quality of life. More attention is now focusing on how transport also affects key environmental resources such as air, water and land. Transport policy makers have always appreciated that, in addition to the economic benefits, transport imposes environmental costs. However, the situation confronting policy-makers today is somewhat different to that of the past, both in terms of the scale of the problem and its nature. To begin with, as income grows and population grows, so does traffic. Secondly, transport has taken on new dimensions because of modal shifts to aviation and automobile travel, both of which are environmentally intrusive. On the freight transport side, the increased dominance of trucking has emerged due to the nature of the goods transported and the increased sophistication of logistics and inventory management. Linked with the trends in both passenger and freight transport is the accelerated urbanization of societies which increases the number of people exposed to the environmental damage inflicted by transport [1].

A group of technologies known as Intelligent Transportation Systems (ITS) have the potential of improving safety, reducing congestion, enhancing mobility, minimizing environmental impact, saving energy, and promoting economic productivity in transport systems. If ITS is to succeed, a concerned society must be convinced that the huge investments will contribute to the solution and not exacerbate the problem. The purpose of this paper is to describe a paradigm for examining the broad links between transport infrastructure, economic benefits, and environmental costs, in general. The modeling paradigm is illustrated for two important ITS categories - Advanced Transportation Management Systems (ATMS) and Advanced Vehicle Control Systems (AVCS) - to show how ITS may contribute to "sustainable development."

Description of the Paradigm

There are many reasons why transport has become the lightening rod for the "sustainable development" debate. First, transport is an important contributor at the local, regional, national and global levels. Second, transport is perceived to be a major intruder in the environment. Third, transport interacts with many areas of activity which are seen as environmentally harmful. Fourth, transport has traditionally been a policy instrument of government with transport supply being manipulated to achieve such non transportation goals as equity and regional development, often at the expense of the environment.

There is a need for an environmentally friendly transport policy that is economically more efficient than those which have been predominant, or at least a policy in which socioeconomic development benefit outweighs the environmental cost as evaluated through rational, objective scientific analysis. This paper features a transport/sustainable development paradigm that can answer the following question: What would be the economic impact A, the social impact B, the demographic impact C, the land-use impact D, the environmental impact E, and the user benefit F, all summed over graphic scale G for a transport investment H on ITS technology I at time T?

The methodology starts with verbal descriptions of perceptions of the process. From these, key variables and their interactions are identified and displayed graphically in the form of "causal diagrams" (see Figs. 1 and 2). Using the causal diagrams mathematical models are developed. The first step, the verbal description, is very important in explaining the reasoning leading to a proposed policy and the consequences of that policy. The graphical display provides a gestalt for synthesizing the contributions of experts and specialists. The mathematical model provides an instrumentality that can be subject to manipulation and sensitivity analysis. By examining the sensitivities of hypothesized relationships, priorities for data collection for model calibration can be established.

While it is possible for experts to understand portions of the transport/economy/environment process fairly well, to synthesize these in a consistent manner without a formal technique is impossible. The process is composed of large numbers of variables spanning many disciplines; the variables are causally related closing on themselves to form higher-order feedback loops; the inputs are stochastic, the relationships are non-linear and there are delays and noise in the information channels--all these characteristics preclude predicting systems behavior by partitioning the problem along disciplinary lines and assembling the component solutions.

The proposed methodology uses all the relevant parameter classes employed in system dynamics--level variables, rate variables, auxiliary variables, supplementary variables and constants. The difference is that the geometric shapes--rectangles, valves, circles, etc. - used in system dynamics diagrams are unnecessary [2]. For example, in the causal diagramming convention used, a level variable is always at the tail of a solid arrow. The sign on the solid arrow tells us if the rate is added to or subtracted from the level or "state" variable. Whereas solid arrows denote physical flows, dashed arrows in the causal diagram define information flows from level variables to rates, or action, variables. Any intermediate variable on the path from a level variable, or from an exogenous input, to a rate variable is called an auxiliary variable. The signs on dashed arrows have the following interpretation: a + means that an increase in the parameter at the tail of the arrow will cause an increase in the parameter at the head of the arrow; a - means that an increase in the parameter at the tail of the arrow will cause a decrease in the parameter at the head of the arrow. Exogenous inputs are easily identified on a causal diagram since they have no arrows leading to them, but have one or more dashed arrows emanating from them. Supplementary variables, in contrast, do not form part of the system itself, but merely indicate its performance, and therefore are always identifiable as being at the head of a dashed arrow, and having no arrows emanating from them. In summarizing the causal diagramming convention: (1) the arrows describe the direction of causality between pairs of variables; (2) the lines (solid or dashed) denote (physical or information) flows; and (3) the signs tell us the nature of the relationship between a dependent-independent variable pair (direct or inverse).

The methodology utilizes the DYNAMO computer language associated with system dynamics. In difference equation terminology, any level variable L_i is expressed as functions of rate variables R_j and the previous value of the level

$$L_i\,(t+dt) = L_i\,(t) + (dt)\sum_{j=1}^{n} R_j\,(t) \qquad i=1,...m, \tag{1}$$

with the R_j's assumed to be constant over the interval from t to t+dt.

The rate variables are of the form

$$R_j\,(t) = F\,[L_i\,(t),\ E_k\,(t),\ A_{ij}\,(t),\ A_{kl}\,(t)] \tag{2}$$

where E_k are the set of exogenous inputs that affect R_j directly and A_{ij} and A_{kj} are the impacts of auxiliary variables in the causal streams from the ith variable and kth exogenous input, respectively. Since the exogenous inputs are known time functions or constants, if the initial values of the level variables are known, all other variables can be computed from them for that time. Then the new values of the level variables for the next point in time can be found from Eq. 1.

Transport/Economic/Environmental Linkages

The modeling paradigm introduced in this paper can be used to analyze infrastructure-induced development and its impact on the environment for any infrastructure system (water resource, transport, electric power, etc.) or combination of infrastructure investments for any geographic region (river valley, transportation corridor, metropolitan area, or country). The minimum number of sectors required to model the process is four: (1) an economic sector, (2) an infrastructure sector, (3) an environmental sector, and (4) a demographic sector. Depending on the nature of the study, it may be convenient to disaggragate the model so as to create a separate employment sector, social overhead sector, agriculture sector, rural sector, etc., for example.

Many of the sectors in the regional or national setting to be modeled can be considered as elements in a national account. The national accounts are concerned with the measure of aggregate output produced within the geographical boundary of a nation to gain a picture of the nation's economic performance. The most comprehensive measure of national output is the gross national product (GNP).

GNP is the value of all goods and services produced annually in a country. The "value-added" approach is used to avoid double-counting, i.e., to include only final goods and not the intermediate goods which are used to make the final goods. Expenditure components of GNP, which means a final use of GNP, include private consumption, private investment, government consumption, and net export.

For the purpose of national accounts analysis, GNP statistics are subdivided into nine major categories, which are mutually exclusive and collectively exhaustive, based on the International Standard Industrial Classification (ISIC). The description of the nine major categories are: 1 - Agriculture, Hunting, Forestry and Fishing; 2 - Mining and Quarrying; 3 - Manufacturing; 4 - Electricity, Gas and Water; 5 - Construction; 6 - Wholesale and Retail Trade, Restaurants, and Hotels; 7 - Transport, Storage, and Communication; 8 - Financing, Insurance, Real Estate, and Business Services; 9 - Community, Social and Personal Services. Using these categories, the economic sector of the model can be disaggregated into virtually hundreds of subsectors, if desired, each with its own capital-output ratio, capital-labor ratio and pollutants per unit of output.

Development indicators are incorporated in the model as measures of effectiveness. Simply speaking, the development indicators can be defined as the elements necessary to describe a nation's or region's future development profile over time. These development indicators are the focus of computer runs used to perform scenario analysis. Typical indicators outputed by computer model runs are population, labor force, jobs, unemployment rate, GNP or GRP, per capita income, infrastructure capital per capita, social overhead capital per capita, pollution ratio for principle pollutants, etc.

To illustrate the modeling paradigm, a hypothetical transportation corridor is selected as the region and two ITS categories, ATMS and AVCS are chosen as the infrastructure systems to help achieve sustainable development for the area. Elements of the model are presented in Figs. 1 and 2. Since the hypothetical study area is a region rather than a country, instead of Gross National Product (GNP), Gross Regional Product is appropriate for this example.

Framework for Measuring ITS Impacts

Three basic impacts of transportation investments are: (1) user benefits, (2) nonuser benefits and (3) environmental impacts. Fig. 3 shows a useful economic analysis framework for measuring ITS user benefits due to congestion reduction. It consists of conventional supply and demand curves for travel in a typical area corridor. The demand curve, D_0, and the supply curve, S_0, are intended to represent conditions without an ITS system. D_0 shows the volume of travel which would occur at any level of congestion, represented by travel time. The supply curve, S_0, shows the volume of traffic which the existing transportation can supply at any given travel time (level of congestion). The existing condition is the equilibrium between the D_0 and S_0 curves which occurs at their intersection (q_0, T_0) [3].

The equilibrium conditions for two ITS alternatives are shown in Fig. 3. For the ATMS alternative, it is assumed that there is no change in supply (capacity) and that congestion reduction is achieved by demand management through better signalization and ramp metering, use of HOV lanes, to increase average vehicle occupancy (AVO), improved public transit so as to reduce highway modal split (HMS), telecommunications to reduce trips per job (TPJ), and real time system status information to defer some trips to a later time which has the effect of increasing the duration of the peak period (DPP). The policy variables, AVO, HMS, TPJ and DPP, increase economic growth as shown by the causal chains in Fig. 2. This is a "nonuser" benefit which will be addressed later.

For the AVCS alternative selected to illustrate the modeling paradigm in this paper, we assume a highly sophisticated hybrid personal transport system capable of operating on existing streets using electrical energy and on specially constructed Automated Highway Systems (AHS) using magnetic levitation. This "Hybrid Personal Maglev" (HPM) system has been the subject of considerable research under a Research Center of Excellence Grant awarded to Virginia Tech by the Federal Highway Administration [4]. The AHS guideways (called "magways") provide full lateral and longitudinal control of vehicles at all speed regimes using magnetic levitation (see Fig. 4).

Returning to Fig. 3, the supply curve for the HPM - AVCS alternative is represented by S_a. Because the individual vehicles on the magway are operated at high speeds and small headways, the travel time T_a is independent of the volume, q, and the equilibrium condition is (q_a, T_a).

The user benefits for the two ITS alternatives are given by the cross-hatched areas on Fig. 3. The units for these areas are dollars per year obtained from the abscissa V and the ordinate P. The variables V and P are obtained from .q and T by converting from vehicles per hour to vehicles per year and analyzing the values of time, respectively.

The nonuser benefits for the two ITS alternatives are calculated by finding the changes in the Gross Regional Product (GRP) due to reductions in the demand capacity ratio (DCR). In the case of the ATMS alternative, the reduction in DCR is accomplished by reducing demand; in the case of the AVCS alternative, it is brought about by the increase in capacity. Following the causal chain in Fig. 1, a decrease in DCR decreases industrial transport costs which decrease the fraction of industrial output to inputs (FIOI) which increases the GRP.

The environmental impacts of the two proposed systems are illustrated in the portion of the modeling paradigm shown in Fig. 2. Through congestion reduction as measured by DCR, vehicle fuel consumption (VFC) and vehicle pollution generation rate (VPGR) are reduced. In addition, fuel efficiency (FE) is greatly increased for the AVCS alternative because the internal combustion engine is replaced by electricity -- battery generated for intracity trips on arterial streets and power-plant generated for intercity trips on the magways. Fig. 4 provides a far more comprehensive picture of the total impact of transport on the environment by showing how the transport system operates through the economic sector to increase industrial output (IO) which increases the industrial pollution generation rate (IPGR). Though congestion, production and emission problems are inter-related, transportation, industrial and environmental officials have seldom worked together on the same page in attacking these problems.

Summary/Conclusions

Sustainable development is an attempt to balance environmental preservation and economic growth; it is development that meets the needs of present generations without compromising the ability of future generations to meet their own needs. The sustainable development paradigm presented in this paper employs the system dynamics modeling methodology for assessing socioeconomic benefits and environmental costs quantitatively.

In the United States, the nation's infrastructure has become a steady theme of national debate. On the one hand, infrastructure is seen as an instrument of community and national development, a source for new jobs in a slow-growth economy, or an ingredient in restoring America's global competitive strength. On the other hand, infrastructure, in general, and transport, in particular, is perceived as a major intruder in the environment. The manufacture of the motor vehicle became the nation's largest industry. The spread of the use of private transport created its own type of low density residential area - a type that no other transport mode can efficiently serve - and a host of service industries. By changing people's living patterns and lifestyles, the automobile has made itself economically indispensable and an integral part of modern culture, but it has brought with it monumental problems of traffic congestion and atmospheric pollution.

More so than for any other mode, there is a need for an environmentally friendly highway transport policy that is economically more efficient than those which have been predominant, or at least a policy in which socioeconomic development benefit outweighs the environmental cost as evaluated through rational, objective scientific analysis. This desirable characteristic is illustrated in Fig. 5. Most technological developments have been growth friendly and environmentally insensitive. The environmental costs have been hidden. Also shown in Fig. 5 is the "do-nothing" negative public response to infrastruct development proposals typified by the growing vocabulary of terms such as NIMBY (not in my back yard). The third curve illustrates a sustainable development policy. The shaded areas illustrate the difference in nonuser benefits and difference in environmental costs between the economic and environmental oriented extremes.

The idea of Intelligent Transport systems (ITS) has been initiated to meet the rapidly growing concerns of congestion and environment. The advanced technologies promise to increase road capacity with improved traffic flow, improve highway safety and air quality, enhance the mobility of people and goods, and promote economic productivity in the country's transportation system. The technique of ATMS described in this paper has received a great deal of attention but its greatest appeal lies in its relative ease of implementation, low cost and low risk. Correspondingly, the benefits are equally modest.

Another alternative introduced in this paper is to apply automation techniques to vehicles and roadways under an evolutionary plan to dramatically increase the capacities of existing freeway corridors while retaining the advantages of personal transport mobility. This is the HPM concept described above. Theoretically, speeds of 400 km per hour and capacities of 30000 vehicles per hour can be realized on specially instrumented guideway (magways) built in existing freeway medians.

If the United States is to accommodate its population growth over the next 50 years, there must be a three-pronged attack: (1) rebuild and reorganize existing cities, (2) rationalize suburban growth and (3) build new cities beyond commuting distance of existing cities in conjunction with HPM guideway construction. An hexagonal arrangement has been adopted for urban areas based on our research [4]. Moreover, a modular structure is proposed in which self-contained urban units could be combined and added-to over time. The size of a module would range from 1 to 3 kilometers on a side so as to accommodate population of from 50,000 to 500,000 persons depending on the intensity of land use. The new cities would consist of various modules combined according to topographic and demographic conditions and would be located at guideway interchanges (see Fig. 6).

References

1. Banister, D. and Button, K.; "Environmental Policy and Transport: An Overview"; in "Transport, the Environment and Sustainable Development" Edited by Banister D. and Button, K.; Chapman and Hall; London; 1993.
2. Forrester, J. W.; "Principle of Systems"; The MIT Press; Cambridge, Mass. 1968.
3. Mobility 2000; "Intelligent Vehicle Highway Systems"; Texas Transportation Institute; College Station, Texas; 1990.
4. Drew, D. R., Trani, A. A. and Lee, S. H.; "An Assessment of Hybrid Personal Maglev"; Proceeding, 64th ITE Annual Meeting; Dallas, Texas; 1994.

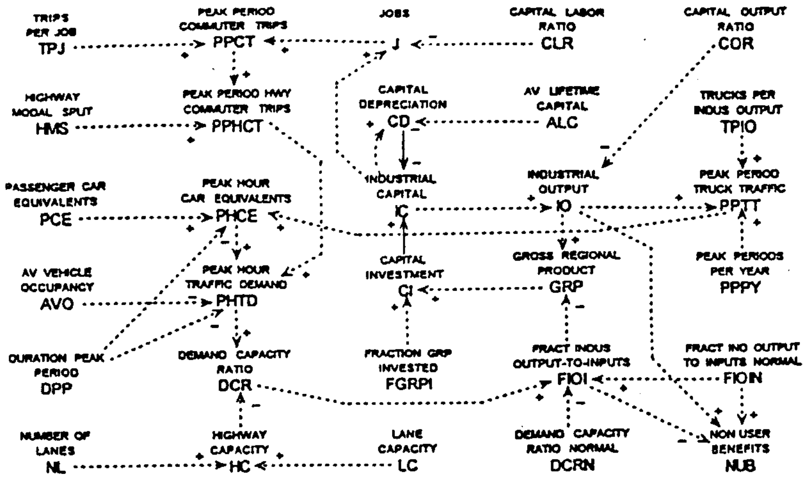

Fig. 1. ITS-Economic Development Relationships

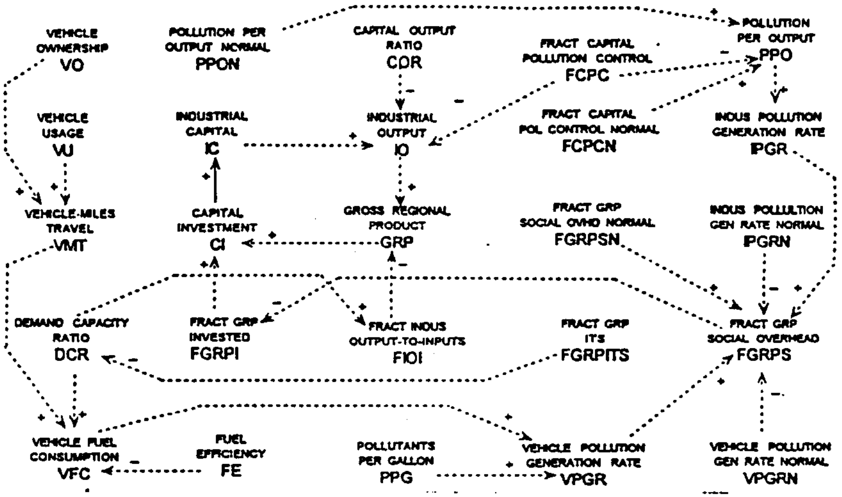

Fig. 2. Environmental-Economic Development Relationships

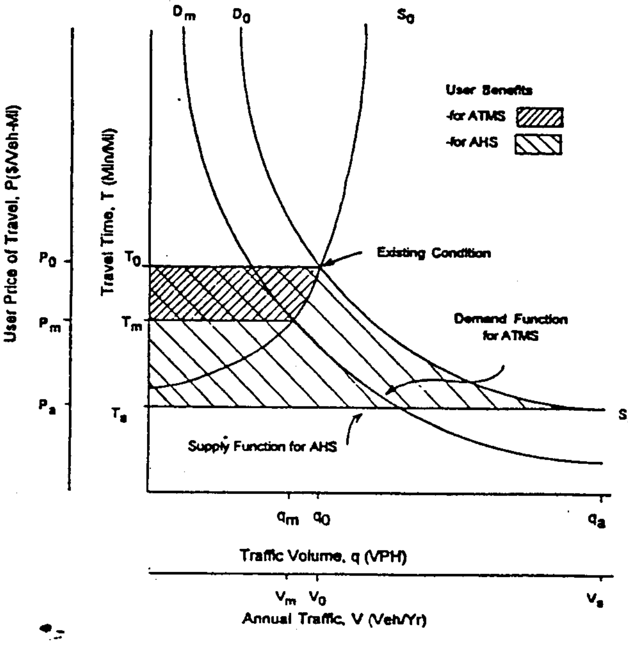

Fig. 3. Determination of User Benefits for ITS

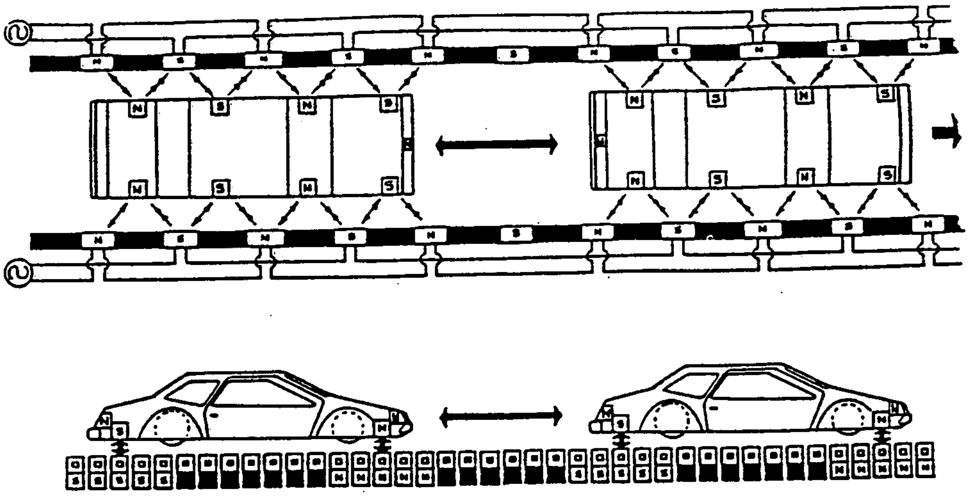

Fig. 4. HPM Levitation, Propulsion and Guidance

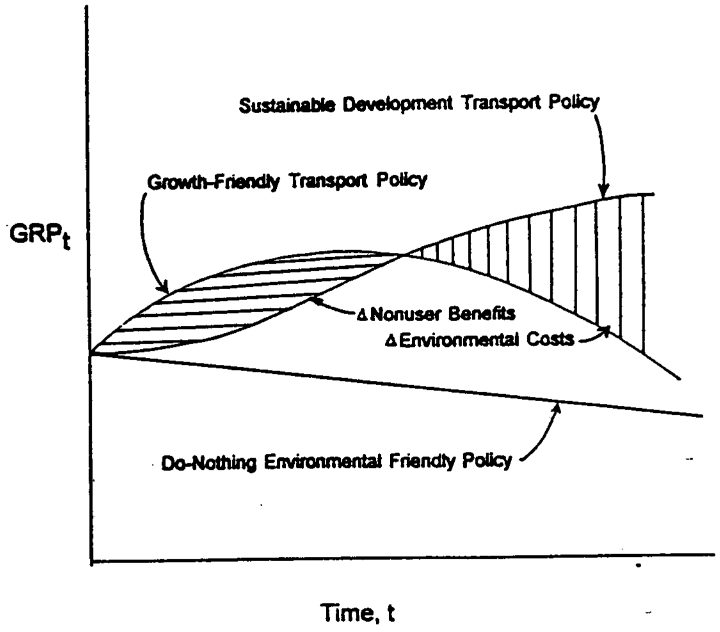

Fig. 5. Model Output Showing Nonuser Benefits and Environmental Costs

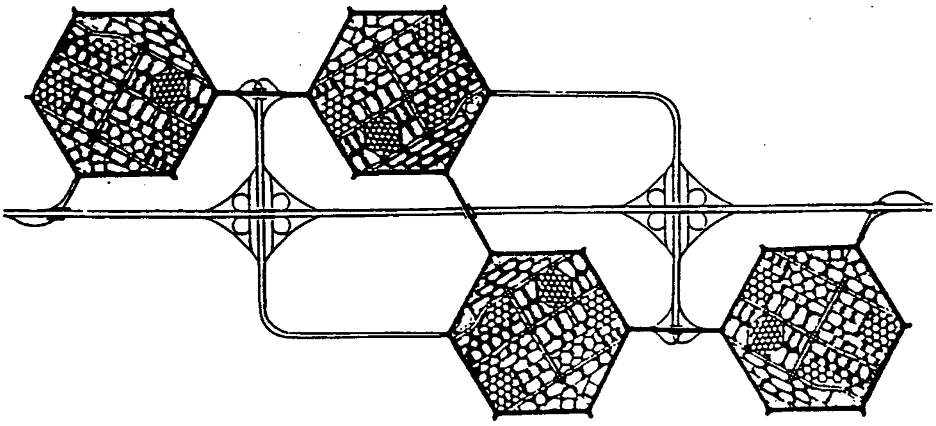

Fig. 6. AVCS Serving Medium Linear Metropolitan Area