

**A DYNAMIC ECONOMIC EVALUATION METHODOLOGY FOR TRANSPORTATION  
SYSTEMS PLANNING**

by

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(ABSTRACT)

The objective of this study is to set a methodology for transportation systems evaluation using an approach different than the traditional. The first part consist on a description of the transportation problem, the different concerns over the years and how transportation planning faced it. The second part explains the systems point of view, that considers problems as part of a bigger ones and relate them through causal relationships that make possible to incorporate social and environmental impacts to the model. Then a description of the traditional approach for transportation systems evaluation is given as a background for the dynamic economic evaluation that allows the planner to see the evolution of the parameters over time. The methodology is applied to a scenario where a new transporation facility is going to be built and the best of the alternatives should be selected. This study also emphasizes that the methodology is a tool for the decision-maker but it will never replace his judgment.

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The last paragraph of these acknowledgements is the most important one, the dedication of this thesis to my parents Greta and Pedro and to my brother Gustavo, with whom I lived 25 years of my life in Buenos Aires, and although they are physically far from me, I feel their presence very close.

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# 1.0 The Problem

## *1.1 Introduction*

Before starting to analyze the methodology of dynamic economic evaluation for transportation systems planning, it is very important to know why the researcher gets to the point where he needs to talk about the topic. He sees the world full of problems and through his knowledge in the way of mathematics, systems analysis, experience, etc., tries to define them, to understand them and, if possible, to solve them.

This chapter consist on a brief description of the transportation problems and concerns through the years, how transportation systems planning faces these problems, and how transportation systems evaluation helps to choose feasible, and the best, alternatives proposed in the planning process.

## ***1.2 Background***

During the first half of the present century, the concerns of transportation planning were only to save money for road construction and to decrease travel distances and cost of vehicle operation. In the 1950s the first urban transportation studies were done with a lot of emphasis on the technical side (data collection), and the main concerns were for the highway user: costs, congestion and accidents. In the 1960s, the *Highway Act of 1962* required comprehensive, coordinated and continuous transportation plans. Later, the topic of concern was mass transit. In the late 1960s and early 1970s the concern was for social and environmental aspects (oil crisis, citizen involvement, etc.). In the late 1970s with the drastic reduction of construction funds, great attention was given to transportation systems management, to give a better use of existing systems. Nowadays, the situation has not changed too much, the funds are still low, but there is a trend of giving to transportation a larger participation in economical development of urban and rural areas [1].

## ***1.3 Transportation Systems Planning Process***

A simple definition of transportation systems planning is that it is an estimation of future transportation patterns in relation to future population, economy and land use.

The basic information comes from every day activities of the population living in certain area. With the information of the present about type and intensity of development, the planner should be able to forecast the state of the development in the future. These projections can be done through land use models. Once they are performed it is necessary to determine the existing and future transportation needs. This is achieved by doing transportation demand studies, in the way of origin-destination surveys. With all the in-situ studies it is possible to develop analytical models. The one to be used in this study is the Urban Transportation Planning Process (UTPP).

The first step is the trip generation analysis, which determines the zonal trip ends. This analysis is done with statistical and mathematical tools such as regression analysis. Some examples of the relationship between land use and trip generation are shown in Fig. 1. With this information and the socio-economic characteristics of the population, trip end modal split analysis is performed to distinguish between choice riders and captive riders. Then, the trips generated for the two types of riders are distributed from each zone to all other zones, that is the trip distribution analysis. The last two steps, trip end modal split and trip distribution, can change in order, doing the trip distribution first and then determine choice and captive riders, as it was done in Chapter 4 of this study. The problem now is to know how many of the choice riders will select car and how many will select transit to their trips. The selection is based on behavioral models with generalized costs, that take into account money spent and time spent in the trip. This is the trip interchange modal split analysis. Having the number of trips by car and the number of trips by transit mode, the next step is to convert them to the number of cars and number of transit units to assign them to the transportation network. The criterion used is the same that a driver would use to choose among different alternate roads to go from one location to another, that is to go on the one that will take him in the minimum time and/or distance [2].

All this procedure is summarized in Fig. 2.

## ***1.4 Transportation Planning Evaluation***

After the transportation planning process is completed, there will be different alternatives to satisfy the transportation needs, going from the do-nothing alternative to the construction of a new facility alternative. Therefore, it is necessary to find a methodology that allows the analyst to evaluate the alternatives to determine if they are worthwhile and which one is the best of them. An important aspect is the point of view, or to whom the project should be worthwhile. In the literature, several arguments about different point of views can be found. Grant [3] argues that the

Land Use Classification	Measures of Intensity of Land Use Activities	Measures of Intensity of Trip Generation
Residential	Work Force (Persons) Population or Households Vehicle Ownership (Autos/ Household), etc.	Trip Origins, $O_i$
Industrial	Number of Jobs Industrial Land Area Industrial Capital (\$) Etc.	Trip Destinations, $D_j$
Commercial	Parking Spaces Sales (\$)	Trip Destinations, $D_j$
Recreational	Number of Hotel Rooms Number of Restaurants Seating Capacity (e.g. Stadium) Etc.	Trip Destinations, $D_j$

Figure 1. Relationship between Land Use and Trip Generation

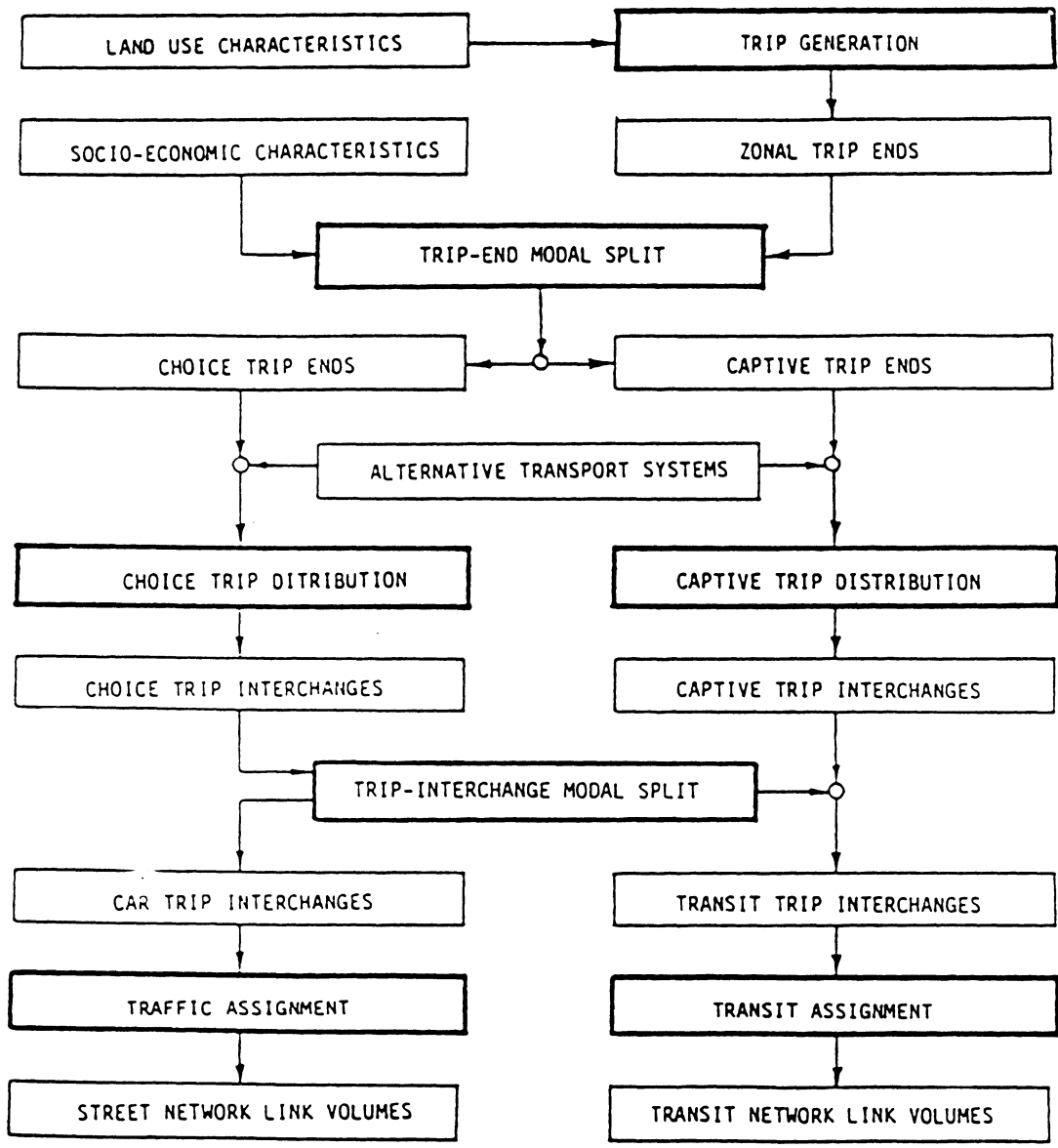


Figure 2. Urban Transportation Planning Process

economy of public works proposals "ideally, perhaps," should be considered from the point of view of all the people of the country. Kuhn [4] takes a stronger position to the same respect saying:

Any public body should, logically, adopt the viewpoint of the economy as a whole. The very term public (authority, or agency, or enterprise) implies responsibility extending over the community at large. Indeed, "promotion and protection of the public interest," or similar principles, are by law supposed to guide the conduct of public bodies. Perhaps even more compellingly, public enterprise agencies are creatures of legislatures and through them answerable to the community. Indeed, under common law all business is public; only an arbitrary distinction separates private and public business. The distinction is suspended when "private" businesses, such as power, gas, telephone and telegraph companies, are regulated "in the public interest." That public enterprise should adopt a public viewpoint appears, then, to be self evident. The point is salient: it has significant practical implications and invokes basic principles. It dictates that normally no costs or gains in public enterprise can be classified as external and disregarded.

An opposite position might be to consider the economic feasibility from the point of view of the ones that risk their funds in the project. Zettel [5], among others, supports that position noting:

The appropriate objective is to maximize benefits to the users who are called upon to finance the programme.... In some circumstances... it may be appropriate to seek contributions from the general treasury to finance that portion of the project which is justified on the grounds of general (rather than user) benefits

Therefore, with a fully self financed highway user tax financing program, only the user's point of view would appear to be relevant.

To know what factors should be consider in evaluation of public projects one must identified what factors are affected by the facility investment. It is known that improvements in the transportation network may cause changes in travel demand, the quality of the trip, capital, operation costs, etc. Taking into account all these consequences, costs and benefits can be categorized as in Fig. 3 [6].

As it is seen, according to the different points of view for the evaluation, it is difficult to satisfy all of them (users, authorities, environmentalists, economists, etc.).

---

**A. Potential Costs Associated with Transport System**

---

1. Facility construction and land acquisition costs
  2. Dislocation and other social costs
  3. Facility operation, maintenance and administration costs
  4. User travel costs, to include:
    - a. Vehicle ownership costs (excluding all fees and taxes levied to recover facility costs)
    - b. Vehicle operating and maintenance costs (excluding all tolls and taxes levied to recover facility costs)
    - c. Time costs
    - d. Discomfort costs
    - e. Inconvenience costs
  5. Accident costs (to include costs of injury to all persons and property involved in vehicular accidents)
  6. Terminal (parking) facilities costs
- 

**B. Potential Benefits Associated with Transport System**

---

1. User travel benefits, to include:
    - a. Perceived user travel benefits
    - b. Non-perceived user travel benefits
  2. Facility associated non-user revenues (such as concession revenues or property taxes)
  3. Intergovernmental transfers (in those cases where other than a broad national viewpoint is taken)
- 

Figure 3. Transport System Cost and Benefits for Public Projects

## *1.5 Goals and Objectives*

Before talking about goals and objectives, it is important to know that they are based on the values of the society. A value is an abstract element that is acquired through social learning. Examples are: freedom, dignity, amenity, economy, etc. Planners should have a big concern for the values of the society, because they lead to two major goals in urban development: (1) improvement of the quality of life of a city, and (2) strengthening of the metropolitan area in terms of production, allocation and use of the natural and human resources, democratic institutions to best advantage of the community. In transportation, there is the problem that sometimes the goals are not mutually supporting. For example to a problem of parking, a new facility might be built creating at the same time, problems of congestion in the surrounding area. As it is seen the values and goals are not measurable entities. Differently, an objective is a measurable end to be reached for a determined group of people, usually in a fixed amount of time. For example, decrease travel time in 10% in a period of 2 months [1]. Summarizing, transportation planning will try to achieve the two goals stated above through different objectives (e.g. improve quality of life by reducing travel time, vehicle running costs, air quality)

The objective of this study is to set a methodology for transportation systems evaluation trying to agree with the urban development goals mentioned above. There are two examples that show this methodology. The first one, Example 3.4/5 in Chapter 3, deals with the development plan of a new bedroom community close to a large city, which is the source of employment. The planned community (Suburbia) is situated across a bay from the large city (Metropolis). Therefore, if the project is going to be carried on, a bridge will be necessary to link Suburbia with Metropolis. The decision maker will have to consider two decision variables, the number of houses to build in Suburbia, and the number of traffic lanes in the bridge to be constructed. The objective of Example 3.4 consists on the determination of the physical feasibility of the project. The objective of Example 3.5 is to determine the number of houses and bridges lanes to make the project economically feasible and the to select the best alternative.

The second example, Chapter 4, consists on the selection of the number of freeway lanes for the construction of a new facility in the city of Asimopolis. Once the physical feasibility of the different alternatives of the project is determined, the objective of this problem is to choose the best alternative, according not only to economic evaluation, but also to environmental and social evaluation.

## *1.6 Plan of Research*

The plan of research followed in this study to achieve the goals of the urban society comprises several aspects. The first one is the approach, that is the one of systems point of view, solving the problems as a whole, considering all the relationships among the social, technological, economic and political aspects. Then, the methodology for evaluation has different parts. The first is the classical economic evaluation with parameters such as present worth, annual cost, rate of return, benefit-cost ratio. Then, the dynamic systems methodology is applied to the traditional approach incorporating user, environmental and socio-economic aspects, giving in this way more realism to the study.

This point of view, of considering the system as a whole with its relationships for evaluation is supported by Sassone and Schaffer [7] when they say:

A major problem in the appraisal of public projects has been the fragmentation of analyses into partial statements covering "economic", "social", and "environmental" impacts. Depending upon which influence groups are dominant, project analyses have included such impact statements in various degrees of completeness. We believe this fragmentation to be in error, and we feel that a properly defined cost-benefit analysis should be addressed to a review of all costs and all benefits. Nevertheless, we would be remiss if we did not at least note some of the special problems associated with social and environmental impacts.... We could say that economic impacts refer to effects on the "national economic development" objective, leading to changes in the output of goods and services and changes in the national economic efficiency. Social impacts are effects on the distribution of income as well as on the psychological, social and physical well-being of individuals affected by the project. Finally environmental impacts result in changes in our physical and biological surroundings as they are perceived to effect the quality of life.

The procedure followed in Example 3.4/5 was to build a model that includes all the variables that affect and that are affected by the development plan. Basically there two are sectors, housing and transportation, that are related through causal relationships. This is an application of the systems point of view, for a better understanding of the problem, and for seeing how the variables are interrelated. Then, the dynamic economic parameters are incorporated to the model to determine which is the best alternative in economic terms. This is done using the advantages of the systems approach that allows the decision maker to analyze all the aspects (housing and transportation, in this example) at the same time, getting better results than if the two variables were analyzed separately.

In the second example , Chapter 4, the problem is also faced with the systems point of view, and translating the Urban Transportation Planning Process (UTPP) into DYNAMO equations (see Chapter 2) allowing the planner to see behavior of the variables over time. The process starts with the data from the land use characteristics and population of the area, then several steps are performed, trip generation analysis, trip distribution analysis, modal split analysis, and network assignment analysis. An additional step is performed, the equilibrium check for the horizon year, that assures that the travel time assumed at the beginning of the process corresponds with the one obtained in the network assignment analysis. Once the physical feasibility of the project is determined, the dynamic evaluation is performed, incorporating all the necessary elements to the UTPP model. In this problem user costs, accident costs, environmental are also consider, besides construction, operations and maintenance costs, as it was done in Example 3.5.

Summarizing, the plan of research to achieve the goals of transportation systems planning, basically consist on the systems approach and the dynamic economic evaluation, that both strive to see the problem as a whole with different models interacting, and to see the evolution of the variables over the time , which allows the decision maker to be better prepared to assess his judgment when the time to of taking decisions arrives.

## 2.0 The Approach

### *2.1 Systems and the Systems Approach*

There are several definitions of a system. One may say that a system is an array of objects combined to achieve an objective according to a plan. Other definition that takes into account the synergetic effects of systems sets, that the whole is more than the individual components considered separately (idea of wholeness). It is important also to consider that the system is not isolated, it is immerse in the environment that encloses it completely and that includes things that affect and that are affected by it. Considering the system as an operational unit, it takes elements from the environment, input, and after process them, the transform elements, output, they go back to the environment. An important attribute of a system is its organization, which means its integrity and the relations among the elements of it.

The systems approach is based on looking at the total activity, project, design or system rather than considering the efficiency of the component tasks independently. It is a set of scientific approaches to conceptualize and solve problems through research, design and analysis. Design consists on finding the system which from a given input will produce the required output. Research and analysis deal with the discovery of laws effecting the transformation from inputs to outputs.

An important feature of the systems approach is the emphasis on the multidisciplinary team to face the problems, bringing together those who command the sophisticated techniques and those who have the expertise in the fields of engineering, economics, planning and management.

For solving problems, the traditional approach is analytic which means to break down the problem in smaller problems, solve them, and then assemble the solutions. The systems approach is rather synthetic which means to consider the problem as part of a larger problem and analyze it within its context. A good example of these different approaches is the analysis of the urban transportation problem as consisting in two separate parts, (1) private transportation problem, and (2) public transportation problem. Advances in solving the problem were achieved only when both were considered as part of a bigger problem.

The state of the system is an important concept in the systems approach. That refers to the value or nature of the system at certain time, that are usually studied in chronological order during a desired period of time. A system is stable when its values are within an acceptable range despite variation in its components. A system is unstable when its values go beyond the acceptable limits [8].

## *2.2 System Dynamics Modeling*

System dynamics is a methodology for analyzing the behavior of complex dynamic socio, technologic, economic and political (S-T-E-P) systems to show how system structure and the policies used in decision-making govern the behavior of the system. System dynamics modeling expresses in mathematical equations the structure of the system upon which policy acts.

System dynamics is based on decision making, feedback systems analysis, and simulation. Decision making refers to how action is to be taken. Feedback analysis refers to how information is to be used for decision making. Simulation refers to how the decision maker can see the implications of the decision over the future. In other words, system dynamics is a way to analyze

problems with variables that change over time, which allows the analyst to determine how the system responds to factors within the decision maker control like organization, system structure, and outside his control like random variations, seasonal fluctuations, etc.

The system dynamics modeling procedure is comprised by three sequences. Given a problem it starts with a verbal description of it, then it is translated to the causal diagram form that finally is expressed in the mathematical system equations. The model is subjected to criticism, corrected, analyzed again and so on in an iterative process [9].

## 2.3 Causal Diagramming

The main characteristic of system dynamics is that the dynamic tendencies of any complex system arise from its causal structure. Social needs, technological progress, economic constraints, physical limits, and political pressures make people to behave in the way they do and to generate the dynamic tendencies that govern the system. An important tool to express the cause and effect relationship is the causal diagram.

The first step to formulate a causal diagram is to identify the variables that best describe the model. These variables that come from the verbal description are arranged in a paper, and cause-effect relationships between pairs are depicted by arrows. For example, force causes acceleration,

FORCE  $\longrightarrow$  ACCELERATION

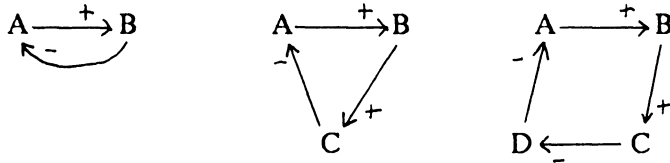
The next step is to assign a sign to the relationship whether it is direct or indirect. An increase in force causes an increase in acceleration,

FORCE  $\xrightarrow{+}$  ACCELERATION

Given a distance, an increase in speed causes a decrease in travel time,

SPEED  $\xrightarrow{-}$  TRAVEL TIME

A feedback loop is formed when two or more variables in a causal diagram close on themselves. The polarity is given the number of negative relationships, positive if even, negative if odd.



There are two principal types of variables: levels and rates. Levels represent the state of the system at a certain time. Rates represent the changes in the levels. If we a bank account as a system, the balance will be the level, and the deposits and withdraws will be the rates.

The effect of the rates on a level can be express in different ways:

causal diagram,  $RI \xrightarrow{+} L \xleftarrow{-} RO$

integral equation,  $L_t = L_{t-1} + \int_{t-1}^t (RI - RO)dt$

difference equation,  $L.K = L.J + (DT)(RI.JK - RO.JK)$

In the equations, past time is given by "t-1" and "J", present time is given by "t" and "K", and future time is given by "t + 1" and "L". DT is the solution interval.

For an easier identification of parameter types solid and dashed arrows are used in this way: level variables are at head of solid arrows, rate variables are at tail of solid arrows, all other variables are linked with dashed arrows in and out, except for the case of constant variables that have dashed going out only.

## 2.4 DYNAMO Equations

The word DYNAMO comes from DYNAMIC MODELS and is a computer language that compiles and executes system dynamics models. Level equations obtain levels at time K based on

levels at time J and rates over the interval JK. Rate equations are evaluated after level equations and determine rates that represent the actions that will be taken over the forthcoming interval KL. All the computation sequence is repeated at intervals of DT. The DYNAMO postscript convention is shown in Fig. 4.

A special DYNAMO function is the TABLE function that is used when a non-linear relationship between two variables is not easily expressed in a mathematical equation. Two statements are needed to formulate it:

```
A DEP.K = TABLE(TNAME,IND.K,XLOW,XHIGH,INC)
T TNAME = YLOW///YHIGH
```

where: A = auxiliary equation, T = table equation, DEP = dependent variable, IND = independent variable, XLOW = minimum value of the independent variable, XHIGH = maximum value of the independent variable, INC = increments between XLOW and XHIGH.

Other special DYNAMO function is the CLIP function, that is a conditional function similar to the IF function in Fortran,

```
A A.K = CLIP(B,C,D,E)
if D ≥ E , A.K = B
if D < E , A.K = C
```

## 2.4.1 First Order Positive Feedback

In a positive feedback loop, a variable feeds back on itself to reinforce its own growth or collapse (e.g. snow-ball effect). The DYNAMO equations are:

$$L \quad L.K = L.J + (DT)(RI.JK - RO.JK) \quad \{2.1\}$$

$$N \quad L = N \quad \{2.2\}$$

$$R \quad RI.KL = L.K \times F \quad \{2.3\}$$

$$C \quad F = .12 \quad \{2.4\}$$

TYPE OF EQUATION	TYPE OF VARIABLE			
	DEPENDENT	INDEPENDENT		
		LEVEL	RATE	AUXILIARY
L: LEVEL	.K	J	.JK	J
R: RATE	,KL	.K	.JK	.K
A: AUXILIARY	.K	.K	.JK	.K

**Figure 4. Summary of DYNAMO Postscript Convention**

$$R \quad RO.KL = .09 \tag{2.5}$$

The causal diagram, the figures of the rates over the level and the level over time are shown in Fig. 5. As it is seen in the graphs, the rate-in, RI, is a linear function of the level, L, and the rate out, RO, is independent of L with a constant value.

#### 2.4.1.1 Steady State Analysis

Steady state analysis means to equate the rates when the system is at equilibrium. The system is in equilibrium when the value of the level, L, does not change. In Eq. 2.1 to be true that  $L.K = L.J$ , should be,  $(RI.JK - RO.JK) = 0$ . Therefore,

$$RI_e = RO_e \tag{2.6}$$

$$L_e \times F = RO \quad , \quad L_e = RO/F \tag{2.7}$$

The value of  $L_e$  is found in Fig. 5 at the intersection of RI and RO and determines where the system is in stable equilibrium. If L is greater than  $L_e$ , L will continue to increase; if less, L will continue to decrease.

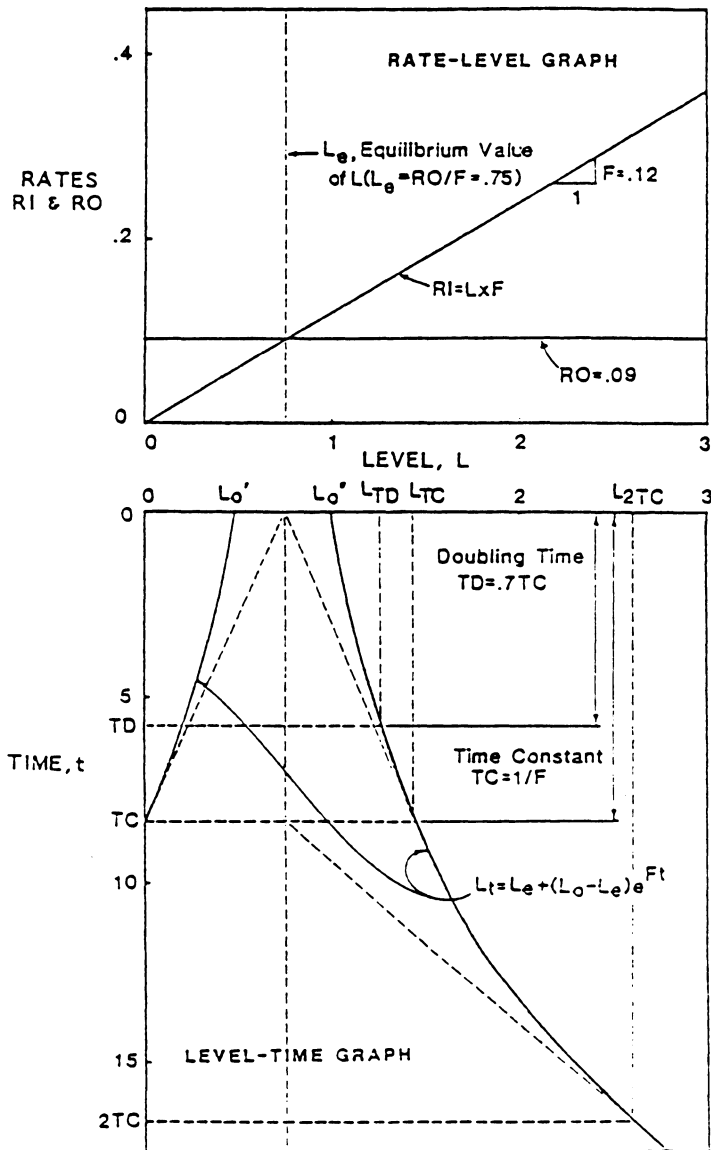
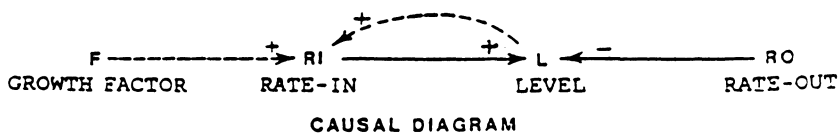


Figure 5. First-Order Positive Feedback Loops

### 2.4.1.2 Analysis of the Transient

From Eq. 2.1, the system can be analytically represented by a first order,

$$\frac{L.K - L.J}{DT} = RI.JK - RO \quad \{2.8\}$$

Converting Eq. 3.8 to the continuous subscript notation and applying the limit as dt approaches to 0,

$$\lim_{dt \rightarrow 0} \frac{L_t - L_{t-1}}{dt} = RI_t - RO \quad \{2.9\}$$

The left hand side is the derivative of the level variable with to time,

$$\frac{dL_t}{dt} = RI_t - RO \quad \{2.10\}$$

Substituting the rate-in for its value in function of the level,

$$\frac{dL_t}{dt} = L_t \times F - RO \quad \{2.11\}$$

Separating variables and integrating both sides,

$$\int_{L_0}^{L_t} \frac{dL_t}{L_t - RO/F} = \int_0^t F \cdot dt \quad \{2.12\}$$

Solving and interpolating the equilibrium value L

$$\ln(L_t - L_e) \Big|_{L_0}^{L_t} = F \cdot t \quad \{2.13\}$$

Applying limits of integration,

$$\frac{L_t - L_e}{L_0 - L_e} = e^{F.t} \quad \{2.14\}$$

The final solution is,

$$L_t = L_e + (L_0 - L_e)e^{F.t} \quad \{2.15\}$$

## 2.4.2 First Order Negative Feedback

A negative feedback acts to counter the direction of the initial trend in any of its variables. It is an equilibrium seeking behavior. The DYNAMO equations are:

$$L \quad L.K = L.J + (DT)(RI.JK - RO.JK) \quad \{2.16\}$$

$$N \quad L = N \quad \{2.17\}$$

$$R \quad RI.KL = D.K \times F \quad \{2.18\}$$

$$C \quad F = .10 \quad \{2.19\}$$

$$A \quad D.K = G - L.K \quad \{2.20\}$$

$$C \quad G = 25 \quad \{2.21\}$$

$$R \quad RO.KL = .4 \quad \{2.22\}$$

The causal diagram, the figures of the rates over the level and the level over time are shown in Fig. 6. As it is seen in the graphs, the rate-in, RI, is a linear function of the level, L, and the rate out, RO, is independent of L with a constant value.

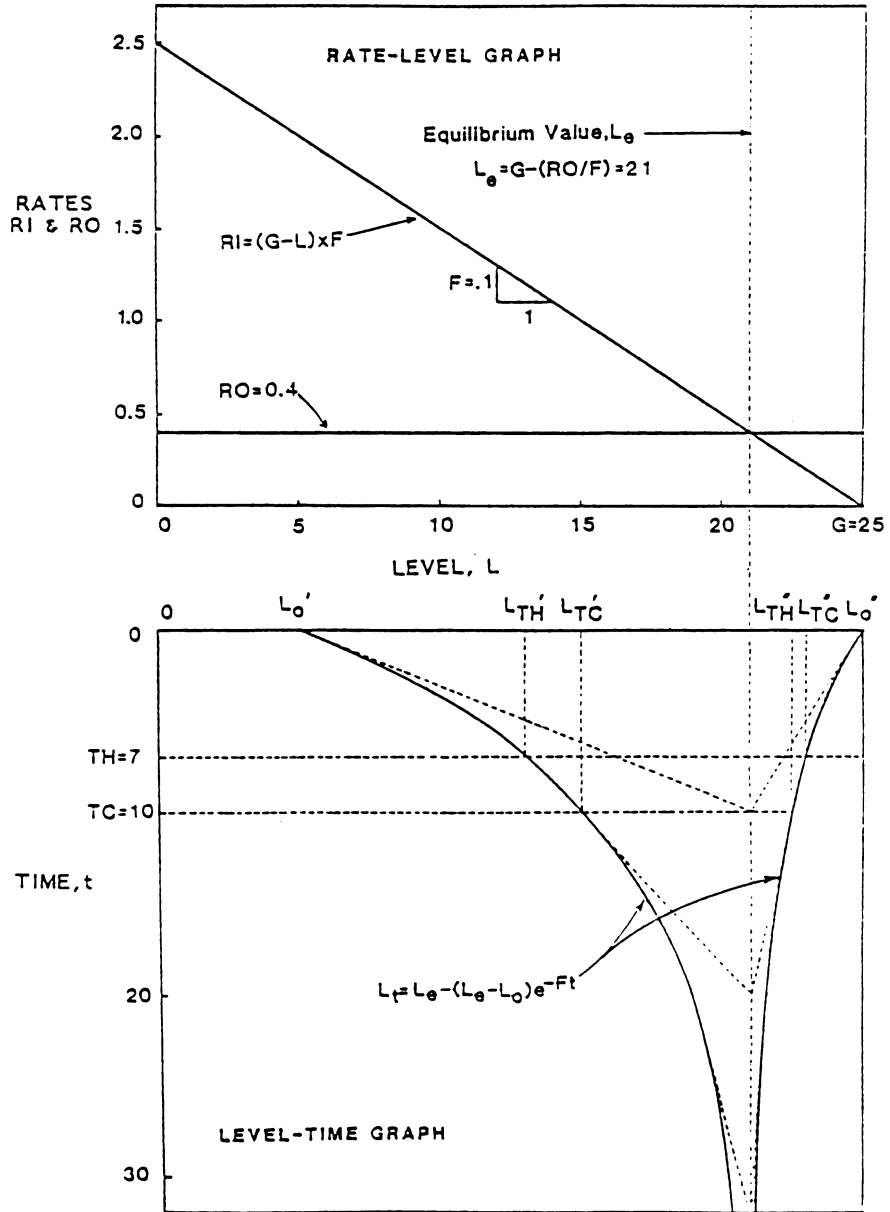
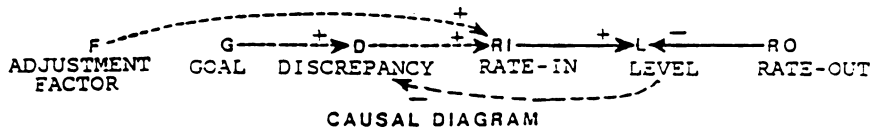


Figure 6. First-Order Negative Feedback Loops

### 2.4.2.1 Steady State Analysis

Steady state analysis means to equate the rates when the system is at equilibrium. The system is in equilibrium when the value of the level,  $L$ , does not change. In Eq. 2.15 to be true that  $L.K = L.J$ , should be,  $(RI.JK - RO.JK) = 0$ . Therefore,

$$RI_e = RO_e \quad \{2.23\}$$

$$(G - L_e) \times F = RO \quad , \quad L_e = G - RO/F \quad \{2.24\}$$

The value of  $L_e$  is found in Fig. 6 at the intersection of RI and RO and determines where the system is in stable equilibrium. If  $L$  is greater than  $L_e$ ,  $L$  will decrease trying to reach the equilibrium value: if less  $L$  will increase trying also to reach the equilibrium value  $L_e$ .

### 2.4.2.2 Analysis of the Transient

The procedure to analyze the transient is similar to the one used for the case of positive feedback loop,

$$\frac{dL_t}{dt} = F \times D.K - RO = F(G - L_t) = [(G - RO/F) - L_t] = (L_e - L_t) \times F \quad \{2.25\}$$

Separating variables and integrating both sides,

$$\int_{L_0}^{L_t} \frac{dL_t}{L_e - L_t} = \int_0^t F \cdot dt \quad \{2.26\}$$

Solving and interpolating the equilibrium value  $L$

$$- \ln(L_e - L_t) \Big|_{L_0}^{L_t} = F \cdot t \quad \{2.27\}$$

Applying limits of integration,

$$\frac{L_e - L_t}{L_e - L_0} = e^{-F.t} \quad \{2.28\}$$

The final solution is,

$$L_t = L_e - (L_0 - L_e)e^{-F.t} \quad \{2.29\}$$

## **3.0 The Methodology**

### ***3.1 Introduction***

Civil engineers are involved in planning, design, construction, operation and maintenance of infrastructure costing large amounts of money. Industry and government expect the civil engineer to report on the economical as well as on the physical aspects of his proposals. Because of the complex technological nature of civil engineered projects that makes difficult for non-engineers to perform even a purely economic evaluation, civil engineers must be capable to determine financial as well as physical and functional feasibility. While it is true, in many cases, that the final decisions regarding engineered systems will be made by administrators, very often these decisions will be based on facts supplied by the engineer.

Since there are many varied policies, programs and projects proposed for equally numerous and varied physical, social and environmental settings, the exact procedures to be followed in determining economic feasibility are neither simple nor straight forward. What is certain is that the civil engineers responsibility extends beyond the project level to the programs and policies from which the project stems of which it is a part.

Policies, programs and projects deservedly have different interpretations. Policies are broad, general guidelines for decision-making usually developed at higher levels of management and government. Programs are plans of action stemming from major ongoing long-range strategic choices of an organization. Projects are discrete components of programs, the more immediate, short-range, tactical, operational choices of an organization. It is important that the engineer understands this hierarchy if he is to perform rational infrastructure evaluation within a regional development context.

### *3.2 Techniques of Systems Evaluation*

Much semantic confusion surrounds the terms planning, analysis and evaluation. Planning is a process by which an organization decides upon the objectives, selects the methods to attain these objectives, and subsequently measures the degree to which its objectives have been achieved. Analysis is the systematic organization of information in useful ways, commonly to assist in making better informed decisions by examining the probable costs and consequences of alternative courses of action. Evaluation is that particular aspect of analysis which examines the degree to which current programs are achieving desired results, or future programs will accomplish future objectives. Some of the techniques for performing planning, analysis and evaluation are cost-effectiveness, cost-benefits and systems analysis -- concepts also subjected to arbitrary and vague interpretations. A "cost-effectiveness" analysis attempts to provide answers to two basic types of questions: (1) What are the costs of alternative methods of achieving equal effectiveness?; (2) What level of achievement of an objective can each alternative produce for a fixed cost? A "cost-benefit" analysis goes one step further. It is addressed to determine how much benefit to society can be expected to be produced by a certain expenditure on each of a number of alternatives or how much cost to produce a gain benefit. "Systems analysis" merely implies that the analyst consciously attempts to

view the problem in the broadest possible terms, recognizing the obvious fact that programs are very often interrelated.

Consider the following example that helps interpret and differentiate between systems evaluation techniques. Suppose analysis of manpower training program for unemployed blue-collar workers is being performed. One objective might be: "to reduce percent of unemployment among blue-collar workers". Alternatives might include institutional training programs, on-the-job training programs, day-release training programs, etc.. The analyst could attempt to estimate the percent reduction in unemployment that might be expected if \$1 million were spent in a particular alternative (cost-effectiveness). On the other hand, if he attempted to estimate how much additional income would be earned by graduates of the \$1 million training program, then he would be performing a cost-benefit analysis [10].

### ***3.3 Framework for Systems Evaluation***

Decision-making is the process employed for allocating scarce means to unlimited ends. The process contains two basic elements: (1) converting the ends into objectives, or quantified desired outputs, the can be measured or ranked, and (2) converting the scarce means into alternative sets of predictable outcomes, or output possibilities, that best correspond to the objective set. The principal difficulty in the decision-making process is the lack of correspondence between ends and means. For example, more miles of paved road (means) are not the same as greater speed and less congestion in moving among geographical points (ends).

Although somewhat arbitrary, the decision-making process is best defined in terms of eight elements: (1) recognition of a problem; (2) definition of the goal or objective ; (3) assembly of relevant data; (4) identification of feasible alternatives; (5) selection of the criterion for judging which is the best alternative; (6) construction of the interrelationships between the objective, alternatives, data, and the outcome; (7) prediction of the outcomes for each alternative; and (8)

choice of the best alternative to achieve the objective. In plain language, decision-making through systems evaluation is deciding what is the desired, how to measure this outcome, what it cost and how the cost is to be measured, what are the "rules of the game" (the constraints), whether or not externalities can be ignored, and how are time, risk and uncertainty to be treated. These will be discussed briefly.

The problem of stating explicitly the objectives of public understandings is no less perplexing than determining a way to define and measure social welfare. What we inevitably end up doing is trying to find measurable narrower proxies for welfare such as income or consumption. Once objectives have been established, it is desirable to determine what physical, legal, political, administrative and financial constraints might compromise achievement. Next, one must decide on the scope of the problem -- how it is to be delimited and what variables are to be included. The variables which are relevant to the decisions can be thought of as "internalities", as they are included within the model; other variables are "externalities" and while they may be outside of the control of the decision-maker, they may affect the success of the project. A good example of an externality over the past decade is the price of oil.

So far we have presumed that the world is timeless and risk free. First of all in a world of time, a dollar has a specific value only in a specific date. A dollar's value is a function of time. for the decision -maker the the first operational issue is to determine what different interest rates might make in any given decision. Even after taking time into consideration, the streams of dollar benefits and costs projected by the analyst are at best only expected values of random variables. While most observers agree that uncertainty needs to be hedged against, there is, in principle, no single uniformly accepted method for adjusting benefit and cost estimates [11].

### *3.4 Engineering Economics*

Historically, engineering education and practice has concerned itself more with the technological capabilities of physical systems and with the design, layout and construction of these physical systems than with the process of deciding whether any system should be built, and if so which system is the best. Increasingly, though, engineers are becoming familiar with and taking advantage of economics analysis techniques. These techniques aid the engineer in developing more creative designs and in the most efficient use of technological resource for social purposes. What is saved today is available tomorrow. In public works there is a strong obligation on the part of public officials to conserve resources and tax dollars because these officials, many of whom are civil engineers, act as the agents of the public [6].

Engineering economy studies are for the purpose of determining whether, or in what manner, an engineering project should be undertaken or modified, with the objective of obtaining the best utilization of available capital, taking into account all pertinent factors -- social, technical, economical and environmental. However, the general objective of economic studies is to permit the maximization of financial efficiency. Financial efficiency is a concept similar to the technical efficiency the engineer encounters in his quest for the most effective utilization of materials and/or energy, usually expressed as output divided by input. The ratio, as it is known, cannot exceed one in the case of engineering phenomena. However, when considering financial efficiency, dollars of income (output) divided by dollars invested (input), the ratio must be greater than unity in order for the undertaking to be feasible.

Most decision-making situations involve a number of courses of action or alternatives. Though each of these alternatives may be employed to realize the established goals, all of them may not be equally desirable. Quantitative methods of analysis for evaluating various courses of action are finding increasing use as aids in decision-making.

In this section the fundamentals of project and equipment evaluation, including time value of money, depreciation, criteria for the evaluation of alternatives, and economic life are going to be reviewed.

### 3.4.1 Time Value of Money

Both public and private sectors frequently face considerations regarding the time value of money. Such considerations are important because the present value of any enterprise depends on future dividends -- in the case of a firm, on future profits; in the case of a highway, on future benefits.

Three parameters that have been found useful in relating the value of money at different times, thus facilitating the comparison of alternatives on equivalent economic basis, are the following:

P = principal or present sum

A = amount invested at the end of each of n years

F = future value of single investment P or series of investments A at the end of n years

Assuming that interest is compounded annually at a rate r,

$$F = P(1 + r)^n = P[SPCAF] \quad \{3.1\}$$

where SPCAF is the single-payment compound-amount factor.

Solving for P, the present-worth of a future sum P gives:

$$P = F(1 + r)^{-n} = F[SPPWF] \quad \{3.2\}$$

where SPPWF is the single-payment present-worth factor.

If instead of single payment or investment a series of amounts A are deposited at the end of each interest period,

$$F = \sum_{i=0}^{n-1} A(1 + r)^i = A \left[ \frac{(1 + r)^n - 1}{r} \right] = A[EPSCAF] \quad \{3.3\}$$

where EPSCAF stands for the equal-payment series compound amount factor.

Solving Eq. 3.3 for A yields

$$A = F \left[ \frac{r}{(1+r)^n - 1} \right] = P[EPSSFF] \quad (3.4)$$

where EPSSFF is the equal-payment series sinking-fund factor.

Substituting Eq. 3.1 in Eq. 3.3 and then solving for A gives

$$A = P \left[ \frac{r(1+r)^n}{(1+r)^n - 1} \right] = P[EPSCRF] \quad (3.5)$$

with EPSCRF standing for the equal-payment series capital-recovery factor.

Solving Eq. 3.5 for P defines the equal-payment series present-worth factor EPSPWF as follows:

$$P = A \left[ \frac{(1+r)^n - 1}{r(1+r)^n} \right] = A[EPSPWF] \quad (3.6)$$

Values of the six factors defined above have been extensively tabulated [12], thus greatly facilitating their use in not only the interest equations but for other applications. While in practice, such tables are always used, it is instructive to look at the limiting values of some of some of this factors.

### Example 3.1

If a bank compounds interest at 10%, what will a \$1,000 deposit be worth in ten years?

Without tables, the solution of Eq. 3.1 for  $P = \$1,000$ ,  $r = .10$  and  $n = 10$  is difficult:

$$F = 1,000(1.10)^{10} = ?$$

However, remembering that the base of the natural logarithms  $e$  is defined as:

$$e = \lim_{x \rightarrow \infty} (1 + x)^{\frac{1}{x}}$$

It is evident that Eq. 3.1 can be written

$$F = P \left[ (1 + r)^{\frac{1}{r}} \right]^{rn} = Pe^{rn}, \quad r \rightarrow 0 \quad \text{and} \quad n \rightarrow \infty$$

The answer using this approximation is

$$F = \$1,000 * 2.718 = \$2,718$$

compared to an actual value of

$$F = \$1,000 * 2.5937 = \$2,593.70$$

### 3.4.2 Depreciation

While some physical assets such as land tend to increase in value, others such as equipment decrease in utility and value in time. The most important causes of depreciation are (1) wear and tear, (2) the effect of the elements, (3) gradual obsolescence, and (4) depletion such as in the case of a natural resource.

Barish [13] lists the purposes of depreciation as lying in the following: (1) the proper charging of the value of an asset to the operating expense of an enterprise so that the profit portrayals will reflect capital-consumption costs; (2) to provide for recovery of capital consumption costs; (3) to provide for proper recording of depreciable assets in accounts of the firm. Since the schedule of accounting of capital costs such as depreciation affect the amount of taxes paid per year, most governments have regulations about the life of the depreciable assets over which the depreciation can be applied.

The annual amount of depreciation of an asset depends on its original purchase price, its estimated useful life, and its estimated salvage value. Of course, forecasting the useful life is a

difficult task. Governments provide statements of policy on estimating average useful lives based on studies of the usual experience of property owners.

Once the original value, salvage value and useful life are known, there are alternative methods available for computing depreciation. The methods for computing depreciation can be classified as functions of time or functions of time or functions of activity. Some of the commonly used models which belong to the first category are: (1) the straight-line method, (2) the declining-balance method, (3) the sum of the digits method, and (4) the sinking fund method. The most commonly used models which are functions of activity are (1) the constant-unit-use charge method and (2) the declining-unit-use charge method. The use of each method will be illustrated in the following example [14].

**Example 3.2**

A machine costs \$5,000, has an estimated life of six years, and a salvage value of \$800. Assume that the machine is capable of producing 200,000 units over six years but that the first 80,000 units will be of higher quality and hence can be charged at twice the rate of the last 120,000 units. Units are to be produced according to the following production schedule:

Year, j	1	2	3	4	5	6
Units (1,000s), S <sub>j</sub>	30	50	40	30	30	20

Letting P = the cost of the asset (the machine), F = the salvage value, and n = the useful life, the machine's depreciation during the second year D(2) for each method will be calculated. Using the straight-line method

$$D(j) = \frac{(P - F)}{6} = \frac{(5,000 - 800)}{6} = \$700, j = 1, 2, \dots, 6$$

The declining-balance method provides for greater depreciation in the early years by taking a constant percentage of declining undepreciated balance. Thus D(2) is found after finding D(1) as follows:

$$D(1) = P \left[ 1 - \left( \frac{F}{P} \right)^{\frac{1}{n}} \right] = 5,000 [.26] = \$1,300 \quad \{3.7\}$$

$$D(2) = (5,000 - 1,300) \cdot 26 = \$962$$

The sum-of-digits method is another way of accelerating depreciation, but without the potentially disastrous effect caused by a low salvage value as in the case of the declining-balance method. It gives

$$D(j) = \frac{(P - F)(n - j + 1)}{\sum n} = \frac{(4200)(7 - j)}{21} \quad \{3.8\}$$

$$D(2) = \$1,000$$

The constant-unit-use charge method is used to determine the depreciation per unit produced, therefore, relating depreciation to use rather than time. One obtains,

$$D(j) = \frac{(P - F)S_j}{\sum_{j=1}^n S_j} \quad \{3.9\}$$

$$D(2) = (4200)50,000/200,000 = \$1,050$$

The declining-unit-use charge method also places depreciation on a per unit basis except that depreciation is accelerated to reflect the decline in efficiency as the asset (machine) ages. Thus

$$D(j) = \frac{(P - F)w_j S_j}{\sum w_i Q_i} \quad \{3.10\}$$

where  $w_1$  is a weighing factor which in this case is  $w_1 = 2w_2$  for  $Q_1 = 80,000$  and  $Q_2 = 120,000$ .

Substituting for  $j = 2$ ,

$$D(2) = \frac{(4200)(2 \times 50,000)}{(2 \times 80,000 + 1 \times 120,000)} = \$1,500$$

The sinking-fund method has been left for last because it is based on the concept that the the depreciation recoveries each year are placed in a sinking fund and therefore considers the time value of money. The sinking fund is fictitious since it would be unusual for a business to establish a

sinking fund in which to invest depreciation recoveries. However, it reflects the fact that in using any of the depreciation models, one should consider the interest on the undepreciated balance as a cost of ownership [12].

The application of the sinking fund model to this example for an interest rate of 6% is as follows:

$$\begin{aligned}
 D(1) &= (P - F)[EPSSFF] = (5,000 - 800)(.1434) = \$602 \\
 D(2) &= D(1) + rD(1) = (1 + r)D(1) + (1.06)(602) = \$636 \\
 D(3) &= D(2) + rD(2) , \text{ etc.}
 \end{aligned}$$

### 3.4.3 Economic Criteria

Having gained some appreciation of the concepts of the time value of money and depreciation, it is necessary now to consider briefly some commonly used economic criteria for evaluating alternatives, especially with respect to choosing investments.

Generally speaking, an investment amounts to the present consumption of limited resources in the hope of returning some future benefit. In developing countries where resources are scarce, projects must be selected with great care. The contribution of economics to project evaluation lies in the identification of the standards by which a project should be taken. A project is worked out by a process of successive approximation involving engineers, financiers, economists and administrators. The role of the engineer is to create a new system to perform a desired task at a minimum cost. The motivation of the financiers of the project is the expectation of benefits to exceed costs sufficiently to justify the effort. The contribution of economics lies in the identification of the standards by which a project or design is to be judged to determine how, or even if, a particular project should be undertaken. The manager's role is to help in clarifying the position of each the experts involved and in defining the various solutions to be considered.

It should be distinguished two main stages: project evaluation and project formulation. Project evaluation analyses determine the economic feasibility of a proposed project. Project

formulation analyses determine the economic formulation of the design features of the project. For example, consider the construction of a new highway bridge to reduce travel. The first step, project evaluation, is to determine the rough cost and rough benefit by assuming a general location, an estimate of the cost of construction, and an estimate of the savings in travel. If the project is feasible, the project formulation might call for the analysis of alternatives of construction, such as the type of bridge (suspension or truss), basic materials (steel beam or prestressed concrete beam), length and number of spans (8 at 40 ft span or 4 at 80 ft span) and approaches (land fill or trestle).

It should be stressed that these stages need not to be sequential. We are seeking the answer to two questions:

(1) of the various alternatives, which is the "best"?

(2) When the "best" scheme has been ascertained, will it prove sufficiently worthwhile to justify initiation?

A criterion is needed in order to answer these questions. Some characteristics of a good criterion have been suggested, as follows: (1) that it include in a single figure all the information needed to make the right decision; (2) that it be applicable to any investment project; and (3) that it lend itself to fairly straightforward and rapid calculation [15]. A brief explanation of some frequently used criteria -- present worth, annual cost, rate of return, and benefit-cost -- will be given using the following example.

### **Example 3.3**

Three alternative schemes I, II and III are proposed for a project. Their respective initial costs  $C$ , average annual revenues  $R$ , and average annual expenses  $E$  are summarized in Table 3.1. Assuming an interest rate of 5%, that remains applicable during the 20 year estimated useful life of the project, which alternative, if any, should be selected?

The present worth criterion provides one tool for comparing different inflows and outflows by expressing them, through the known rate of discount, in terms of a single figure which takes account of the total amount of revenues and expenses, the pattern in which they are spread over

time, and the life span of the project. Substituting A by (R - E) in Eq. 3.6, gives the present worth of future benefits B as

$$B = (R - E)[EPSPWF] \quad \{3.11\}$$

It follows that the present worth PW of a project alternative is obtained by subtracting the project cost C from B, or

$$PW = B - C \quad \{3.12\}$$

The annual cost criterion has appeal because by expressing all costs, revenues and expenses as equivalent annual costs, budget planning and control can be facilitated. Applying Eq. 3.5, the annual cost AC of a project alternative is

$$AC = C[EPSCRF] - (R - E) \quad \{3.13\}$$

In both present worth and annual cost methods, alternatives are compared on the basis of pre-determined rates of return (the interest rate r). However in the rate of return approach, the rate of return ROR on the proposed investment is calculated and evaluated. Mathematically ROR is determined by finding r for an investment C that would give us (R - E) annually for 20 years. This can be obtained using Eq. 3.5:

$$\text{solving } (R - E)/C = [EPSCRF] \text{ for } r \quad \{3.14\}$$

As has been mentioned, benefits are measured in different ways in different sectors. The private sector uses money, income, profits, etc. In the public sector which do not yield a monetary return, the benefit-to-cost ratio is a useful index. The criterion can be applied equally well using uniform annual benefit and costs or the present values of future benefits and costs B/C.

The results of the application of the four criteria to the data for this example are summarized in Table 1.

**Table 1. Use of Economic Criteria for Project Evaluation (Example 3.3)**

Parameters and Criteria	project alternatives			Remarks (* denotes preferred)
	I	II	III	
C, Initial Cost	\$1,600,000	\$1,520,000	\$1,880,000	
R, Annual Revenues	\$840,000	\$840,000	\$840,000	
E, Annual Expenses	\$720,000	\$780,000	\$660,000	
PW, Present Worth	-\$100,000	-\$770,000	\$370,000*	positive PW
AC, Annual Cost	\$8,000	\$61,600	-\$29,600*	negative AC
ROR, Rate of Return	4.2%	< 2.0%	7.2%*	7.2% > 5.0%
BC, Benefit-Cost	0.94	0.49	1.20*	B/C > 1.0

### 3.4.4 Economic Life

In the previous subsections, "Depreciation" and "Economic Criteria", the variable  $n$ , useful life, was treated rather innocuously. However, in practice a physical asset does not have any inherent economic life. Physical deterioration, functional depreciation, technological obsolescence, and changing demand patterns -- all with varying degrees of unpredictability -- work together to complicate the estimation of the useful life of a single piece of equipment or an entire facility. Which is the best way to estimate economic life of a physical asset?

The key in determining economic life lies in the manner in which the term is defined. One logical definition is that the economic life of a physical asset is the number of years that minimizes the annual cost of the asset.

### 3.5 Continuous Formulation of Economic Evaluation

#### Methods

Let  $b_t \Delta t$  equal the benefits in dollars generated by the project in the interval of time between  $t$  and  $t + \Delta t$ . Then the present value of these benefits  $B$ , is given by the expression

$$B = \sum_{t=0}^n \frac{b_t \Delta t}{(1 + r/x)^{xt}} \quad (3.15)$$

where  $r$  is the annual interest rate,  $x$  is the number of times per year that interest is compounded, and  $n$  is the project lifetime in years. Taking the limit as  $\Delta t$  approaches zero yields the continuous formulation of Eq. 3.15 which is

$$B = \int_0^n \frac{b_t dt}{(1 + r/x)^{xt}} \quad (3.16)$$

Benefits  $b_t$ , are equal to annual revenues  $R$ , minus annual expenses  $E$ . Substituting in, and rewriting Eq. 3.16, gives

$$B = (R - E) \int_0^n \frac{dt}{\left[1 + \frac{1}{x/r}\right]^{x/r} r^t} \quad (3.17)$$

Since

$$\lim_{x/r \rightarrow \infty} \left[1 + \frac{1}{x/r}\right]^{x/r} = e \quad (3.18)$$

Eq. 3.17 becomes

$$B = (R - E) \int_0^n e^{-rt} dt \quad (3.19)$$

Integrating and applying the limits of integration yields

$$B = (R - E) \frac{1 - e^{-rn}}{r} \quad \{3.20\}$$

If the net present worth is represented by PW and project cost by C, the fundamental equation for this important commonly used criterion is

$$PW = (R - E) \frac{1 - e^{-rn}}{r} - C \quad \{3.21\}$$

The annual cost criterion represented by AC, is

$$AC = C \frac{r}{1 - e^{-rn}} - (R - E) \quad \{3.22\}$$

The rate of return criterion, ROR, is based on solving Eq. 3.22 when  $AC = 0$ , as follows

$$\frac{r}{1 - e^{-rn}} = \frac{R - E}{C} \quad \{3.23\}$$

The benefit-cost criterion, as the names implies, is simply B divided by C. It turns

$$BC = \frac{R - E}{C} \times \frac{1 - e^{-rn}}{r} \quad \{3.24\}$$

Economic viability is determined by checking if:

$$PW > 0$$

$$AC < 0$$

$$ROR > r, \text{ where } r \text{ is the interest rate used for the project}$$

$$BC > 1$$

### 3.6 Systems Dynamics Formulation

In the systems dynamics formulation of the project evaluation problem the key variable is "project cost to be amortized" PCA. The best project alternative is the one with the minimum time T required to amortize the project cost C for annual revenues R and annual expenses E. The causal diagram representation of the model is shown in Fig. 7.

The DYNAMO equations for the model appear in Fig. 8. Analytical treatment of the model is based on the formulation and solution of the differential equation of the system:

$$\frac{dPCA_t}{dt} = IPCAPY_t - B_t \quad \{3.25\}$$

Repeated substitution in the right hand side of Eq. 3.25 results in

$$\frac{dPCA_t}{dt} = (PCA_t - PCA_e)r \quad \{3.26\}$$

where,

$$PCA_e = \frac{R - E}{r} \quad \{3.27\}$$

Substitution of variables, integration, and application of limits gives,

$$\ln \frac{(PCA_t - PCA_e)}{(PCA_0 - PCA_e)} = rt \quad \{3.28\}$$

Conversion from the natural logarithms to the base of the natural logarithms yields

$$\frac{PCA_t - PCA_e}{PCA_0 - PCA_e} = e^{rt} \quad \{3.29\}$$

Replacing  $PCA_0$  with the project cost C and solving for  $PCA_t$ , one obtains

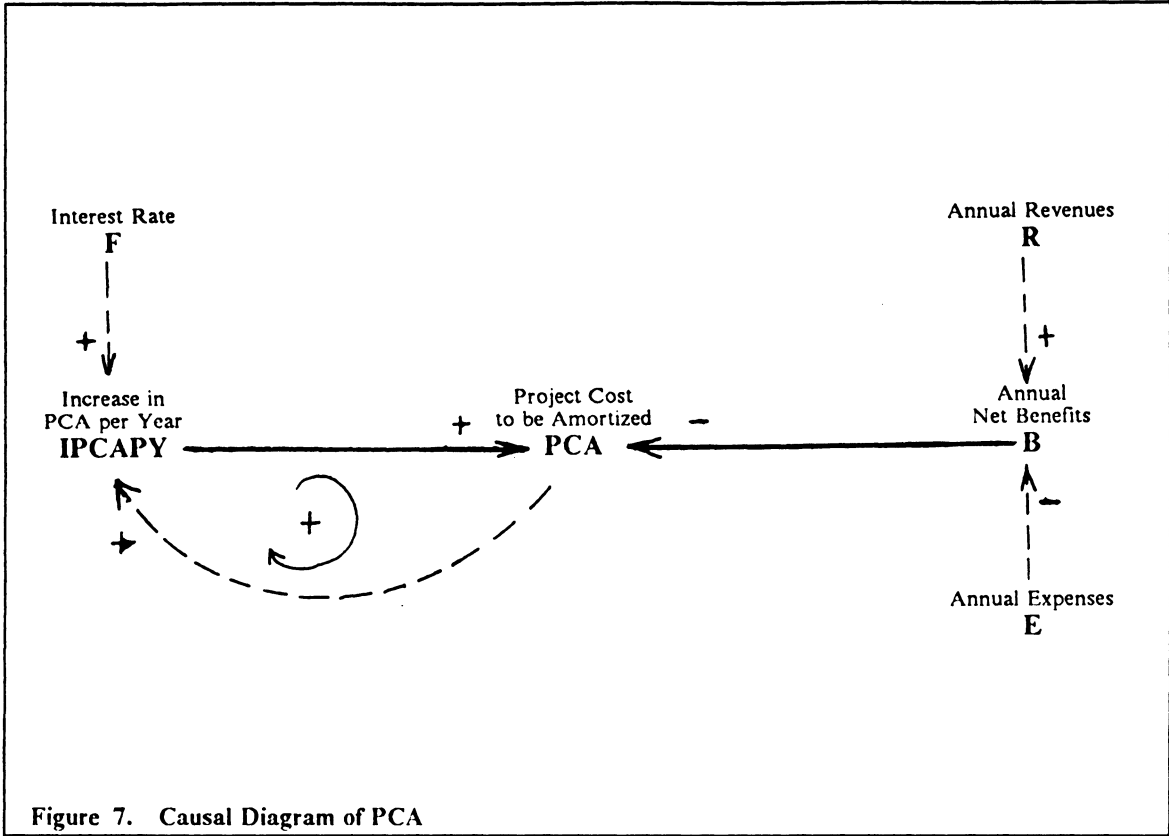


Figure 7. Causal Diagram of PCA

$$PCA_t = PCA_e - (PCA_e - C)e^{rt} \quad \{3.30\}$$

Solving Eq. 3.30 for  $PCA_t = 0$  gives PT the time required to amortize the project cost C or payback time.

$$PT = -\frac{1}{r} \ln \left[ 1 - \frac{C}{\frac{R-E}{r}} \right] \quad \{3.31\}$$

L	$PCA.K = PCA.J + (DT)(IPCAPY.JK - B.JK)$
N	$PCA = C$
R	$IPCAPY.KL = PCA.K * F$
R	$B.KL = R - E$

Figure 8. DYNAMO Equations for Model

### 3.7 *Dynamic Economic Evaluation Procedures*

Current social problems have characteristics that make them difficult to analyze fully because causes and effects are manifold and separated in time. Potential solutions that attack symptoms of these problems are likely to fail or result in rather small benefits. Even when the intricate cause-and-effect relationships are identified, a tool for evaluating the economic consequences of proposed solutions is needed, which means that good estimates must be made of the dynamic path of benefits and costs of proposed programs and the ensuing projects. Standard static methods of benefit-cost analysis (and the other variations of the same approach including present worth, annual cost and rate of return) cannot capture the underlying time-varying behavior of social systems.

There are dangers in the application of static benefit-cost analysis. First of all, costs and benefits are seldom constant over time and if they are not, they cannot be captured by a static and incomplete benefit-cost evaluation procedure. Secondly, in addition to immediate benefits and immediate costs, public projects such as those the responsibility of engineers, often produce secondary or induced dynamic effects upon other economic variables. These induced effects, which include non-monetary external effects, must be incorporated into estimates of benefits and costs [16].

#### **Example 3.4**

Metropolis is a large city located on the coast. A bedroom community, Suburbia, is being planned across the bay which will be connected to Metropolis' CBD (Central Business District) by a new bridge (see Fig. 9). The systems dynamics equations governing the dynamics of

Suburbia's growth are given in Appendix A, and the causal diagram corresponding to these equations appears in Fig. 10. Find (1) the expression for the steady state number of households in Suburbia,  $HH_s$ , as a function of houses built in Suburbia,  $HS$ , and (2) the expression for the number of households at time  $t$ ,  $HH_t$ , for  $t = 9$ ,  $HS = 12,000$ , and highway capacity (of the bridge),  $HC = 4,800$  (vehicles per hour).

In this problem the decision maker has two decisions variables --  $HS$ , the number of houses to be built, and  $NBL$ , the number of traffic lanes in the bridge to be constructed. The purpose of this example is to show the interrelatedness of two subsystems as a prelude to tracing the cause and effect relationships throughout the system in a dynamic benefit-cost analysis.

The distribution of traffic during the morning and afternoon peaks is shown in Fig. 11. For the morning peak it is seen that 20% of the daily traffic occurs between 7 am. and 9 am.. Thus, the peak hour factor,  $PHF$ , is equal to 0.2. The parameter  $PHF$  is important because it is used to find the peak demand,  $PD$ , which when divided by the hourly capacity,  $HC$ , permits one to determine the travel time from Suburbia to the CBD of Metropolis,  $TTSC$ . This travel time is calculated from either the free-flow travel time,  $FT$ , or the congested travel time,  $CT$ , depending upon whether the demand to capacity ratio ( $PD/HC$ ) is less than or greater than unity (see Fig. 12 and Fig. 13). The decision for households to relocate from Metropolis to Suburbia is assumed to be based on the relative availability of housing in Suburbia,  $HS$ , compared to housing in Metropolis,  $HM$ , and the relative travel time to jobs in the CBD of Metropolis,  $TTMC$ . The complete formulation of households projected for Suburbia,  $HHP$ , adopted from classical accessibility-gravity model is given in Eq. 3.32:

$$HHP_t = K \times \frac{HS \times JC \times TTMC}{AHS \times LPF \times HH \times TTSC} \quad \{3.32\}$$

where  $JC$  is the number of jobs in the CBD,  $AHS$  is the average household size,  $LPF$  is the labor participation fraction, and  $K$  is a calibration constant for the model.

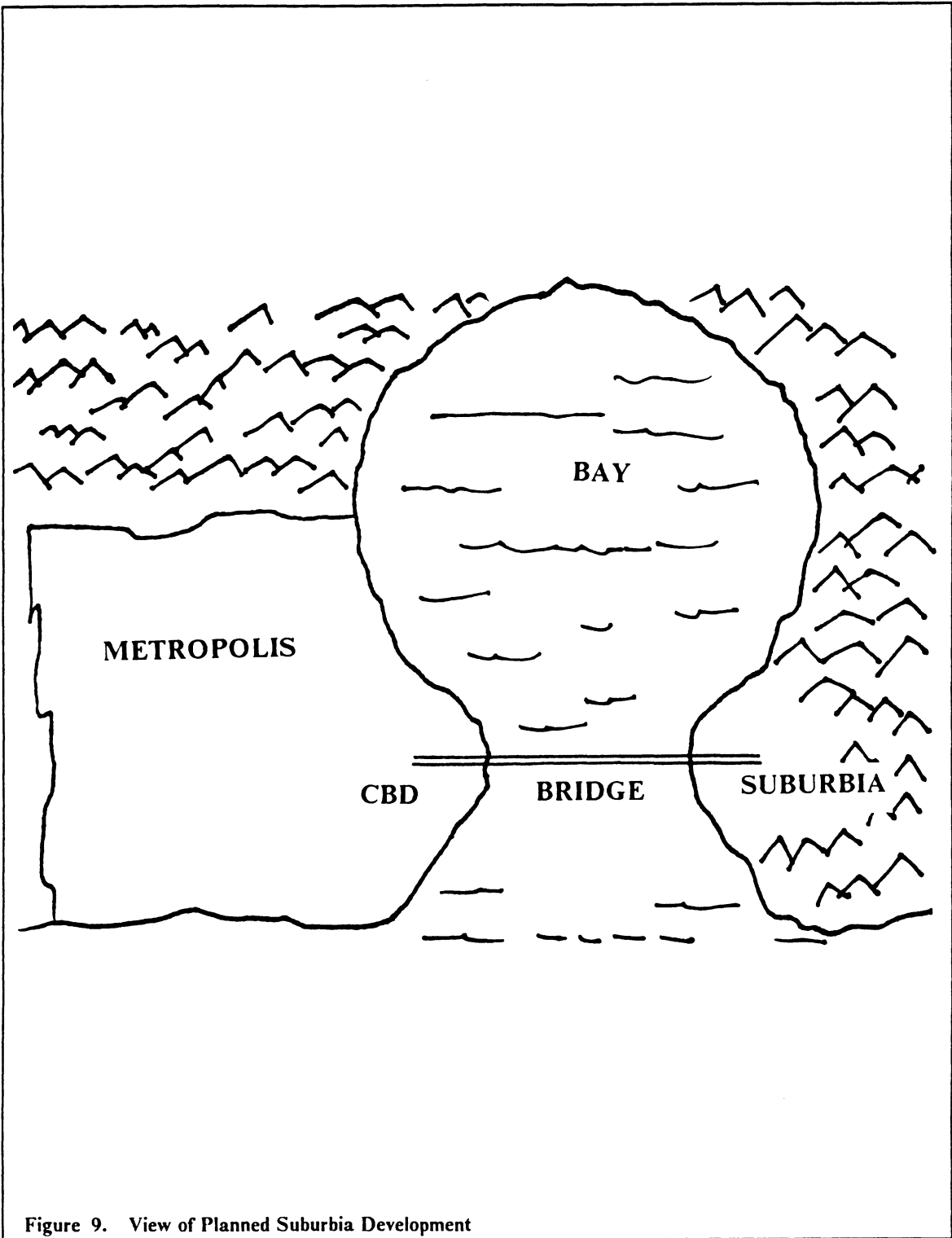


Figure 9. View of Planned Suburbia Development

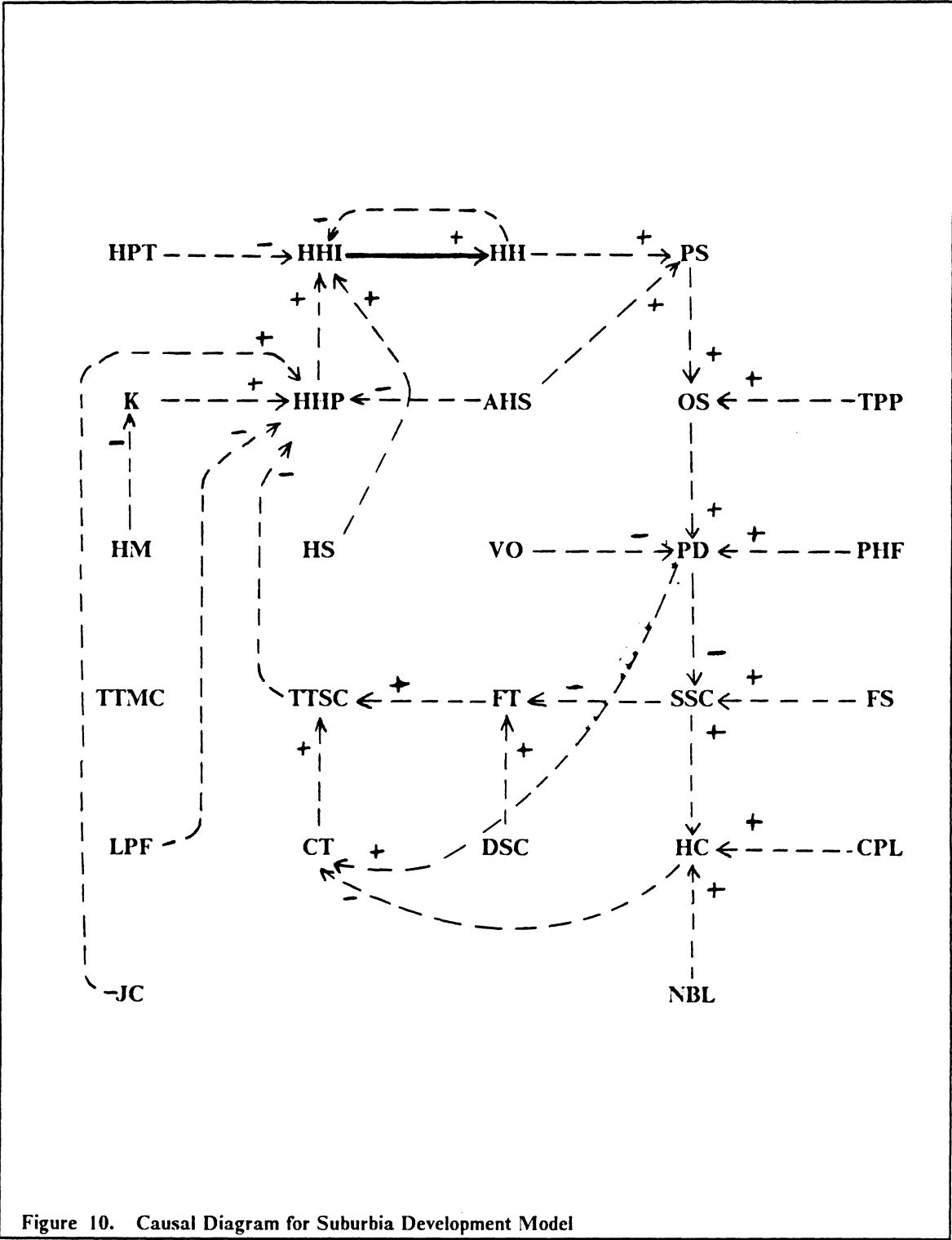


Figure 10. Causal Diagram for Suburbia Development Model

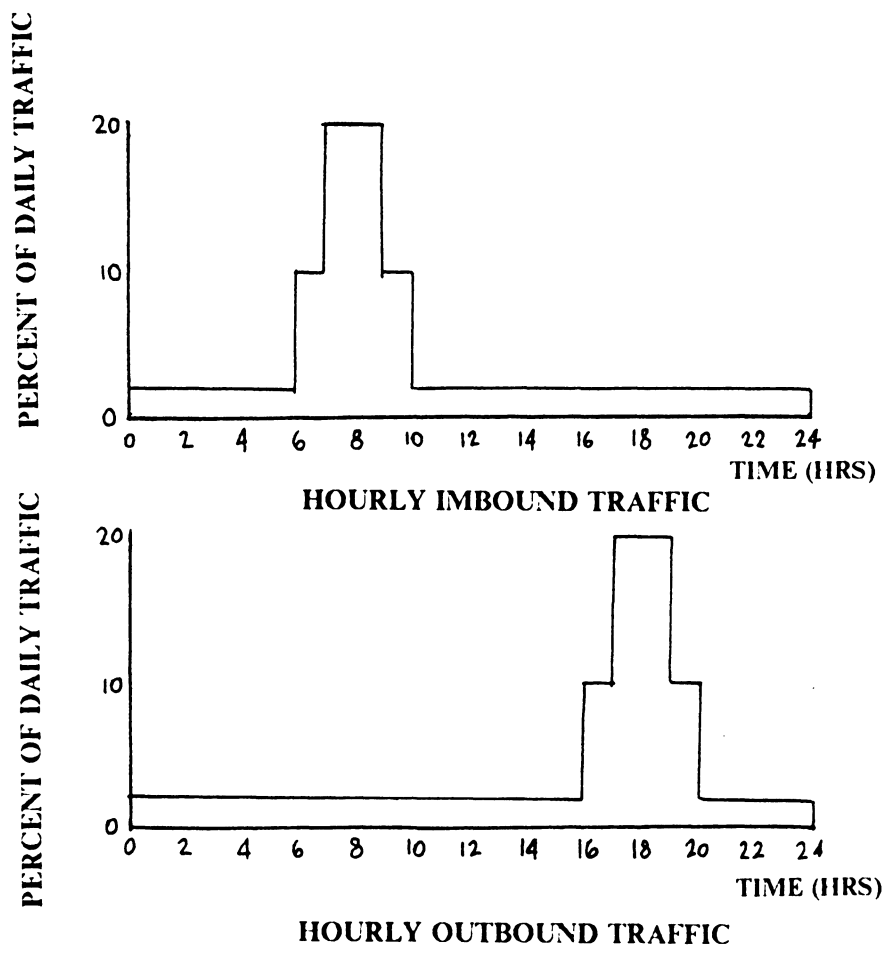


Figure 11. Distribution of Traffic Showing AM. and PM. Peaks

CT = MAXIMUM FREE-FLOW TRAVEL TIME + CONGESTION DELAY

$$CT = DSC/(FS/2) + W$$

WHERE,  $W = D/(HC * T_c)$ ,  $D = 0.5 L_{T_s} v T_c$

THEREFORE,  $W = L_{T_s}/(2 * HC)$

NOW,  $L_{T_s} = (PD - HC) * T_s$

AND,  $T_c = T_s + L_{T_s}/(HC - PD/2)$

SUBSTITUTING,  $PD(T_c = 3) = 1.2 * HC$ ,

$$W = (PD - HC) * T_s / (2 * HC) = (PD - HC) * 2 / (2 * HC) = (PD - HC) / HC$$

$$CT = DSC/(FS/2) + (PD - HC) / HC = 10/40 + (1.2 - 1) / 1 = 0.45 @ T_c = 3$$

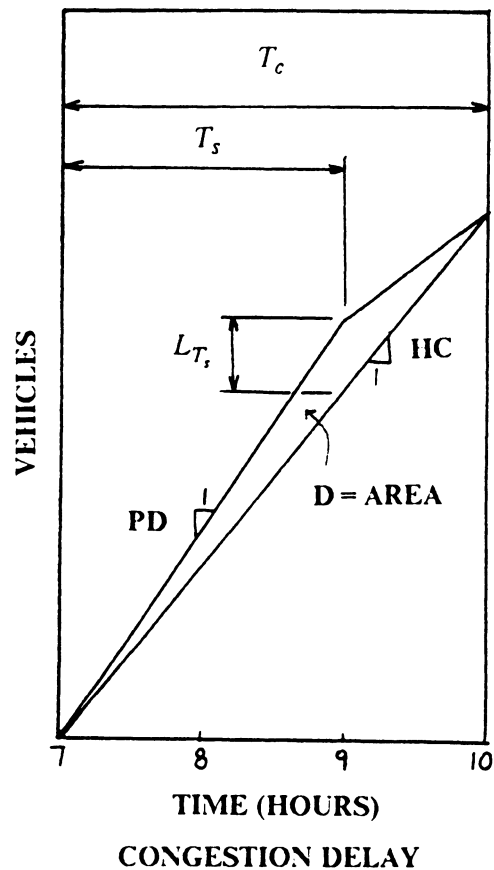


Figure 12. Derivation of Equation for CT

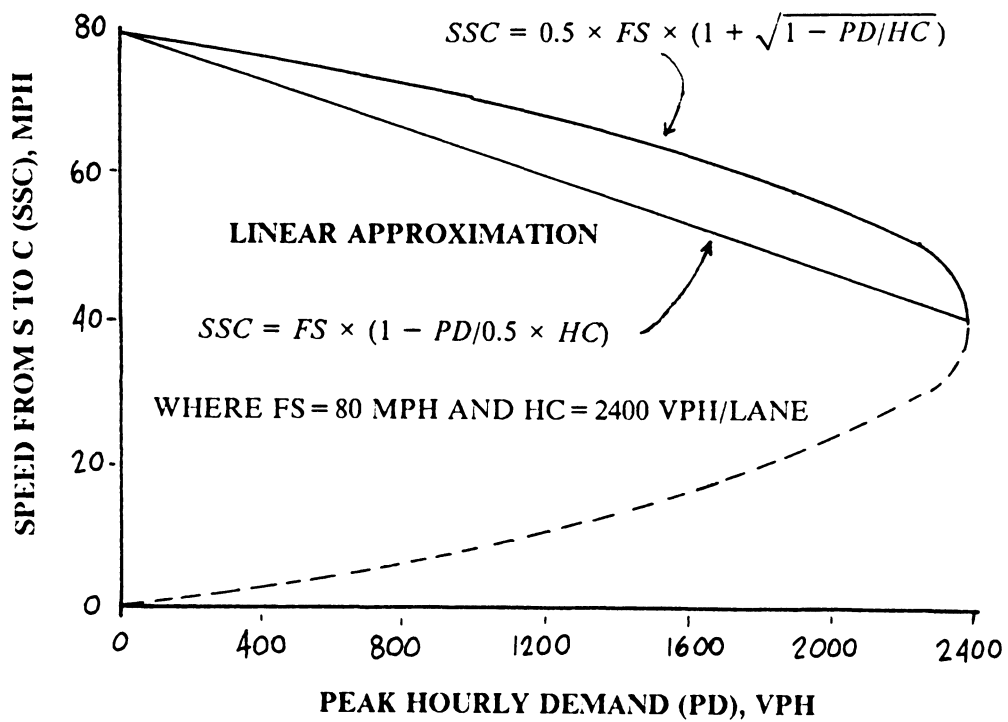


Figure 13. Forms of Traffic Speed (SSC) vs. Traffic Flow (PD)

The execution of the analytical solution is instructive. It involves both steady state analysis and analysis of the transient. Regarding the former, it is convenient to look at the two cases --  $PD/HC \geq 1.0$ , and  $PD/HC \leq 1.0$ . Consider the former. For steady state analysis

$$PD_e \geq HC \quad \{3.33\}$$

Repeated substitution in the left hand-side yields

$$HH_e = \frac{VO}{AHS \times TPP \times PHF} \times HC = 1.25 \times HC \quad \{3.34\}$$

where VO is vehicle occupancy and TPP is trips per person.

The next step is to find  $HH_e$ , the number of households at equilibrium, as a function of HS, the number of houses built, and HC, the hourly capacity of the bridge. The reason for this is that these values will be used later on to perform the economic evaluation of this hypothetical venture. Specifically, HS and HC (since HC depends on the number of bridge lanes, NBL) will be used to determine the cost of housing and the cost of the bridge for Suburbia. On the other hand,  $HH_e$ , since it is the number of households, represents the number of houses of the total number of houses of Suburbia, HS, that are leased and hence generating revenues. This will be consider in more detail later.

Returning to steady state analysis for Example 3.4, the summation of rates in the system dynamics model must equal zero at equilibrium; therefore,

$$HHI_e = 0 \quad \{3.35\}$$

Repeated substitution into the left-hand-side eventually yields,

$$HH_e = \frac{JC \times TTMC_e}{HM \times AHS \times LPF} \times \frac{K \times HS}{TTSC_t} = \frac{0.5 \times K \times HS}{CT_e}$$

$$HH_e = \frac{0.5 \times K \times HS}{-0.75 + HH_e \times AHS \times PHF \times TPP / (HC \times VO)} \quad \{3.36\}$$

Expressing Eq. 3.36 in quadratic form,

$$0.8 \times HH_e^2/HC - 0.75 \times HH_e - 0.5 \times K \times HS = 0 \quad \{3.37\}$$

The roots of Eq. 3.37 are:

$$HH_e = \frac{-(-0.75) \pm \sqrt{0.5625 - 4 \times (0.8/HC)(-0.5 \times K \times HS)}}{1.6/HC}$$

$$HH_e = \frac{0.75 \pm \sqrt{0.5625 + 1.6 \times K \times HS/HC}}{1.6/HC} \quad \{3.38\}$$

For  $K = 1$  and  $HC = 4,800$ , a table of values relating  $HH_e$  and  $HS$  can be prepared:

HS	12,000	9,000	7,600	7,500	7,200
$HH_e$	8,658	7,912	7,528	7,500	7,413

Therefore, for these values of  $K$  and  $HC$ ,

$$HH_e = \begin{cases} HS & ; HS \leq 7,500 \\ \frac{0.75 \pm \sqrt{0.5625 + 1.6 \times K \times HS/HC}}{1.6/HC} & ; HS \geq 7,500 \end{cases} \quad \{3.39\}$$

Now looking at the steady state analysis for the case in which  $PD_e \leq HC$ , or equivalently for  $HH_e \leq 1.25 \times HC$ . Again, from Eq. 3.35

$$HH_e = HHP_e = \frac{JC \times TTMC}{HM \times AHS \times LPF} \times \frac{K \times HS}{TTSC_t} = \frac{0.5 \times HS}{HC}$$

$$HH_e = 0.5.K \times HS \times FS \times \left[ 1 - \frac{PD_e}{2 \times HC} \right] / DSC \quad \{3.40\}$$

Substituting for  $PD_e$  yields

$$HH_e = \frac{0.5 \times K \times HC \times FS}{DSC} \left[ 1 - \frac{AHS \times TPP \times PHF \times HH_e}{2 \times HC \times VO} \right]$$

$$HH_e = \frac{0.4 \times K \times HS}{HC} \times (HC - 0.4 \times HH_e) \quad \{3.41\}$$

Depending on the value of  $HS$ ,  $HH_e$  has two forms just as in the previous case:

$$HH_e = \begin{cases} \frac{2.5 \times K \times HC \times HS}{(HC/1.6) + K \times HS}; & HS \geq 2.5 \times K \times HC - HC/1.6 \\ HS & ; HS \leq 2.5 \times K \times HC - HC/1.6 \end{cases} \quad \{3.42\}$$

For values of  $K$  and  $HC$  the two cases can be combined. For example,  $K = 1$  and  $HC = 4,800$  the  $PD_e \geq HC$  case dominates and the general solution is:

$$HH_e = \begin{cases} HS & ; HS \leq 7,500 \\ 2,250 \pm 3,000 \times \sqrt{0.5625 + HS/3,000} & ; HS \geq 7,500 \end{cases} \quad \{3.43\}$$

Having completed the steady state analysis for Example 3.4, the analysis of the transient is going to be addressed. Forming the differential equation corresponding to the DYNAMO equations of the system one gets:

$$\frac{dHH_t}{dt} = HHI_t = \begin{cases} HS - HH_t & ; HS \leq 7,500 \\ HH_e - HH_t & ; HS \geq 7,500 \end{cases} \quad \{3.44\}$$

The solution has three cases:

Case 1 is defined for  $HH_e \leq HS \leq 7,500$  and has the solution

$$HH_t = HS \times (1 - e^{-t/HPT}) \quad \{3.45\}$$

Case 2 is defined for  $HH_e \leq 7,500 \leq HS$  and has the solution

$$HH_t = HH_e \times (1 - e^{-t/HPT}) \quad \{3.46\}$$

Case 3 is defined for  $7,500 \leq HH_e \leq HS$  and has the solution

$$HH_T = HH_e - (HH_e - 7,500) \times e^{-(T-t)/HPT} \quad \{3.47\}$$

where

$$t = -HPT \times \ln(1 - 7,500/HS) \quad \{3.48\}$$

For Example 3.4, if  $T = 9$  and  $HS = 12,000$  yielding  $HH_t = 8,658$  from Eq. 3.43, one finds by substitution into Eq. 3.48 and then into Eq. 3.49 that  $t = 2.94$  and  $HH_t = 8,504$ .

### Example 3.5

For the Suburbia Development Model of Example 3.4 assuming an interest rate of 8% per year compounded continuously and a period of  $n = 30$  years, find the following for  $HS = 12,000$  and  $NBL = 4$ : (1) the present worth  $PW$ ; (2) the annual cost  $AC$ ; (3) the rate of return  $ROR$ ; (4) the benefit-cost ratio  $BC$ ; and (5) the time to amortize the cost  $PT$ . Should the Suburbia project be undertaken and, if so, How many bridge lanes  $NBL$  and how many houses  $HS$  should be built?

The system dynamics equations for the economic evaluation of the Suburbia Development Model are given in Appendix A. While, as is evident from the equations, in this example revenues  $R$  and expenses  $E$  are assumed to be constants equal to the steady state values, it will still be considered an application of dynamic economic evaluation because an increase in  $NBL$ , the number of bridge lanes, causes an increase in  $RH$ , housing revenues, and an increase in  $HS$ , houses built, leads to an increase in  $RB$ , bridge revenues. It is accounting for this feedback between subsystems that distinguishes dynamic from static economic evaluation.

From the computer output, in Appendix A, for  $NBL = 4$  and  $HS = 12,000$  the equilibrium values for revenues, expenses, and cost at time  $T = 30$  years are:

$$\begin{aligned} R &= 83.55 \text{ M} \\ E &= 15.80 \text{ M} \\ C &= 920.00 \text{ M} \end{aligned}$$

These are the values to be used in the economic evaluation.

- (1) present worth: from Eq. 3.21,  $PW = -150.00 \text{ M} < 0$
- (2) annual cost: from Eq. 3.22,  $AC = 13.19 \text{ M} > 0$
- (3) rate of return: from Eq. 3.23 and using trial and error method,  $ROR = 6.2\% < 8\%$
- (4) benefit-cost ratio: from Eq. 3.24,  $BC = 0.837 < 1$

(5) time to amortize the cost: from Eq. 3.31, the time to amortize the cost does not exist, which means that the project will never be able to finance itself.

The conclusion, from the results of the economic parameters set above, is that the project must not be carried on.

The question now, is how many bridge lanes NBL, and how many houses HS should be built to make the Suburbia project economically feasible.

The methodology used to get the best alternative is the same used for the problem solved above. All the results were obtained from the computer output in Appendix A, except for the rate of return, ROR, that was solved by trial and error. The results are summarized in Tables 2 to 6, varying the parameters NBL and HS.

The comparative values, according to the number of bridge lanes, NBL, of ROR, and BC can be seen in Figs. 14 and 15, respectively.

Now it is time to take the decision . According to the numbers that are shown in tables and figures, mathematics tells that the best alternative is to build 18,000 houses ( $HS = 18,000$ ) and 10 bridge lanes ( $NBL = 10$ ). But as it was stated in Sec. 3.1 decisions are not taken by mathematicians but by politicians and administrators. In this example, the Mayor of Suburbia says that the investment for  $HS = 18,000$  and  $NBL = 10$  is too high ( $C = 1,400$  M) for the budget of the city. He would need to borrow funds at higher interest rates to face the project. Instead of doing that, he selects another alternative that is almost as profitable as the former but with a lower initial investment,  $HS = 15,000$  and  $NBL = 8$  with a cost  $C = 1,205$  M.

This is a good example to show that economic evaluation with the systems point of view is not a set of mechanical calculations only. The social and political aspects are also considered.

**Table 2. Economic Parameters for NBL = 4**

HS	7,000	8,000	9,000	10,000	11,000	12,000
R (M)	67.55	73.73	76.35	78.85	81.25	83.55
E (M)	12.47	13.27	14.00	14.67	15.27	15.80
C (M)	736.7	786.7	830.0	866.7	896.7	920.0
PW (M)	-110.6	-99.4	-121.3	-137.0	-147.0	-150.0
AC (M)	9.73	8.73	10.67	12.06	12.91	13.19
ROR (%)	6.4	6.6	6.4	6.3	6.2	6.2
BC	0.8498	0.8737	0.8539	0.8418	0.8364	0.8370
PT (YR)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

**Table 3. Economic Parameters for NBL = 6**

HS	9,000	10,000	11,000	12,000	13,000	14,000
R (M)	86.85	96.50	106.1	110.6	113.2	115.8
E (M)	15.00	15.67	16.27	16.80	17.70	18.60
C (M)	910.0	946.7	976.7	1,000	1,038	1,073
PW (M)	-93.0	-28.0	45.0	66.0	48.0	31.0
AC (M)	8.22	2.43	-3.90	-5.80	-11.20	-2.80
ROR (%)	6.9	7.7	8.5	8.7	8.5	8.3
BC	0.8974	0.9705	1.046	1.066	1.046	1.029
PT (YR)	N.A.	34.6	25.4	24.0	25.4	26.9

**Table 4. Economic Parameters for NBL = 8**

HS	13,000	14,000	15,000	16,000	17,000	18,000
R (M)	125.4	135.1	144.7	147.5	150.1	152.7
E (M)	18.70	19.60	20.50	21.67	22.87	24.10
C (M)	1,138	1,173	1,205	1,233	1,258	1,280
PW (M)	75	139	207	197	188	182
AC (M)	-6.6	-12.3	-18.2	-17.3	-16.5	-16.0
ROR (%)	8.7	9.2	9.8	9.7	9.5	9.5
BC	1.066	1.119	1.172	1.159	1.149	1.142
PT (YR)	24.0	20.9	18.7	19.2	19.6	19.9

**Table 5. Economic Parameters for NBL = 10**

HS	16,000	17,000	18,000	19,000	20,000	21,000
R (M)	154.4	164.0	173.3	181.6	184.3	187.0
E (M)	22.67	23.87	25.10	26.37	27.67	29.00
C (M)	1,353	1,378	1,400	1,482	1,567	1,655
PW (M)	144	215	289	283	214	141
AC (M)	-12.7	-18.9	-25.4	-24.9	-18.8	-12.4
ROR (%)	9.1	9.6	10.1	9.9	9.4	8.9
BC	1.106	1.156	1.206	1.191	1.137	1.085
PT (YR)	21.6	19.3	17.5	18.0	20.1	22.8

**Table 6. Economic Parameters for NBL = 12**

HS	18,000	19,000	20,000	21,000	22,000	23,000
R (M)	173.7	183.3	193.0	202.6	212.3	218.5
E (M)	26.10	27.37	28.67	30.00	31.37	32.77
C (M)	1540	1622	1707	1795	1887	1982
PW (M)	138	151	161	167	170	129
AC (M)	-12.1	-13.3	-14.2	-14.7	-14.9	-11.4
ROR (%)	8.9	9.0	9.0	9.0	8.9	8.7
BC	1.089	1.093	1.094	1.093	1.090	1.065
PT (YR)	22.5	22.3	22.2	22.3	22.5	24.0

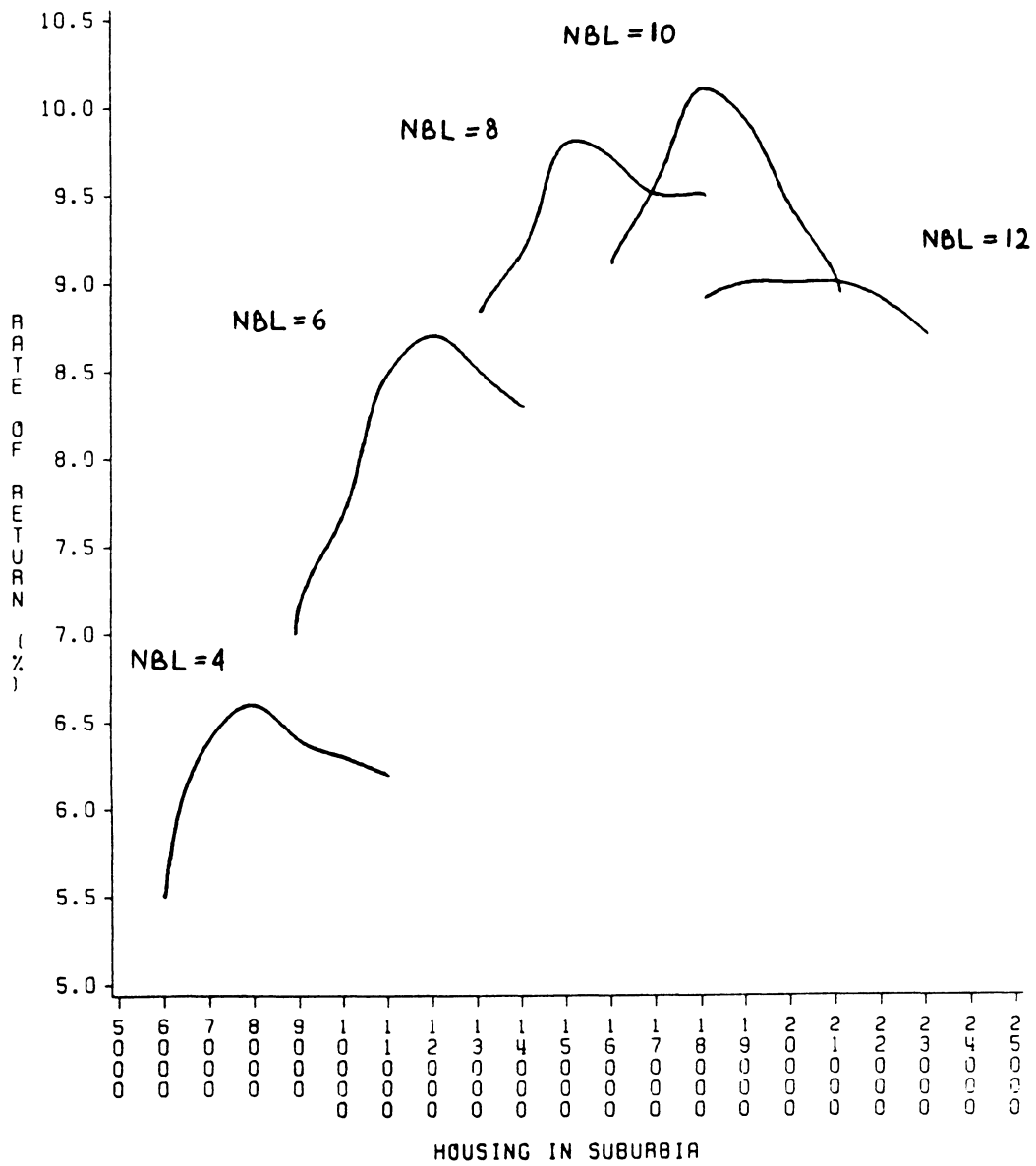


Figure 14. Comparative Values of ROR for Different Number of Lanes

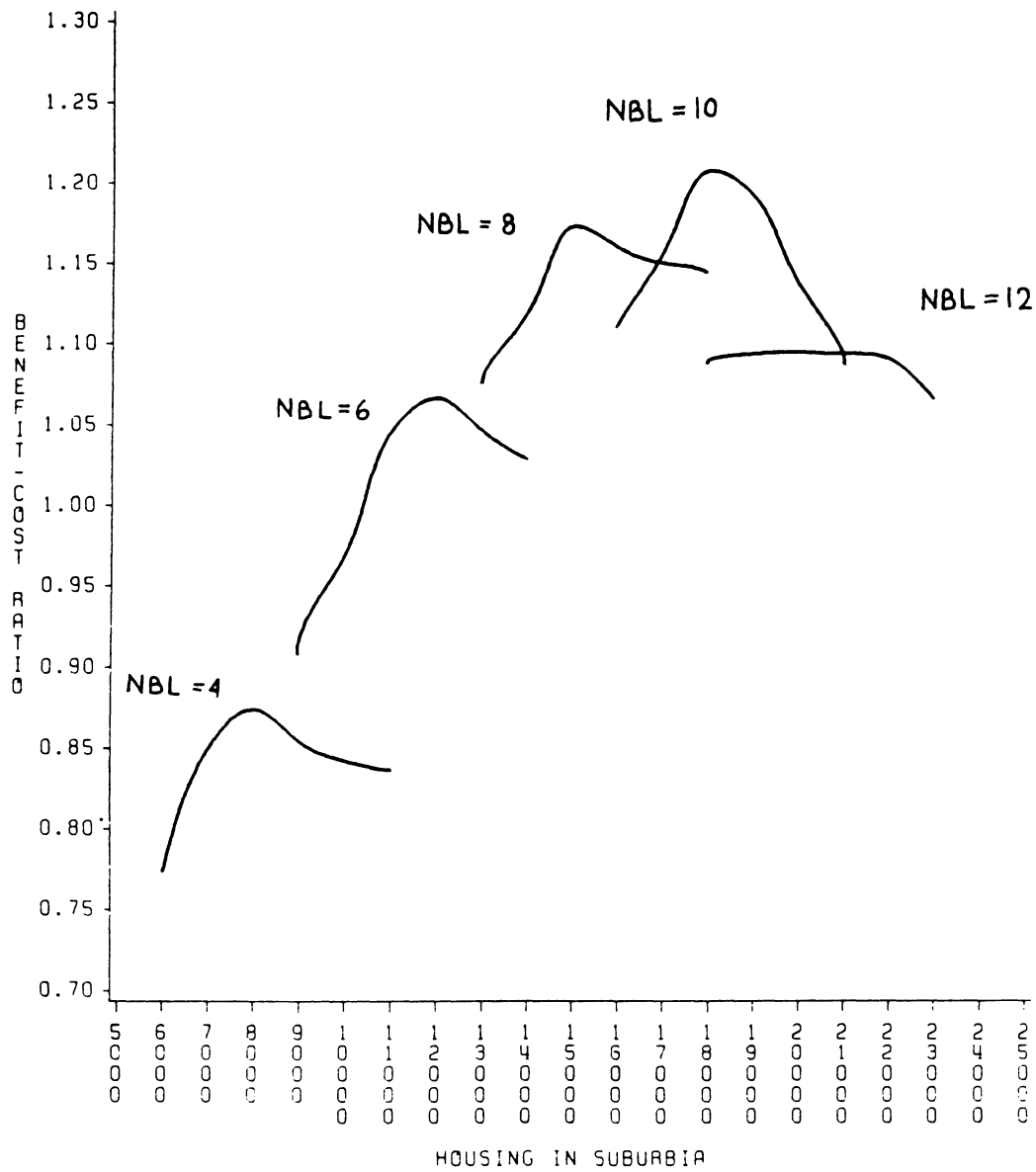


Figure 15. Comparative Values of BC for Different Number of Lanes

## 4.0 The Scenario

### 4.1 *Introduction*

Asimopolis is a medium-size city where a freeway is going to be built. The new road will link the four zones in which the city is divided. Population is located in zones 2, 3 and 4, while working places are in zones 1 and 2. Note that working and residential activities are shared in zone 2. This four zones are already linked by an arterial.

Planners are deciding whether to build 4, 6, 8, 10 or 12 lanes for the freeway, according to the travel demand, economic, social and environmental considerations. Conceptually, the problem is carefully analyzed in all its aspects in this chapter, while the numerical results will appear in Chapter 5.

## 4.2 Travel Demand

The first step in this study is to solve the problem according to the designer's point of view, which means to give the physical answer to the desires of the population. In this case the physical answer is the new transportation facility, and the public desires are translated by the travel demand.

This first step is analyzed using the Urban Transportation Planning Process (UTPP) which consists on studies to describe the base year conditions and models to help deduce the same functions over the horizon year.

The problem of predicting traffic flows in a transportation system and its impacts is an application of economic theory: the traffic flows which will result from a transportation system  $T$ , and the pattern of socio-economic activities  $A$ , can be determined by finding the resulting equilibrium in the transportation market. Calling  $V$ : volume of traffic, and  $L$ : level of service of that volume,  $F = f(V,L)$  is the traffic flow pattern. The equilibrium value  $F^*$  is found by establishing the supply  $S$  and the demand  $D$  functions consistent with both relations:

$$F^* = f(V^*, L^*) \quad \begin{cases} L = S(V, T) \\ V = D(L, A) \end{cases} \quad (4.1)$$

Using the usual notation that accounts for the dynamic nature and spatial orientation of the problem,

$t_{ij}^{mr}$  : time  $t$ , from zone  $i$  to  $j$ , by mode  $m$ , using route  $r$ ,

the conceptualization of the UTPP is:

$$F^*(t)_{ij}^{mr} = f[V^*(t)_{ij}^{mr}, L^*(t)_{ij}^{mr}] \quad \begin{cases} L(t)_{ij}^{mr} = S[V(t)_{ij}^{mr}, T(t)_{ij}^{mr}] \\ V(t)_{ij}^{mr} = D[L(t)_{ij}^{mr}, A(t)_{ij}^{mr}] \end{cases} \quad (4.2)$$

$A(t)_{ij}$  describes the magnitude, spatial distribution, and composition of the varied aspects of society, over zones  $i, j$  at time  $t$ , that influence the demand for, and impact of, transportation.  $T(t)_{ij}^{mr}$  refers to the elements of the transportation network at time  $t$ .

The process concentrates on the demand function, which because of its complexity is broken down into four analytical submodels, as follows:

(1) the network assignment submodel,

$$V(HY)_{ij}^{mr} = \delta_{ij}^{mr} \times V(HY)_{ij}^m \quad \{4.3\}$$

(2) the modal split submodel,

$$V(HY)_{ij}^m = \gamma_{ij}^m \times V(HY)_{ij} \quad \{4.4\}$$

(3) the trip distribution submodel,

$$V(HY)_{ij} = \alpha_i \times \beta_j \times O(HY)_i \times D(HY)_j \times z(t_{ij}^x) \quad \{4.5\}$$

(4) the trip generation submodel,

$$O(HY)_i = f[A(HY)_i] \quad \{4.6\}$$

$$D(HY)_j = f[A(HY)_j] \quad \{4.7\}$$

where the values of the parameters used in the submodels for the horizon year,  $\delta_{ij}^{mr}$ ,  $\gamma_{ij}^m$ ,  $\alpha_i$ ,  $\beta_j$ , are determined from the base year conditions  $V(BY)$ ,  $L(BY)$ ,  $A(BY)$  and  $T(BY)$  [2].

To facilitate the iteration process necessary to solve the problem, a computer program in DYNAMO language was written and can be found in Appendix B. The program contains, step by step, and in the same order, all the methodology that it is explained in the following paragraphs.

#### 4.2.1 Allocation of Residential Activity Using the Accessibility Model

Given:

- $J_j$  : number of jobs in zone  $j$
- $t_{ij}$  : peak-hour travel time from  $i$  to  $j$
- $x$  : measure of the importance of proximity
- $H_i$  : living capacity in zone  $i$

one gets that the value of  $A_i$ , the accessibility to employment opportunities from zone  $i$  is:

$$A_i = \sum_{j=1}^2 \frac{J_j}{t_{ij}^x} \quad (i = 2, 3, 4) \quad \{4.8\}$$

For this problem the value of  $x = 1$  and  $t_{ij}$  is assumed arbitrarily for the first iteration, then is compared with the travel time obtained from the network assignment analysis and a corrected value is used for the second iteration, and so on, until the equilibrium is reached for the horizon year.

The laborforce  $L_i$ , that chooses to live in zone  $i$  is:

$$L_i = \frac{A_i \times H_i}{\sum_{i=2}^4 A_i \times H_i} \times \sum_{j=1}^2 J_j \quad \{4.9\}$$

Finally the population  $P_i$ , of zone  $i$  will be:

$$P_i = \frac{L_i}{LPF_i} \quad \{4.10\}$$

where  $LPF_i$  is the labor participation fraction in zone  $i$ .

## 4.2.2 Trip Generation Analysis Using Linear Regression

The model used to the origins,  $O_i$ , and destinations,  $D_j$ , in the horizon year is:

$$O_i = \alpha \times L_i \quad (i = 2, 3, 4) \quad \{4.11\}$$

$$D_j = \beta \times J_j \quad (j = 1, 2) \quad \{4.12\}$$

where the coefficients  $\alpha$  and  $\beta$  are obtained based on the values for the base year of origins, destinations, jobs, and laborforce, as follows:

$$\alpha = \frac{\sum_{i=2}^4 L_i \times O_i}{\sum_{i=2}^4 L_i^2} \quad \{4.13\}$$

$$\beta = \frac{\sum_{j=1}^2 J_j \times D_j}{\sum_{j=1}^2 J_j^2} \quad \{4.14\}$$

### 4.2.3 Trip Distribution Analysis Using the Double-Constrained Gravity

#### Model

The general equation of the double-constrained gravity model is:

$$V_{ij} = \frac{K \times O_i \times D_j}{t_{ij}^x} \quad \{4.15\}$$

where,

$V_{ij}$  : number of trips from  $i$  to  $j$

$x$  : a measure of the importance of proximity, in this problem  $x = 1$

$K$  : set of constants that permit the model to meet the following constraints:

$$(1) \sum_j V_{ij} = O_i \quad \{4.16\}$$

$$(2) \sum_j V_{ij} = D_j \quad \{4.17\}$$

$$(3) \sum_i O_i = \sum_j D_j = \sum_i \sum_j V_{ij} \quad \{4.18\}$$

It is convenient to express  $K$  as:

$$K = A_i \times B_j \quad \{4.19\}$$

Thus,

$$V_{ij} = \frac{A_i \times B_j \times O_i \times D_j}{t_{ij}} \quad \{4.20\}$$

Applying constraint (1),

$$A_i = \frac{1}{\sum_j B_j \times D_j / t_{ij}} \quad \{4.21\}$$

Applying constraint (2),

$$B_j = \frac{1}{\sum_i A_i \times O_i / t_{ij}} \quad \{4.22\}$$

Obtaining the final values of  $V_{ij}$  is an iterative process. Starting with the assumption that  $B_j = 1$ , then calculating  $A_i$  and  $V_{ij}$ , and so on, until  $V_{ij}^{(n)} = V_{ij}^{(n-1)}$ .

#### 4.2.4 Trip End Modal Split Analysis

This is the first step in the modal split analysis and it is used to divide riders between:

- (1) choice riders
- (2) captive riders

according to car ownership in zone  $i$ ,  $C_i$ , that divided by  $O_i$ , gives the fraction  $p_i^{CH}$  of choice riders. Therefore,

$$V_{ij}^{CH} = p_i^{CH} \times V_{ij} \quad \{4.23\}$$

$$V_{ij}^{CA} = (1 - p_i^{CH}) \times V_{ij} \quad \{4.24\}$$

where,

$$p_i^{CH} = \begin{cases} \frac{C_i}{O_i} & C_i \leq O_i \\ 1.0 & C_i > O_i \end{cases} \quad \{4.25\}$$

$V_{ij}^{CH}$  : number of trips from i to j by choice riders

$V_{ij}^{CA}$  : number of trips from i to j by captive riders

#### 4.2.5 Determination of Trip Interchange Modal Split Parameters

The first problem is to obtain a value of time to use in the second step of the modal split analysis. The procedure is as follows, from a set of data from the base year of travel times and travel costs by car and by bus, one can get the values of:

ADTCS: average difference in travel time when car is selected

ADTBS: average difference in travel time when bus is selected

ADCCS: average difference in cost when car is selected

ADCBS: average difference in cost when bus is selected

Then, the minimum value of time for those selecting car is,

$$V_{\min} = ADCCS/ADTCS \quad \{4.26\}$$

and the maximum value of time for those selecting bus is,

$$V_{\max} = ADCBS/ADTBS \quad \{4.27\}$$

Finally, the value of time to be used, is the average of the ones calculated above:

$$VTMT = (V_{\min} + V_{\max})/2 \quad \{4.28\}$$

The values of the money spent using mode m (car or bus) from i to j,  $c_{ij}^m$ , are assumed from actual values and they increase over time, to make the problem realistic.

## 4.2.6 Trip Interchange Modal Split Analysis

This is the last step in the modal split analysis, trying to get the fraction of riders from i to j selecting mode m,  $p_{ij}^m$ , according to behavioral models.

This approach considers a generalized cost function of using different modes,  $z_{ij}^m$ , which is equal to:

$$z_{ij}^m = c_{ij}^m + VTMT \times t_{ij}^m \quad \{4.29\}$$

where,

$c_{ij}^m$  : cost of using mode m from i to j  
 $t_{ij}^m$  : time spent using mode m from i to j  
 $VTMT$  : average value of time in the horizon year

Using a logistic function to relate  $p_{ij}^m = f(z_{ij}^m)$ ,

$$p_{ij}^m = \frac{e^{-z_{ij}^m}}{\sum_j e^{-z_{ij}^m}} \quad \{4.30\}$$

and considering for this case  $m = (\text{car, bus})$ ,

$$\Delta z = z_{ij}^b - z_{ij}^c \quad \{4.31\}$$

one gets:

$$p_{ij}^c = \frac{e^{\Delta z}}{1 + e^{\Delta z}} \quad \{4.32\}$$

and

$$p_{ij}^b = \frac{1}{1 + e^{\Delta z}} \quad | \quad p_{ij}^b = 1 - p_{ij}^c \quad \{4.33\}$$

Therefore, the number of trips from i to j by car,  $V_{ij}^c$ , is:

$$V_{ij}^c = p_{ij}^c \times V_{ij}^{CH} \quad \{4.34\}$$

and the number of trips from i to j by bus,  $V_{ij}^b$ , is:

$$V_{ij}^b = p_{ij}^b \times V_{ij}^{CH} + V_{ij}^{CA} \quad \{4.35\}$$

## 4.2.7 Determination of Peak-Hour Vehicle Trip Demands

The number of cars going from i to j during the peak-hour is:

$$q_{ij}^c = \frac{V_{ij}^c \times FDTPH}{ACO} \quad \{4.36\}$$

where,

FDTPH: fraction of daily trips during the peak-hour  
ACO: average car occupancy

for buses,

$$q_{ij}^b = \frac{V_{ij}^b \times FDTPH}{ABO} \quad \{4.37\}$$

where,

ABO: average bus occupancy

## 4.2.8 Network Assignment Analysis

This part consists on the allocation of car travel demands between zones to alternative routes, existing arterial or proposed highway, taking into account the results of peak-hour vehicle trip demands and the driver route-selection criterion according to savings in time.

It is assumed that all the buses operate only on the arterial.

The unknown parameters of this analysis are:

$q_{kl}^{cf}$  : peak-hour car volume on freeway link kl  
 $q_{kl}^{ca}$  : peak-hour car volume on arterial link kl  
 $q_{kl}^{ba}$  : peak-hour bus volume on arterial link kl  
 $t_{kl}^{cf}$  : peak-hour car travel time on freeway link kl  
 $t_{kl}^{ca}$  : peak-hour car travel time on arterial link kl  
 $t_{kl}^{ba}$  : peak-hour bus travel time on arterial link kl

subject to the following constraints:

$$(1) \quad q_{kl}^{cf} + q_{kl}^{ca} = q_{kl}^c \quad (4.38)$$

$$(2) \quad q_{kl}^{cf} \leq n_{kl}^f \times Q_{kl}^{cf} \quad (4.39)$$

$$(3) \quad q_{kl}^{ca} + BEF \times q_{kl}^{ba} \leq n_{kl}^a \times Q_{kl}^{ca} \quad (4.40)$$

$$(4) \quad t_{kl} = \begin{cases} t_{kl}^{ca} = \frac{x_{kl}^a}{v_{kl}^a} \times 60 & , \quad v_{kl}^a \leq v_f^a \\ t_{kl}^{cf} = \frac{x_{kl}^f}{v_{kl}^f} \times 60 & , \quad v_{kl}^f \leq v_f^f \end{cases} \quad (4.41)$$

where,

$n_{kl}^f$  : number of freeway lanes  
 $n_{kl}^a$  : number of arterial lanes  
 $Q_{kl}^{cf}$  : freeway traffic capacity per lane  
 $Q_{kl}^{ca}$  : arterial traffic capacity per lane  
 $BEF$  : bus equivalent factor to cars  
 $x_{kl}^f$  : length of freeway link kl  
 $x_{kl}^a$  : length of arterial link kl  
 $v_{kl}^f$  : speed on freeway  
 $v_{kl}^a$  : speed on arterial  
 $v_f^f$  : freeway free flow speed  
 $v_f^a$  : arterial free flow speed

The supply function relates volume with speed. For the freeway:

$$v_{kl}^f = v_f^f \times \left[ 0.5 + 0.5 \times \sqrt{1 - q_{kl}^{cf}/n_{kl}^f \times Q_{kl}^{cf}} \right] \quad (4.42)$$

To equate the demand and supply functions is an iterative process. Assigning first an arbitrary number of vehicles to the freeway,  $q_{kl}^{ef}$ , obtaining  $v_{kl}^e$  and  $t_{kl}^{ef}$  with Eq. 4.42 and Eq. 4.41, respectively. Then, the remaining cars and all the buses are assigned to the arterial ( $q_{kl}^{ag}$ ), and  $v_{kl}^g$  and  $t_{kl}^{ag}$  are obtained. The times  $t_{kl}^{ef}$  and  $t_{kl}^{ag}$  are compared, and based on that, the assignment of cars for the next iteration may vary, assigning more cars where the travel time is lower. The process goes on until

$$t_{kl}^{ef} = t_{kl}^{ag}$$

This iteration procedure is facilitated by the DYNAMO computer program placed in Appendix B.

**Note:** the previous analysis was done for the case when volume is less or equal than capacity. In the case of congestion, Eq. 4.42 is not applicable. To obtain the congested travel times the procedure used was the one used in Example 3.4.

## 4.2.9 Equilibrium Check for the Horizon Year Demand Function

Once equilibrium in the network assignment analysis has been achieved, still remains to check whether there is equilibrium between it and the other steps of the UTPP demand function. It was only at the network assignment analysis where the supply function was first used (characteristics of the transportation facilities). Now the travel times obtained in the last step should be compared with the travel times used in the allocation of residential activity, trip distribution, and modal split.

The demand-supply equilibrium will be achieved when  $t_{ij}^{mr} = t_{ij}^m$ , and  $Wt_{ij} = t_{ij}$ , where  $Wt_{ij}$  is the weighted travel time for all modes and routes. The link travel times are added to the collection-distribution times,

$$t_{ij}^{mr} = cdt_{ij}^m + \begin{cases} t_{kl}^{mr} & (i = k, j = l) \\ 0 & (i = j \mid i - 1 < l) \\ \sum_{i=j}^{i-1} t_{l+1,l}^{mr} & (i - 1 \geq l) \end{cases} \quad (4.43)$$

The weighted travel time is,

$$Wt_{ij} = \frac{(t_{ij}^{cf} \times V_{ij}^c + t_{ij}^{ba} \times V_{ij}^b)}{V_{ij}} \quad \{4.44\}$$

## 4.3 *Economic Evaluation*

As it was mentioned in Chapter 3, once the civil engineer studied the physical and functional aspects of the project, the next step is to analyze the economic feasibility of the system and be able to select among the alternatives proposed.

The methodology to be used for this part of the study is the one explained in Chapter 3, using the equations of dynamic economic evaluation for the different alternatives, 4, 6, 8, 10, 12 lanes. There are also two other aspects of the evaluation, user costs, and environmental and socio-economic impacts.

All the equations and tables necessary for this economic evaluation are added to the regular UTPP DYNAMO computer program (section 12). The results are expressed in Chapter 5.

### 4.3.1 **Construction, Maintenance and Operation Costs**

The cost, C, is represented by the total construction cost (includes engineering, right-of-way, earthwork and drainage, structures and flexible pavement). The expenses, EF, are represented by the annual cost of maintenance (surface and base, roadside and drainage, snow and ice control, etc.) and operation (lighting, traffic operation, etc.) of the facility. The data was based on figures at "Economic Analysis for Highways", Winfrey, R. [14]

## 4.3.2 User Costs

### 4.3.2.1 *Vehicle Running Cost*

The freeway and traffic factors affecting the vehicle running cost are: distance, vertical grades, horizontal curvature, roadway surface, speed, and traffic control devices. The vehicle factors are: fuel, engine oil, tires, maintenance and depreciation. Fuel is the most important of them.

Speed is the only freeway and traffic factor that varies from alternative to alternative. Therefore, it is the one considered for calculating the running cost. The results for this problem were found in Fig. 16 [17].

### 4.3.2.2 *Value of Travel Time*

An important component of the benefits of highway improvements (addition of lanes in this case) is savings in travel time. Research studies have indicated that the value of time depends on trip purpose, income level, and amount of travel time saved per trip. The value of time is very low for reductions of less than five minutes.

The methodology to apply is to select a unit value of time and multiply it by the amount of travel time saved among the different alternatives.

In this problem, however, the savings of time never go beyond two minutes. As it can be seen in Fig. 17, the value of time is not significant for this comparative study [17].

### 4.3.2.3 *Traffic Accidents Cost*

It is very difficult to assign a value to accident casualties. There are several research studies that give values for fatalities, non-fatal personal injuries, and property damages. The one used for this

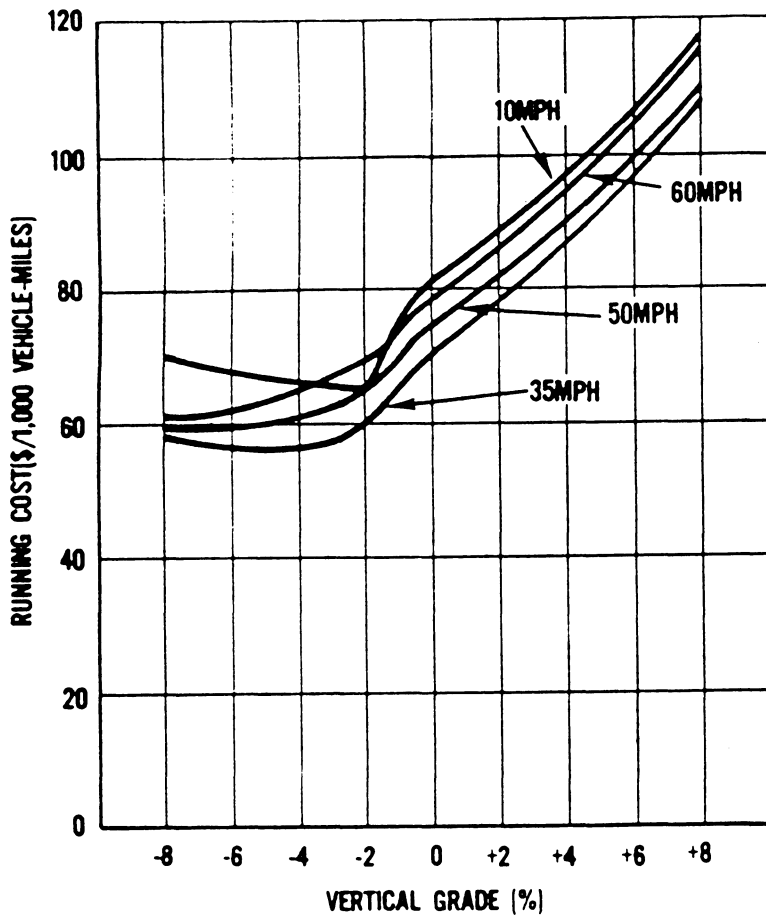


Figure 16. Passenger Running Cost at Uniform Speed

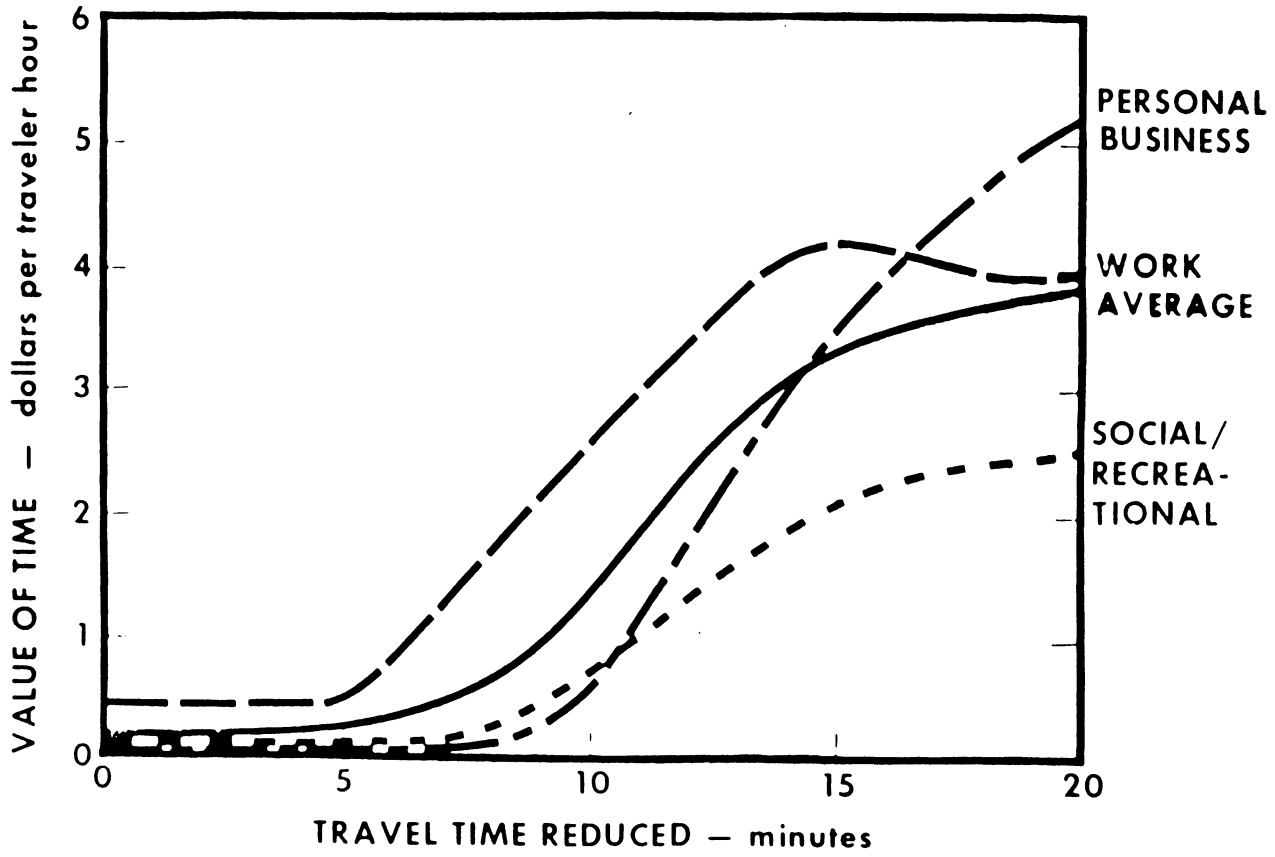


Figure 17. Value of Time as a Function of Travel Time Reduced, by Purpose

evaluation is the one conducted by the National Highway Traffic Safety Administration in 1975 (Fig. 18) [17]. It is assumed that the accidents will be reduced by 20% for each lane added to the freeway.

### **4.3.3 Revenues**

Two different choices in the way of funding the freeway. In the first one, the freeway is financed from three different funds, a fuel tax, a car sales tax, and a fixed federal fund for construction, and maintenance and operation of the facility. In the second one the funds come from converting the facility a toll freeway.

### **4.3.4 Determination of the Economic Parameters**

The methodology to be used is the same that was explained in Chapter 3. With the values of C, E and R determine, one can get:

- (1) Present worth, PW, using Eq. 3.21
- (2) Annual Cost, AC, using Eq. 3.22
- (3) Rate of Return, ROR, using Eq. 3.23 with trial and error method.
- (4) Benefit-Cost ratio, BC using Eq. 3.24
- (5) Time to amortize the cost, PT, using Eq. 3.31

Study Conducted By	Study Year	Cost in Dollars		
		Fatality	Nonfatal Personal Injury	Property Damage Only
National Highway Traffic Safety Administration 400 7th Street, SW. Washington, D.C. 20590 (See Reference No. 11)	1975	6. 287,175*	5. 192,240*	520
			4. 86,955*	
			3. 8,085*	
			2. 4,350*	
			1. 2,190*	
			Avg. Inj. 3,185	
National Safety Council 444 North Michigan Ave. Chicago, Illinois 60611 (See Reference No. 12)	1976	125,000	A. 10,500**	670
			B. 3,000**	
			C. 700**	
		Avg. Inj. 4,700		
	1975	110,000	A. 9,000**	570
			B. 2,600**	
		C. 630**		
	Avg. Inj. 4,200			

\*The average costs per fatality and injury are shown by Abbreviated Injury Scale (AIS) developed by the American Medical Association, Society of Automotive Engineers, and American Association of Automotive Medicine. The scale, as it now stands, is as follows:

<u>AIS Code</u>	<u>Category</u>	<u>AIS Code</u>	<u>Category</u>
1	Minor	4	Severe (life threatening survival probable)
2	Moderate	5	Critical (survival uncertain)
3	Severe (not life threatening)	6	Maximum Severity (currently untreatable)

\*\*The letter designations for injuries are defined in the Manual on Classification of Motor Vehicle Traffic Accidents, ANSI Standard D 16.1-1970, as follows:

- A. Incapacitating Injury
- B. Nonincapacitating Evident Injury
- C. Possible Injury

Figure 18. Cost of Accidents

## **4.3.5 Environmental Impacts**

### ***4.3.5.1 Energy Consumption***

Because of the rapid increase of the prices of oil during the 1970s, fuel consumption is a topic that was faced with big emphasis. Fuel consumption is related with speed, being high values associated with low speeds, decreasing with the increase of speed, reaching a minimum at 35 mph approximately, and increasing slightly for higher values of speed. For this problem the were found in Fig. 19, and it is called FC1 in the computer program [17].

### ***4.3.5.2 Air Pollution***

It is known that a change in a transportation facility will cause a change in the air quality. The emission of pollutants are also related with speed. Carbon monoxide (CO) and hydrocarbons (HC) follow the same trend that fuel consumption does, the difference is that the minimum value for emission is observed at 45 mph approximately. On the other hand hand, nitrogen oxides (NOX), has almost direct linear relation with speed. These values can be found in Fig. 19 [17].

Other important impacts that affect the environment are noise and visual impacts. However, they are not considered in this study because of their complexity and/or difficulty of quantifying them.

**Fuel Consumption and Emissions  
of Carbon Monoxide, Hydrocarbons, and  
Nitrogen Oxides from Driving 1,000  
Miles at Various Uniform Speeds  
(For light-duty vehicles)**

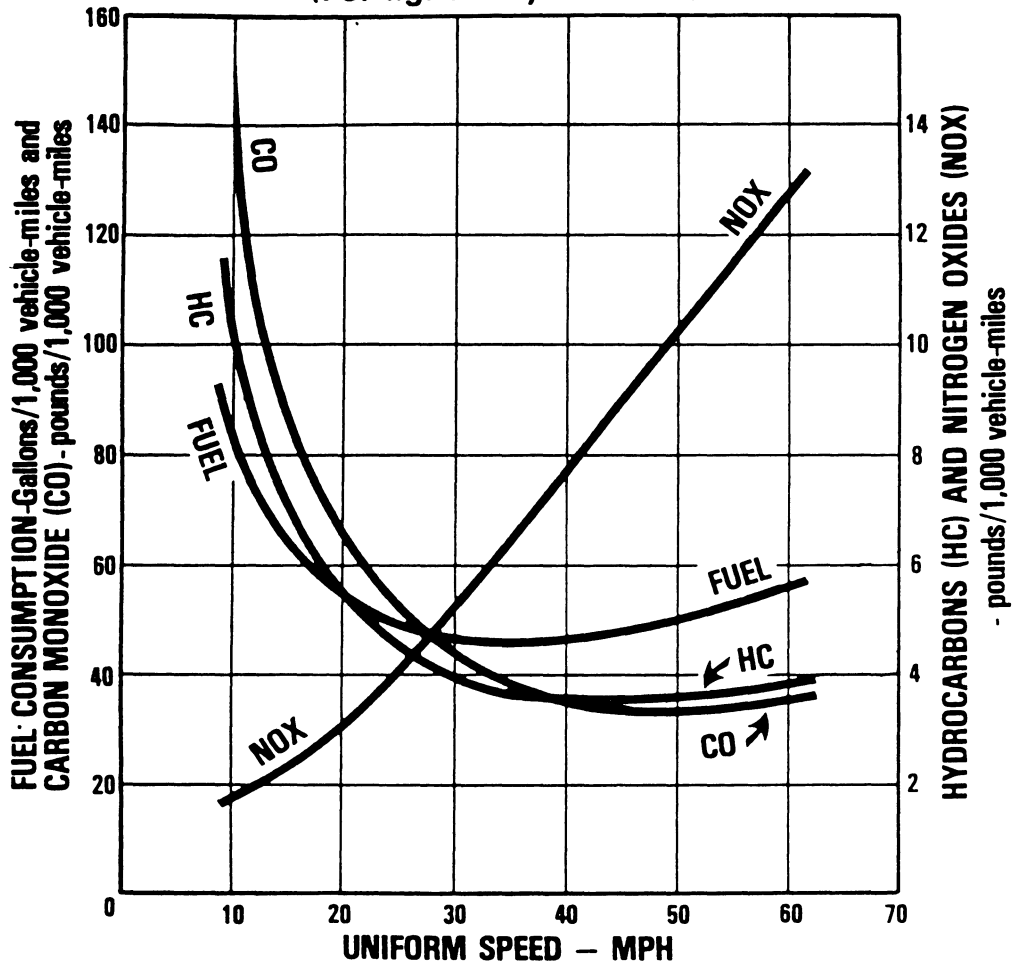


Figure 19. Environmental Costs

### 4.3.6 Socio-Economic Impacts

Although they are difficult to measure, socio-economic impacts such as relocation, land value and retail sales variations, accessibility, community effects, etc., are that important that may alter drastically the result of the decision-making process.

Variation in retail sales and land value impacts are an example of economic impacts. Horwood [17] did several highway impact studies in the 1960s concentrating in the two mentioned above. He divided them in three different categories, by-pass studies, urban circumferential studies, and urban radial freeway studies. He based the studies on information from sales-tax for retail sales, and from real-estate firms for land value. But sometimes it is difficult to distinguish between the impacts of the improvement or construction of a new facility, and the impacts of previous economic situation or seasonal changes.

As an example of social impacts, relocation can be mentioned as the one that was given the most attention. Probably, because it affects the most disadvantaged sectors of the community. Christensen and Jackson [18] said about the topic:

When expressways run through a major city, large numbers of people and many businesses are displaced. Unfortunately, the highways are frequently routed through the least desirable sections of the city, and those who are displaced are the poor, the aged, and those who are least able to take care of themselves, and there is little likelihood that many of them will use the highway that displaces them....

In theory, relocation assistance is simple. In practice it is difficult, complicated, and time-consuming. Frequently, successful relocation depends on solving personal problems, both financial and social, in addition to finding replacement property.

These impacts differ from place to place, but experiences from past projects can be of great utility for the planner. Collection of socio-economic past and present data from the area to be affected by the new transportation facility is mandatory in order to have a good background for forecasting the conditions after the construction of it.

In this study, because of the complexity and the need of external data, these impacts are not going to be included in the evaluation, but notice the reader of the importance of them.

## 5.0 The Results

### 5.1 Introduction

As it was explained before, in this chapter the numerical results of the evaluation of the freeway construction of Asimopolis are to be presented. These results have been obtained from the UTPP DYNAMO computer program that can be found in Appendix B, that was used to solve the equations explained in Chapter 4. To make the reading easier, the solutions are presented in tables for the horizon year, broken down in sections with brief explanations to remind the reader of the procedure explained in the last chapter, and with comments about the results. Then the discussion is done and the decision is taken.

Within the tables, the results are compared for the different project alternatives that will be called as follows:

Alternative 1: 4 freeway lanes (2 in each direction)

Alternative 2: 6 freeway lanes (3 in each direction)

Alternative 3: 8 freeway lanes (4 in each direction)

Alternative 4: 10 freeway lanes (5 in each direction)

Alternative 5: 12 freeway lanes (6 in each direction)

## 5.2 Travel Demand

Given:

$$J_1 = 40,000, J_2 = 40,000$$

$$t_{21} = 18, t_{31} = 19, t_{41} = 30$$

$$t_{22} = 13, t_{32} = 14, t_{42} = 25$$

$$x = 1$$

$$H_2 = 125,000, H_3 = 38,000, H_4 = 225,000$$

$$\text{LPF} = 0.4$$

the values of laborforce,  $L_i$ , and population,  $P_i$ , for the horizon year are in Table 7.

**Table 7. Values of Laborforce and Population for the Horizon Year**

Alternative	1	2	3	4	5
$L_2$	29,890	29,390	29,070	28,860	28,700
$L_3$	10,980	11,090	11,140	11,160	11,200
$L_4$	39,130	39,520	39,790	39,980	40,100
$P_2$	74,730	73,470	72,680	72,140	71,750
$P_3$	27,450	27,720	27,850	27,910	28,000
$P_4$	97,810	98,810	99,470	99,900	100,300

With the values of laborforce,  $L_i$ , and jobs,  $J_j$  and through Eq. 4.11 and 4.12, the values of the trip generation analysis can be obtained (Table 8).

**Table 8. Values of Origins and Destination the Horizon Year**

Alternative	1	2	3	4	5
$O_2$	29,890	29,390	29,070	28,860	28,700
$O_3$	10,980	11,090	11,140	11,160	11,200
$O_4$	39,130	39,520	39,790	39,980	40,100
$D_1$	40,000	40,000	40,000	40,000	40,000
$D_2$	40,000	40,000	40,000	40,000	40,000

With the values of origins and destination for the horizon year and with equations explained in Sec. 4.2.3, one can get the number of trips from  $i$  to  $j$ ,  $V_{ij}$  (Table 9)

**Table 9. Values of Trip Distribution Analysis for the Horizon Year**

Alternative	1	2	3	4	5
$V_{21}$	15,830	15,560	15,380	15,250	15,160
$V_{31}$	5,074	5,131	5,165	5,190	5,212
$V_{41}$	19,100	19,310	19,450	19,560	19,630
$V_{22}$	14,070	13,830	13,690	13,610	13,540
$V_{32}$	5,907	5,957	5,976	5,974	5,987
$V_{42}$	20,030	20,210	20,330	20,420	20,470

**Table 10. Values of Choice Riders for the Horizon Year**

Alternative	1	2	3	4	5
$V_{21}^{CH}$	10,590	10,590	10,580	10,570	10,560
$V_{31}^{CH}$	4,621	4,628	4,636	4,649	4,654
$V_{41}^{CH}$	17,080	17,100	17,110	17,120	17,130
$V_{22}^{CH}$	9,411	9,413	9,418	9,431	9,435
$V_{32}^{CH}$	5,379	5,372	5,364	5,351	5,346
$V_{42}^{CH}$	17,920	17,900	17,890	17,880	17,870

**Table 11. Values of Captive Riders for the Horizon Year**

Alternative	1	2	3	4	5
$V_{21}^{CA}$	5,258	4,969	4,800	4,680	4,595
$V_{31}^{CA}$	454	504	529	541	558
$V_{41}^{CA}$	2,014	2,211	2,341	2,436	2,497
$V_{22}^{CA}$	4,655	4,418	4,272	4,176	4,104
$V_{32}^{CA}$	528	585	612	623	641
$V_{42}^{CA}$	2,112	2,314	2,447	2,543	2,605

Tables 10 and 11 are the results of the trip end modal split analysis, and were obtained with the number of trips,  $V_{ij}$ , and the car ownership,  $C_i$  (Eq. 4.23 and 4.24).

Up to this point the reader can see that the values in Tables 7 to 11 change at most 10% among the different alternatives. That is because the number of jobs for the horizon year are fixed.

Tables 12 and 13 were obtained with the number of captive and choice riders and with the equations explained in Sec. 4.2.5 and 4.2.6. In this case the generalized costs for bus and car vary over the years (bus fares, price of oil, etc.)

**Table 12. Values of Car-Trips for the Horizon Year**

Alternative	1	2	3	4	5
$V_{21}^c$	10,260	10,240	10,230	10,230	10,230
$V_{31}^c$	4,608	4,546	4,551	4,567	4,576
$V_{41}^c$	17,070	16,960	16,970	16,990	17,010
$V_{22}^c$	8,891	8,893	8,898	8,910	8,914
$V_{32}^c$	5,361	5,268	5,258	5,245	5,244
$V_{42}^c$	17,890	17,740	17,730	17,730	17,730

**Table 13. Values of Bus-Trips for the Horizon Year**

Alternative	1	2	3	4	5
$V_{21}^b$	5,572	5,319	5,153	5,023	4,933
$V_{31}^b$	467	586	613	623	636
$V_{41}^b$	2,033	2,350	2,483	2,568	2,619
$V_{22}^b$	5,174	4,937	4,792	4,697	4,625
$V_{32}^b$	546	689	718	729	743
$V_{42}^b$	2,135	2,471	2,605	2,694	2,747

With the number of trips by car and by bus, and the occupancy factors (Eq. 4.36 and 4.37) one gets the number of cars and buses in the network for the horizon year (Tables 14 and 15).

**Table 14. Number of Cars the Horizon Year**

Alternative	1	2	3	4	5
$Q_{21}^b$	6,386	6,349	6,350	6,357	6,362
$Q_{32}^b$	8,985	8,903	8,902	8,906	8,911
$Q_{43}^b$	6,992	6,941	6,940	6,944	6,947

**Table 15. Number of Buses for the Horizon Year**

Alternative	1	2	3	4	5
$Q_{21}^b$	81	83	82	82	82
$Q_{32}^b$	52	61	64	66	67
$Q_{43}^b$	42	48	51	53	54

Tables 16 to 19 are the results of the network assignment analysis. The values were obtained following the procedure explained in Sec. 4.2.8. Notice that the number of cars on freeway does not increase for alternatives 4 and 5 (Table 16), that the number of cars on arterial is 0 for alternatives 4 and 5 (Table 17). Speeds on freeway vary from 50 mph to 70 mph (Table 18), but as the distances travelled are not very long, 17 miles at the most, the savings of time never go beyond 2 minutes (Table 19).

**Table 16. Values of Cars on Freeway for the Horizon Year**

Alternative	1	2	3	4	5
$Q_{21}^f$	4,077	5,418	6,350	6,357	6,362
$Q_{32}^f$	4,406	6,712	8,007	8,906	8,911
$Q_{43}^f$	4,236	6,010	6,940	6,944	6,947

**Table 17. Values of Cars on Arterial for the Horizon Year**

Alternative	1	2	3	4	5
$Q_{21}^{ar}$	2,308	931	0	0	0
$Q_{32}^{ar}$	4,580	2,192	895	0	0
$Q_{43}^{ar}$	2,756	931	0	0	0

**Table 18. Values of Speed on the Freeway for the Horizon Year**

Alternative	1	2	3	4	5
$v_{21}^f$	55.52	59.90	63.27	67.43	69.88
$v_{32}^f$	51.46	50.42	56.29	60.31	64.70
$v_{43}^f$	53.71	56.26	61.06	65.97	68.78

**Table 19. Values of travel time on Freeway for the Horizon Year**

Alternative	1	2	3	4	5
$t_{21}^f$	5.40	5.01	4.74	4.45	4.29
$t_{32}^f$	5.83	5.95	5.33	4.97	4.64
$t_{43}^f$	7.82	7.46	6.88	6.37	6.11

**Table 20. Values of Weighted Travel Time for the Horizon Year**

Alternative	1	2	3	4	5
$Wt_{21}$	25.39	24.63	24.19	23.89	23.71
$Wt_{31}$	24.27	22.88	22.07	21.49	21.11
$Wt_{41}$	38.06	35.88	34.60	33.67	33.10
$Wt_{22}$	18.15	18.00	17.90	17.83	17.78
$Wt_{32}$	18.53	17.52	16.98	16.66	16.41
$Wt_{42}$	32.26	30.48	29.46	28.78	28.34

The equilibrium check for the horizon year (Table 20) is a very important step because assures that the times assumed in the beginning of the process correspond with the ones obtained in network assignment analysis. In this study, they correspond to each other and the equilibrium is assured.

### ***5.3 Economic Evaluation***

Tables 21 and 22 are a summary of the economic and environmental parameters that were obtained following the procedure explained in Sec. 4.3. It is helpful to remind the reader of the meaning of the variables in both tables: C is the construction cost (millions \$); EF, maintenance and operation costs of the freeway (millions \$); EACC, accident costs (millions \$); E, total annual expenses (millions \$); R, total annual revenues (millions \$); PW, present worth (millions \$); AC, annual cost (millions \$); ROR, rate of return (%); BC, benefit-cost ratio (dim.); PT, time to amortize the cost (years); FC1, fuel consumption (million of gallons); CO1, carbon monoxide (pounds); HC1, hydrocarbons (pounds); NOX1, nitrogen oxides (pounds).

**Table 21. Values of Economic Evaluation Parameters for the case of the non-toll facility**

Alternative	1	2	3	4	5
C (M)	34.00	40.00	45.00	49.00	52.00
EF (M)	0.36	0.44	0.52	0.60	0.68
ERC (M)	0.59	0.85	1.01	1.07	1.09
EACC (M)	1.22	0.92	0.62	0.32	0.31
E (M)	2.17	2.21	2.15	1.99	2.08
R (M)	5.15	6.65	7.69	8.22	8.51
PW (M)	-0.02	10.54	17.97	21.76	21.05
AC (M)	0.00	-0.93	-1.58	-1.91	-1.85
ROR (%)	7.9	10.6	11.9	12.3	11.9
BC	0.99	1.26	1.40	1.44	1.41
PT (YR)	30.07	15.90	13.11	12.42	13.03
FCI (G*E6)	6.85	9.99	12.36	13.58	14.11
CO1 (P)	4.48	6.50	7.94	8.68	8.98
HC1 (P)	0.46	0.71	0.86	0.95	0.99
NOX1 (P)	1.47	2.18	2.82	3.18	3.37

**Table 22. Values of Economic Evaluation Parameters for the case of the toll facility**

Alternative	1	2	3	4	5
C (M)	34.00	40.00	45.00	49.00	52.00
EF (M)	0.36	0.44	0.52	0.60	0.68
ERC (M)	0.59	0.85	1.01	1.07	1.09
EACC (M)	1.22	0.92	0.62	0.32	0.31
E (M)	2.17	2.21	2.15	1.99	2.08
R (M)	5.42	7.72	9.04	9.37	9.38
PW (M)	2.96	22.70	33.34	34.88	30.97
AC (M)	-0.26	-1.99	-2.93	-3.07	-2.73
ROR (%)	8.8	13.5	15.1	14.8	13.8
BC	1.09	1.57	1.74	1.71	1.60
PT (YR)	30.07	15.90	13.11	12.42	13.03
FC1 (G*E6)	6.85	9.99	12.36	13.58	14.11
CO1 (P)	4.48	6.50	7.94	8.68	8.98
HC1 (P)	0.46	0.71	0.86	0.95	0.99
NOX1 (P)	1.47	2.18	2.82	3.18	3.37

The interpretation and discussion of the results of the evaluation are explained in Chapter 6, because they are, at the same time, part of the conclusion of the whole study.

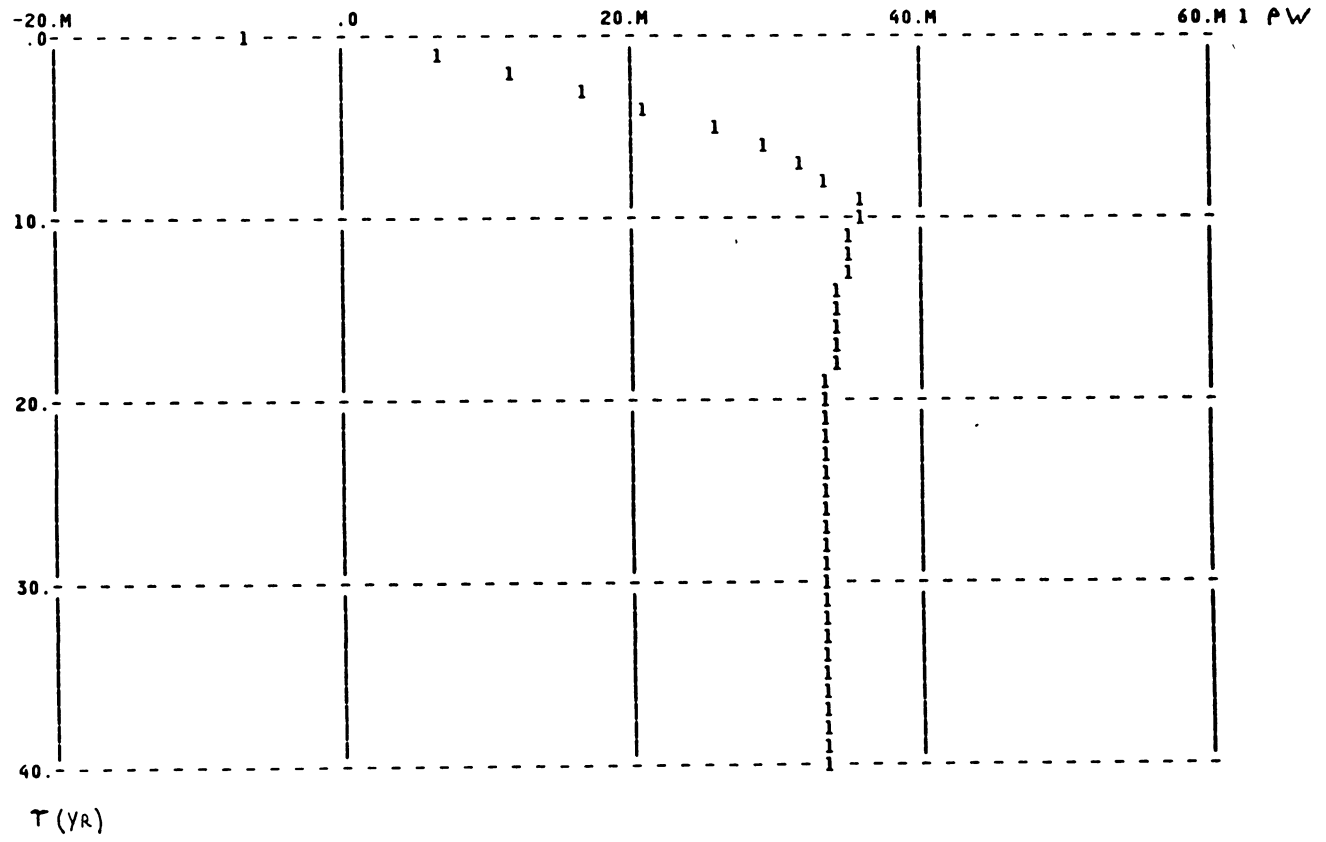


Figure 20. Present Worth for Alternative 3 (toll facility)

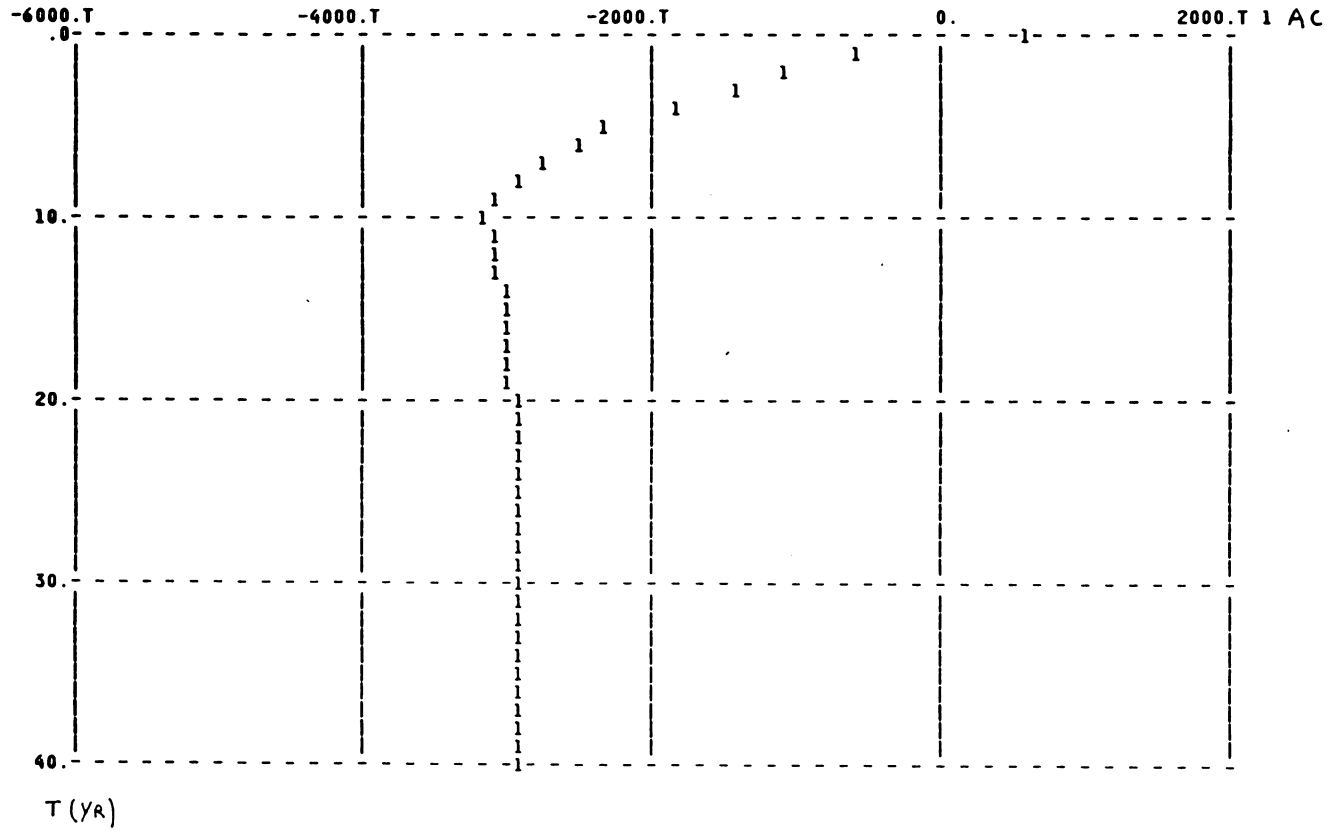


Figure 21. Annual Cost for Alternative 3 (toll facility)

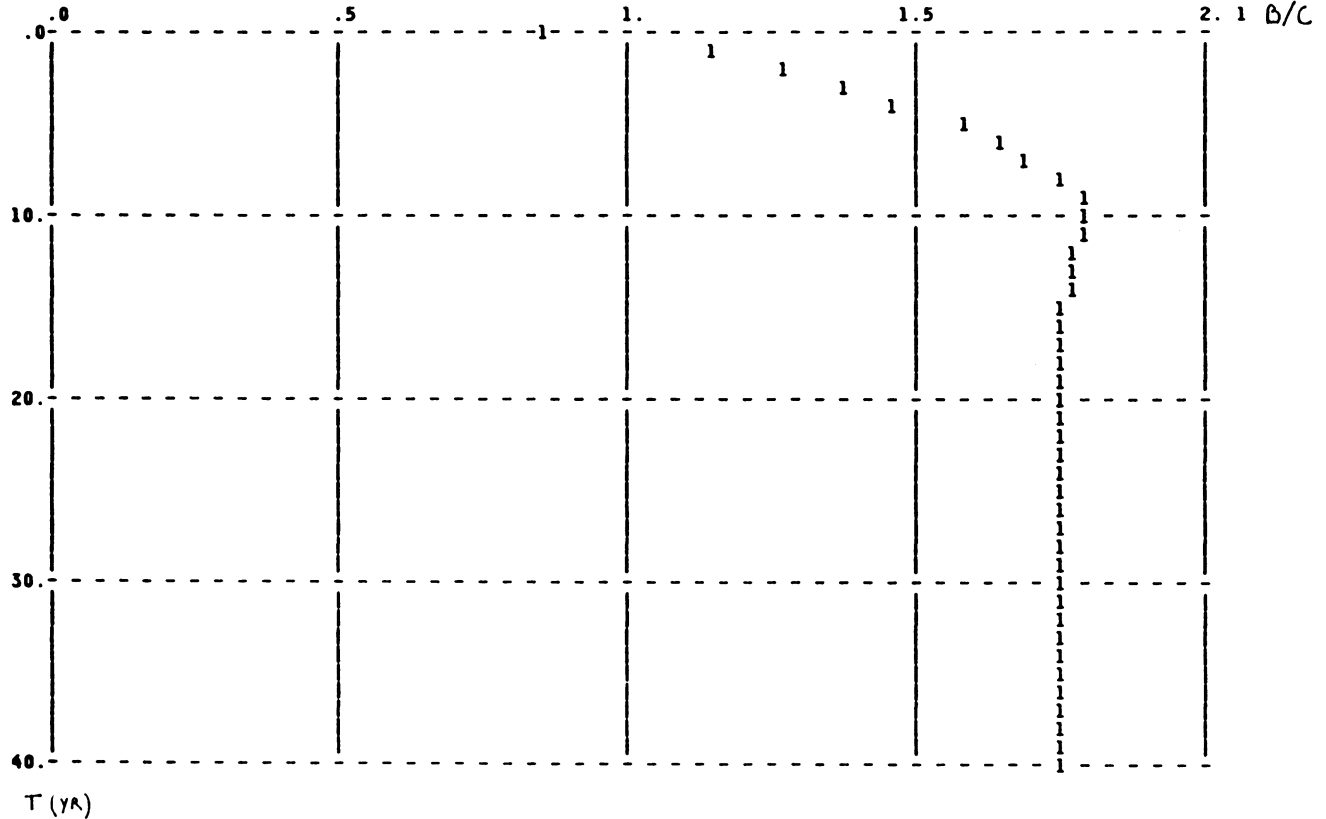


Figure 22. Benefit-Cost Ratio for Alternative 3 (toll facility)

## 5.4 Discussion

In the first part of this chapter the results of the evaluation for the cases of non-toll and toll freeway (Chapter 5) are going to be discussed. The values for the first case can be found in Table 21, and the ones for the second case in Table 22. The dynamic characteristics of this study allows the decision-maker to see how every single variable involved in it, is evolving through the years. As an example, the evolution of the present worth (PW), annual cost (AC), and benefit-cost ratio (BC) for alternative 3 (4 lanes each direction) for the case of the toll facility are shown in Figs. 20, 21, and 22 respectively.

Now it is time to analyze the results in order to select the "best" alternative for each of the two cases. Looking at the values in Tables 21 and 22, one can notice some common patterns:

- as the number of lanes increases, the "environmental" parameters (FC1, CO1, HC1, NOX1) increase
- as the number of lanes increases, the cost of the facility (C), operation and maintenance costs (EF), running costs (ERC), and revenues (R) increase
- as the number of lanes increase, the number of accidents decrease
- the economic indicators, present worth (PW), annual cost (AC), rate of return (ROR), benefit-cost ratio (BC), and payback time (PT) increase up to certain point and decrease (opposite for AC and PT)

It would not be sensible to take the decision just by looking at the table and selecting the alternative with the highest PW, ROR, BC and the lowest AC and PT (point of view of the investors, Chapter 1). It is also mandatory to look at the "bottom" of the table and determine the levels of emission of CO, HC, and NOX that will not damage the environment. But the framework

for the decision-maker is not complete. There are other considerations to be taken into account for the evaluation that are not shown in the table. These considerations refer to the socio-economic impacts in the area affected by the new transportation facility, such as excessive right of way and relocation effects, inappropriate and/or undesirable land development, unequal impact upon different population groups, accessibility to the disadvantaged, and so on. All these considerations are so important that may alter the final outcome of the decision-making process.

After analyzing the results and providing similar socio-economic impacts among the different alternatives, for the case of the non-toll facility one can see that the economic parameters for alternatives 3, 4 and 5 are very close to each other. The ones for alternative 4 are the "best", economically speaking. But the planning commission of Asimopolis, following the same rationale of the Mayor of Suburbia (Example 3.5), selects alternative 3 because the values are alike, and the initial investment and the environmental parameter are lower. For the case of the toll facility the economic parameters show that the "best" alternative is number 3. The planning commission, after looking at the environmental and social impacts, agrees with the outcome of the economic evaluation and decides to select alternative 3.

Summarizing, in both cases alternative 3 (4 lanes each direction) is the one chosen by the Asimopolis authorities to carry on their project of the new freeway.

## 6.0 Summary

### 6.1 *Conclusion*

The conclusion of this study is based on the results of the two major examples analyzed in its context, Example 3.4/5 (Suburbia development project) and Chapter 4 (The Scenario). In the first one, the problem was to determine the physical and economic feasibility of the construction of a new bedroom community across a bay from a big city and a bridge to link them. The problem was faced with the systems point of view, building a model with causal relationships. Basically there were two sectors, housing and transportation, and two decision variables which belonged each to one sector, number of houses to be built and number of traffic lanes in the bridge to be constructed. The evaluation was performed to get the best combination of both, considering them at the same time (one of the advantages of the systems approach) in order to optimize the solution and getting a better one than if they were considered separately. Then, based on the evaluation results and on external factors, the Mayor of Suburbia chose the alternative that fulfilled the community needs in the best way.

The second problem, the selection of freeway lanes for the construction of the new facility in Asimopolis was also faced with the systems approach translating in DYNAMO the equations of

the UTPP, allowing the planner to see the variation of the variables over time. For the dynamic evaluation several aspects, besides construction, maintenance and operation costs, were included, accident costs environmental factors, etc., to make the problem a more realistic one. Then, the planning commission took the decision to select the best alternative for their needs.

The writer believes that the methodology developed helped to achieve the objectives stated in the problems and the goals of transportation systems planning in general and wants to highlight several characteristics of this study:

- the systems point of view, which means to consider the problem as a part of a bigger problem that is related to it (transportation problem as a part of the urban problem) and it is more realistic than considering it as an isolated system with no relationship to the external environment
- the dynamic approach for the economic evaluation, that allows the decision-maker to realize how the parameters vary with time and could be useful to know, for example, how to manage the funds for the investment
- the consideration of social and environmental impacts for the evaluation, that make the problem closer to real life
- the fact that the methodology for evaluation is a tool for the decision-maker, will help him in his task and the more informed he is, the better framework to take a decision he will have, but it will never replace his judgment. As Alain Enthoven [11] said:

Ultimately all policies are made on the basis of judgments. There is no other way, and there never will be. The question is whether those judgments have to be made in the fog of inadequate and inaccurate data, unclear and undefined issues, and a welter of conflicting personal opinions, or whether they can be made on the basis of adequate, reliable information, relevant experience, and clearly drawn issues. In the end, analysis is but an aid to judgment.... Judgment is supremment.

## 6.2 *Recommendations*

The recommendations after this study are pretty much related to the conclusions. The writer recommends: first, identify the problem; understand the causal relationships between it and the environment; build a model of it in order to take advantage of all the mathematical and computing tools that are available; collect all the data useful for the study; solve the physical problem with its different alternatives; study the economical feasibility of them and determine which is the "best"; study all the environmental and social impacts in the area of interest, and see if the alternative selected as the "best" in the previous step does not go against the society; finally, use **judgment** when taking the decision.

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# Appendix A. DYNAMO Program of the Suburbia Development Model

NOTE \*\*\*\*\*  
 NOTE SUBURBIA DEVELOPMENT MODEL  
 NOTE \*\*\*\*\*  
 NOTE GLOSSARY  
 NOTE -----  
 NOTE HH-HOUSEHOLDS  
 NOTE HHI-HOUSEHOLDS INCREASE  
 NOTE HHIP-HH PROJECTED  
 NOTE TTSC-TRAVEL TIME S TO C  
 NOTE FT-FREEFLOW TRAVEL TIME  
 NOTE SSC-SPEED FROM S TO C  
 NOTE PD-PEAK HOURLY DEMAND  
 NOTE OS-TRIP ORIGINS IN S  
 NOTE PS-POPULATION OF S  
 NOTE CT-CONGESTED TRAVEL TIME  
 NOTE HC-HOURLY CAPACITY  
 NOTE K-ACCESSIBILITY CONSTANT  
 NOTE HII-HOUSEHOLDS INITIALLY  
 NOTE HS-HOUSES IN SUBURBIA  
 NOTE JOBS IN CBD  
 NOTE HM-HOUSES IN METROPOLIS  
 NOTE TTMC-TRAVEL TIME FROM M TO C  
 NOTE AHS-AVERAGE HOUSEHOLD SIZE  
 NOTE LPF-LABOR PARTICIPATION FACTOR  
 NOTE CPL-CAPACITY PER LANE  
 NOTE DSC-DISTANCE FROM S TO C  
 NOTE FS-FREE SPEED  
 NOTE PHF-PEAK HOUR FACTOR  
 NOTE VEHICLE OCCUPANCY  
 NOTE TPP-TRIPS PER PERSON

```

NOTE      NBL-NUMBER OF BRIDGE LANES
NOTE      HPT-HOUSING PERCEPTION TIME
NOTE
NOTE      EQUATIONS
NOTE      -----
NOTE
L          HH.K = HH.J + (DT)(HHI.JK)
R          HHI.KL = (MIN(HS,HHP.K)-HH.K)/HPT
A          HHP.K = (K*HS*JC*TTMC)/(AHS*LPF*HM*TTSC.K)
A          TTSC.K = CLIP(FT.K,CT.K,HC,PD.K)
A          FT.K = DSC/SSC.K
A          SSC.K = FS*(1-PD.K)/(2*HC)
A          PD.K = OS.K*PHF/VO
A          OS.K = PS.K*TPP
A          PS.K = HH.K*AHS
A          CT.K = TABXT(CTT,PD.K/HC,1,1.2,.2)
T          CTT = .25/.45
N          HC = CPL*NBL/2
NOTE
NOTE      CONSTANTS
NOTE      -----
NOTE
N          HH = HHN
C          HHN = 0
C          HS = 15000
C          JC = 2E6
C          HM = 1.5E6
C          TTMC = .75
C          AHS = 4
C          LPF = .5
C          CPL = 2400
C          DSC = 10
C          FS = 80
C          PHF = .2
C          VO = 1.0
C          TPP = 1.0
C          NBL = 8
C          HPT = 3
C          K = 1.0
NOTE      *****
NOTE      EQUATIONS FOR THE ECONOMIC EVALUATION OF SUBURBIA
DEVELOPMENT
NOTE      MODEL
NOTE      *****
A          RH.K = HH.K*UHR
C          UHR = 6000
A          EH.K = HS*UHE.K
A          UHE.K = TABLE(UHET,HS,0,27000,3000)
T          UHET = 1500/1300/1100/1000/900/900/950/1000/1050/1100
A          CH.K = HS*UHC.K
A          UHC.K = TABLE(UHCT,HS,0,27000,3000)
T          UHCT = 11E4/9E4/8E4/7E4/6E4/5.5E4/5E4/5.5E4/6E4/6.5E4
A          RB.K = OS.K*365*2*BT
C          BT = 1.25
A          EB.K = TABLE(EBT,NBL,2,12,2)
T          EBT = 4E6/5E6/6E6/7E6/8E6/9E6

```

```

A      CB.K = TABLE(CBT,NBL,2,12,2)
T      CBT = 140E6/200E6/280E6/380E6/500E6/640E6
A      R.K = RH.K + RB.K
A      E.K = EH.K + EB.K
A      C.K = CH.K + CB.K
N      FRN = (1-EXP(-I*N))/I
C      I = .08
C      N = 30
A      PW.K = (R.K-E.K)*FRN-C.K
A      AC.K = (C.K/FRN)-(R.K-E.K)
A      BC.K = ((R.K-E.K)/C.K)*FRN
A      RE.K = CLIP(1E-6,R.K-E.K,0,R.K-E.K)
A      CRE.K = CLIP(999999,1-(I*C.K/RE.K),I*C.K/RE.K,1)
A      PT.K = (-1/I)*LOGN(CRE.K)
SPEC  DT = .0625/LENGTH = 30/PRTPER = 1/PLTPER = 1
PRINT PW,AC,BC,PT
PLOT  PW,AC,BC,PT
RUN
QUIT

```

## Appendix B. DYNAMO Program of the UTPP

MODEL OF THE UTPP  
 NOTE \*\*\*\*\*  
 NOTE INDEX  
 NOTE \*\*\*\*\*  
 NOTE 1 . ALLOCATION OF RESIDENTIAL ACTIVITY USING THE  
 ACCESSIBILITY  
 NOTE MODEL  
 NOTE 2 . TRIP GENERATION ANALYSIS USING LINEAR REGRESSION  
 NOTE 3 . TRIP DISTRIBUTION ANALYSIS USING THE DOUBLE  
 CONSTRAINED  
 NOTE GRAVITY MODEL  
 NOTE 4 . TRIP END MODAL SPLIT ANALYSIS  
 NOTE 5 . DETERMINATION OF TRIP INTERCHANGE MODAL SPLIT  
 PARAMETERS  
 NOTE 6 . TRIP INTERCHANGE MODAL SPLIT ANALYSIS  
 NOTE 7 . DETERMINATION OF PEAK HOUR VEHICLE TRIP DEMANDS  
 NOTE 8 . NETWORK ASSIGNMENT ANALYSIS  
 NOTE 9 . EQUILIBRIUM CHECK OF HORIZON YEAR DEMAND FUNCTION  
 NOTE 10. ECONOMIC EVALUATION  
 NOTE 11. CONTROL STATEMENTS  
 NOTE 12. COMPUTER OUTPUT  
 NOTE \*\*\*\*\*  
 NOTE 1 . ALLOCATION OF RESIDENTIAL ACTIVITY USING THE  
 ACCESSIBILITY  
 NOTE MODEL  
 NOTE \*\*\*\*\*  
 NOTE GLOSSARY  
 NOTE -----  
 NOTE ATACIJ-INITIAL ASSUMED PEAK-HR TRAVEL TIME FROM I TO J  
 (MIN)  
 NOTE WTTAIJ-WEIGHTED TRAVEL TIME FROM NETWORK ASSIGNMENT  
 FROM I TO J  
 NOTE (MIN)  
 NOTE TTAIJ-PEAK-HOUR TRAVEL TIME FROM I TO J CALCULATED WITH  
 WTTAIJ  
 NOTE FROM NETWORK ASSIGNMENT (MIN)  
 NOTE TACIJ-PEAK-HOUR TRAVEL TIME FROM I TO J USED IN THE  
 ACCESSIBILITY  
 NOTE MODEL (MIN)  
 NOTE JJHY-JOBS IN ZONE J IN HORIZON YEAR (PERSONS)

NOTE LIHY-LABORFORCE IN ZONE I IN HORIZON YEAR (PERSONS)  
 NOTE ACI-ACCESSIBILITY TO EMPLOYMENT IN ZONE I (PERSONS/MIN)  
 NOTE HI-HOLDING CAPACITY IN ZONE I (PERSONS)  
 NOTE FLI-FACTOR USED IN THE FORMULA FOR LIHY (DIM)  
 NOTE LPFI-LABOR PARTICIPATION FRACTION IN ZONE I (DIM)  
 NOTE PIHY-POPULATION IN ZONE I IN THE HORIZON YEAR (PERSONS)  
 NOTE HI-HOLDING CAPACITY IN ZONE I (PERSONES)

NOTE EQUATIONS

NOTE -----

NOTE  
 A TAC21.K = CLIP(ATAC21,TTA21.K,0,TTA21.K)  
 L TTA21.K = TTA21.J + (DT)(WTTA21.J-TTA21.J)  
 N TTA21 = 0  
 C ATAC21 = 18  
 A AC2.K = (J1.K/TAC21.K) + (J2.K/TAC22.K)  
 C J1HY = 40000  
 C J2HY = 40000  
 A L2.K = FL2.K\*(J1.K + J2.K)  
 A FL2.K = (AC2.K\*H2)/(AC2.K\*H2 + AC3.K\*H3 + AC4.K\*H4)  
 C H2 = 125000  
 C H3 = 38000  
 C H4 = 225000  
 A P2.K = L2.K/LPF2  
 C LPF2 = .4  
 A TAC31.K = CLIP(ATAC31,TTA31.K,0,TTA31.K)  
 L TTA31.K = TTA31.J + (DT)(WTTA31.J-TTA31.J)  
 N TTA31 = 0  
 C ATAC31 = 19  
 A AC3.K = (J1.K/TAC31.K) + (J2.K/TAC32.K)  
 A L3.K = FL3.K\*(J1.K + J2.K)  
 A FL3.K = (AC3.K\*H3)/(AC2.K\*H2 + AC3.K\*H3 + AC4.K\*H4)  
 A P3.K = L3.K/LPF3  
 C LPF3 = .4  
 A TAC41.K = CLIP(ATAC41,TTA41.K,0,TTA41.K)  
 L TTA41.K = TTA41.J + (DT)(WTTA41.J-TTA41.J)  
 N TTA41 = 0  
 C ATAC41 = 30  
 A AC4.K = (J1.K/TAC41.K) + (J2.K/TAC42.K)  
 A L4.K = FL4.K\*(J1.K + J2.K)  
 A FL4.K = (AC4.K\*H4)/(AC2.K\*H2 + AC3.K\*H3 + AC4.K\*H4)  
 A P4.K = L4.K/LPF4  
 C LPF4 = .4  
 A TAC22.K = CLIP(ATAC22,TTA21.K,0,TTA22.K)  
 L TTA22.K = TTA22.J + (DT)(WTTA22.J-TTA22.J)  
 N TTA22 = 0  
 C ATAC22 = 13  
 A TAC32.K = CLIP(ATAC32,TTA32.K,0,TTA32.K)  
 L TTA32.K = TTA32.J + (DT)(WTTA32.J-TTA32.J)  
 N TTA32 = 0  
 C ATAC32 = 14  
 A TAC42.K = CLIP(ATAC42,TTA42.K,0,TTA42.K)  
 L TTA42.K = TTA42.J + (DT)(WTTA42.J-TTA42.J)  
 N TTA42 = 0  
 C ATAC42 = 25  
 A J1.K = INPUT1\*TABLE(J1T1,TIME.K,0,40,5)

```

X      + INPUT2*TABLE(J1T2,TIME.K,0,40,5)
X      + INPUT3*TABLE(J1T3,TIME.K,0,40,5)
T      J1T1 = 30000/35000/37500/39000/40000/40000/40000/40000/40000
T      J1T2 = 30000/32500/35000/37500/40000/42500/45000/47500/50000
T      J1T3 = 30000/31000/33000/36000/40000/44000/47000/49000/50000
A      J2.K = INPUT1*TABLE(J2T1,TIME.K,0,40,5)
X      + INPUT2*TABLE(J2T2,TIME.K,0,40,5)
X      + INPUT3*TABLE(J2T3,TIME.K,0,40,5)
T      J2T1 = 10000/25000/32500/37500/40000/40000/40000/40000/40000
T      J2T2 = 10000/17500/25000/32500/40000/47500/55000/62500/70000
T      J2T3 = 10000/13500/19000/28000/40000/52000/61000/66500/70000
C      INPUT1 = 1,INPUT2 = 0,INPUT3 = 0
NOTE
NOTE      *
NOTE      2 . TRIP GENERATION ANALYSIS USING LINEAR REGRESSION
NOTE      *
NOTE      GLOSSARY
NOTE      -----
NOTE
NOTE      ALPHA-COEFFICIENT OF THE REGRESSION EQUATION ORIGINS
(DIM)
NOTE      BETA-COEFFICIENT OF THE REGRESSION EQUATION
DESTINATIONS (DIM)
NOTE      LIBY-LABORFORCE IN ZONE I IN THE BASE YEAR (PERSONS)
NOTE      JJBY-JOBS IN ZONE J IN THE BASE YEAR (PERSONS)
NOTE      OIBY-ORIGINS IN ZONE I IN THE BASE YEAR (PER-TRIP/DAY)
NOTE      DJBY-DESTINATIONS TO ZONE J IN THE BASE YEAR
(PER-TRIP/DAY)
NOTE      OIHY-ORIGINS IN ZONE I IN THE HORIZON YEAR (PER-TRIP/DAY)
NOTE      DJHY-DESTINATIONS TO ZONE J IN THE HORIZON YEAR
(PER-TRIP/DAY)
NOTE      LIHY-LABORFORCE IN ZONE I FROM THE ACCESSIBILITY MODEL
(PERSONS)
NOTE      JJHY-JOBS IN ZONE J FROM THE ACCESSIBILITY MODEL (PERSONS)
NOTE
NOTE      EQUATIONS
NOTE      -----
NOTE
N      ALPHA = (L2BY*O2BY + L3BY*O3BY + L4BY*O4BY)/
X      (((L2BY) 2) + ((L3BY) 2) + ((L4BY) 2))
C      L2BY = 30000
C      L3BY = 5000
C      L4BY = 5000
C      O2BY = 30000
C      O3BY = 6000
C      O4BY = 4000
N      BETA = (J1BY*D1BY + J2BY*D2BY)/(((J1BY) 2) + ((J2BY) 2))
C      J1BY = 10000
C      J2BY = 30000
C      D1BY = 10000
C      D2BY = 30000
A      O2.K = ALPHA*L2.K
A      O3.K = ALPHA*L3.K
A      O4.K = ALPHA*L4.K
A      D1.K = BETA*J1.K
A      D2.K = BETA*J2.K
NOTE

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NOTE 3 . TRIP DISTRIBUTION ANALYSIS USING THE DOUBLE  
CONSTRAINED

NOTE GRAVITY MODEL

NOTE

NOTE GLOSSARY

NOTE

NOTE

NOTE BJ-CONSTRAINT OF THE GRAVITY MODEL (DIM)

NOTE AI-CONSTRAINT OF THE GRAVITY MODEL (DIM)

NOTE TBJ-TRIAL VALUES OF THE CONSTRAINT BJ

NOTE VIJ-NUMBER OF TRIPS FROM ZONE I TO ZONE J  
(PERSONS-TRIP/DAY)

NOTE TTDIJ-PEAK-HR TRAVEL TIME FROM I TO J USED IN THE GRAVITY  
MODEL

NOTE (MIN). SAME THAT WAS USED IN THE ACCESSIBILITY MODEL

NOTE OI-ORIGINS IN ZONE I OBTAINED FROM THE GRAVITY MODEL  
(PER-TRIP/DAY)

NOTE DJ-DESTINATIONS TO ZONE J OBTAINED FROM THE GRAVITY  
MODEL

NOTE (PER-TRIP/DAY)

NOTE

NOTE EQUATIONS

NOTE

NOTE

NOTE

L  $B1.K = B1.J + (DT)(TB1.J - B1.J)$

N  $B1 = B1N$

C  $B1N = 1$

L  $B2.K = B2.J + (DT)(TB2.J - B2.J)$

N  $B2 = B2N$

C  $B2N = 1$

A  $TB1.K = (1/((A2.K * O2.K / TTD21.K) + (A3.K * O3.K / TTD31.K)$

X  $+ (A4.K * O4.K / TTD41.K)))$

N  $TB1 = 1$

A  $TB2.K = (1/((A2.K * O2.K / TTD22.K) + (A3.K * O3.K / TTD32.K)$

X  $+ (A4.K * O4.K / TTD42.K)))$

N  $TB2 = 1$

A  $A2.K = (1/((B1.K * D1.K / TTD21.K) + (B2.K * D2.K / TTD22.K)))$

A  $A3.K = (1/((B1.K * D1.K / TTD31.K) + (B2.K * D2.K / TTD32.K)))$

A  $A4.K = (1/((B1.K * D1.K / TTD41.K) + (B2.K * D2.K / TTD42.K)))$

A  $V21.K = A2.K * B1.K * O2.K * D1.K / TTD21.K$

A  $V31.K = A3.K * B1.K * O3.K * D1.K / TTD31.K$

A  $V41.K = A4.K * B1.K * O4.K * D1.K / TTD41.K$

A  $V22.K = A2.K * B2.K * O2.K * D2.K / TTD22.K$

A  $V32.K = A3.K * B2.K * O3.K * D2.K / TTD32.K$

A  $V42.K = A4.K * B2.K * O4.K * D2.K / TTD42.K$

A  $TTD21.K = TAC21.K$

A  $TTD31.K = TAC31.K$

A  $TTD41.K = TAC41.K$

A  $TTD22.K = TAC22.K$

A  $TTD32.K = TAC32.K$

A  $TTD42.K = TAC42.K$

NOTE

NOTE

NOTE

NOTE

NOTE

NOTE

NOTE

NOTE

NOTE

NOTE

4. TRIP END MODAL SPLIT ANALYSIS

GLOSSARY

-----

NOTE  
NOTE PICH-PERCENTAGE OF CHOICE RIDERS IN ZONE I (DIM)  
NOTE PICA-PERCENTAGE OF CAPTIVE RIDERS IN ZONE I (DIM)  
NOTE CARI-CAR OWNERSHIP FOR ZONE I (CARS)  
NOTE CIHY-NUMBER OF CARS IN ZONE I FOR THE HORIZON YEAR  
(CARS)  
NOTE VIJCH-NUMBER OF TRIPS FROM I TO J BY CHOICE RIDERS  
(PER-TRIP/DAY)  
NOTE IJCA-NUMBER OF TRIPS FROM I TO J BY CAPTIVE RIDERS  
(PER-TRIP/DAY)  
NOTE VIJ-NUMBER OF TRIPS FROM I TO J OBTAINED FROM THE  
GRAVITY MODEL  
NOTE (PER-TRIP/DAY)  
NOTE  
NOTE EQUATIONS  
NOTE -----  
NOTE  
A  $P2CH.K = CLIP(1.0, CAR2.K/O2.K, CAR2.K, O2.K)$   
A  $P3CH.K = CLIP(1.0, CAR3.K/O3.K, CAR3.K, O3.K)$   
A  $P4CH.K = CLIP(1.0, CAR4.K/O4.K, CAR4.K, O4.K)$   
A  $P2CA.K = 1.0 - P2CH.K$   
A  $P3CA.K = 1.0 - P3CH.K$   
A  $P4CA.K = 1.0 - P4CH.K$   
A  $V21CH.K = V21.K * P2CH.K$   
A  $V31CH.K = V31.K * P3CH.K$   
A  $V41CH.K = V41.K * P4CH.K$   
A  $V22CH.K = V22.K * P2CH.K$   
A  $V32CH.K = V32.K * P3CH.K$   
A  $V42CH.K = V42.K * P4CH.K$   
A  $V21CA.K = V21.K * P2CA.K$   
A  $V31CA.K = V31.K * P3CA.K$   
A  $V41CA.K = V41.K * P4CA.K$   
A  $V22CA.K = V22.K * P2CA.K$   
A  $V32CA.K = V32.K * P3CA.K$   
A  $V42CA.K = V42.K * P4CA.K$   
A  $CAR2.K = L2.K * C2HY / L2.K$   
A  $CAR3.K = L3.K * C3HY / L3.K$   
A  $CAR4.K = L4.K * C4HY / L4.K$   
C  $C2HY = 20000, C3HY = 10000, C4HY = 35000$   
NOTE \*  
NOTE 5. DETERMINATION OF TRIP INTERCHANGE MODAL SPLIT  
PARAMETERS \*  
NOTE \*  
NOTE GLOSSARY  
NOTE -----  
NOTE  
NOTE VTMT-AVERAGE VALUE OF TIME (\$/HR)  
NOTE VMIN-MINIMUM VALUE OF TIME (\$/HR)  
NOTE VMAX-MAXIMUM VALUE OF TIME (\$/HR)  
NOTE ADTCS-AVERAGE DIFFERENCE OF TIME WHEN CAR IS SELECTED  
(HR)  
NOTE ADTBS-AVERAGE DIFFERENCE OF TIME WHEN BUS IS SELECTED  
(HR)  
NOTE ADCCS-AVERAGE DIFFERENCE OF COST WHEN CAR IS SELECTED  
(\$)

NOTE ADCBS-AVERAGE DIFFERENCE OF COST WHEN BUS IS SELECTED  
(\$)  
NOTE CIJCAR-COST OF USING CAR FROM I TO J (\$)  
NOTE CDDIJ-COLLECTION DISTRIBUTION DISTANCE FROM I TO J (MI)  
NOTE LHDIJ-LENGTH OF HIGHWAY FROM I TO J (MI)  
NOTE UTCC-UNIT TRAVEL COST FOR CARS (\$/MI)  
NOTE CIJBUS-COST OF USING THE FROM I TO J (\$)  
NOTE TIJCAR-TIME SPENT USING CAR FROM I TO J (MIN)  
NOTE CDTIJC-COLLECTION DISTRIBUTION TIME FROM I TO J USING CAR  
(MIN)  
NOTE LHTIJ-INITIAL TIME ON HIGHWAY FROM I TO J (MIN)  
NOTE TIJCF-TRAVEL TIME FROM I TO J USING CAR ON HIGHWAY (MIN)  
NOTE TTCFIJ-TRAVEL TIME FROM I TO J USING CAR ON HIGHWAY  
OBTAINED  
NOTE FROM NETWORK ASSIGNMENT (MIN)  
NOTE TIJBUS-TIME SPENT USING BUS FROM I TO J (MIN)  
NOTE CDTIJB-COLLECTION DISTRIBUTION TIME FROM I TO J USING BUS  
(MIN)  
NOTE TIJBA-TRAVEL TIME FROM I TO J USING CAR ON ARTERIAL (MIN)  
NOTE TTBAIJ-TRAVEL TIME FROM I TO J USING BUS ON ARTERIAL  
OBTAINED  
NOTE FROM NETWORK ASSIGNMENT (MIN)  
NOTE  
NOTE EQUATIONS  
NOTE -----  
NOTE  
N  $VTMT = (VMIN + VMAX)/2$   
N  $VMIN = ADCCS/ADTCS$   
N  $VMAX = ADCBS/ADTBS$   
C  $ADCCS = 2.55$   
C  $ADTCS = 1.2$   
C  $ADCBS = 3.85$   
C  $ADTBS = 1.1167$   
A  $C21CAR.K = (CDD21 + LHD21)*UTCC.K$   
A  $C31CAR.K = (CDD31 + LHD31)*UTCC.K$   
A  $C41CAR.K = (CDD41 + LHD41)*UTCC.K$   
A  $C22CAR.K = (CDD22 + LHD22)*UTCC.K$   
A  $C32CAR.K = (CDD32 + LHD32)*UTCC.K$   
A  $C42CAR.K = (CDD42 + LHD42)*UTCC.K$   
A  $UTCC.K = TABHL(UTCCT, TIME.K, 0, 30, 30)$   
T  $UTCCT = .08/.16$   
C  $CDD21 = 4.125$   
C  $CDD31 = 2.75$   
C  $CDD41 = 4.625$   
C  $CDD22 = 2.875$   
C  $CDD32 = 4.375$   
C  $CDD42 = 6.125$   
C  $LHD21 = 5$   
C  $LHD31 = 10$   
C  $LHD41 = 17$   
C  $LHD22 = 0$   
C  $LHD32 = 5$   
C  $LHD42 = 12$   
A  $C21BUS.K = TABHL(BFT1, TIME.K, 0, 30, 30)$   
A  $C31BUS.K = TABHL(BFT1, TIME.K, 0, 30, 30)$   
A  $C41BUS.K = TABHL(BFT1, TIME.K, 0, 30, 30)$

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A      C22BUS.K = TABHL(BFT2,TIME.K,0,30,30)
A      C32BUS.K = TABHL(BFT1,TIME.K,0,30,30)
A      C42BUS.K = TABHL(BFT1,TIME.K,0,30,30)
T      BFT1 = .5/1.0
T      BFT2 = .25/.5
A      T21CAR.K = CDT21C + CLIP(LHT21,T21CF.K,0,T21CF.K)
A      T31CAR.K = CDT31C + CLIP(LHT31,T31CF.K,0,T31CF.K)
A      T41CAR.K = CDT41C + CLIP(LHT41,T41CF.K,0,T41CF.K)
A      T22CAR.K = CDT22C + CLIP(LHT22,T22CF.K,0,T22CF.K)
A      T32CAR.K = CDT32C + CLIP(LHT32,T32CF.K,0,T32CF.K)
A      T42CAR.K = CDT42C + CLIP(LHT42,T42CF.K,0,T42CF.K)
C      CDT21C = 13
C      CDT31C = 9
C      CDT41C = 13
C      CDT22C = 13
C      CDT32C = 9
C      CDT42C = 13
C      LHT21 = 5
C      LHT31 = 10
C      LHT41 = 17
C      LHT22 = 0
C      LHT32 = 5
C      LHT42 = 12
A      T21BUS.K = CDT21B + CLIP(LHT21,T21BA.K,0,T21BA.K)
A      T31BUS.K = CDT31B + CLIP(LHT31,T31BA.K,0,T31BA.K)
A      T41BUS.K = CDT41B + CLIP(LHT41,T41BA.K,0,T41BA.K)
A      T22BUS.K = CDT22B + CLIP(LHT22,T22BA.K,0,T22BA.K)
A      T32BUS.K = CDT32B + CLIP(LHT32,T32BA.K,0,T32BA.K)
A      T42BUS.K = CDT42B + CLIP(LHT42,T42BA.K,0,T42BA.K)
C      CDT21B = 32
C      CDT31B = 34
C      CDT41B = 49
C      CDT22B = 27
C      CDT32B = 31
C      CDT42B = 46
L      T21CF.K = T21CF.J + (DT)(TTCF21.J-T21CF.J)
L      T31CF.K = T31CF.J + (DT)(TTCF31.J-T31CF.J)
L      T41CF.K = T41CF.J + (DT)(TTCF41.J-T41CF.J)
L      T22CF.K = T22CF.J + (DT)(TTCF22.J-T22CF.J)
L      T32CF.K = T32CF.J + (DT)(TTCF32.J-T32CF.J)
L      T42CF.K = T42CF.J + (DT)(TTCF42.J-T42CF.J)
N      T21CF = 0
N      T31CF = 0
N      T41CF = 0
N      T22CF = 0
N      T32CF = 0
N      T42CF = 0
L      T21BA.K = T21BA.J + (DT)(TTBA21.J-T21BA.J)
L      T31BA.K = T31BA.J + (DT)(TTBA31.J-T31BA.J)
L      T41BA.K = T41BA.J + (DT)(TTBA41.J-T41BA.J)
L      T22BA.K = T22BA.J + (DT)(TTBA22.J-T22BA.J)
L      T32BA.K = T32BA.J + (DT)(TTBA32.J-T32BA.J)
L      T42BA.K = T42BA.J + (DT)(TTBA42.J-T42BA.J)
N      T21BA = 0
N      T31BA = 0
N      T41BA = 0

```

N T22BA = 0  
 N T32BA = 0  
 N T42BA = 0  
 NOTE \*  
 NOTE 6. TRIP INTERCHANGE MODAL SPLIT ANALYSIS  
 NOTE \*  
 NOTE GLOSSARY  
 NOTE -----  
 NOTE  
 NOTE ZIJCAR-GENERALIZED COST OF USING CAR FROM I TO J (\$)  
 NOTE ZIJBUS-GENERALIZED COST OF USING BUS FROM I TO J (\$)  
 NOTE DZIJ-DIFFERENCE OF GENERALIZED COSTS FROM I TO J (\$)  
 NOTE VTMTHY-AVERAGE VALUE OF TIME IN THE HORIZON YEAR (\$/HR)  
 NOTE PIJCAR-FRACTION OF TRIPS FROM I TO J DONE BY CAR (DIM)  
 NOTE PIJBUS-FRACTION OF TRIPS FROM I TO J DONE BY BUS (DIM)  
 NOTE VIJCAR-NUMBER OF TRIPS FROM I TO J BY CAR (PER-TRIP/DAY)  
 NOTE VIJBUS-NUMBER OF TRIPS FROM I TO J BY BUS (PER-TRIP/DAY)  
 NOTE VIJCH-NUMBER OF TRIPS FROM I TO J BY CHOICE RIDERS  
 OBTAINED FROM  
 NOTE TRIP END MODAL SPLIT ANALYSIS (PER-TRIP/DAY)  
 NOTE VIJCA-NUMBER OF TRIPS FROM I TO J BY CAPTIVE RIDERS  
 OBTAINED FROM  
 NOTE TRIP END MODAL SPLIT ANALYSIS (PER-TRIP/DAY)  
 NOTE  
 NOTE EQUATIONS  
 NOTE -----  
 NOTE  
 A  $Z21CAR.K = C21CAR.K + T21CAR.K * VTMTHY / 60$   
 A  $Z31CAR.K = C31CAR.K + T31CAR.K * VTMTHY / 60$   
 A  $Z41CAR.K = C41CAR.K + T41CAR.K * VTMTHY / 60$   
 A  $Z22CAR.K = C22CAR.K + T22CAR.K * VTMTHY / 60$   
 A  $Z32CAR.K = C32CAR.K + T32CAR.K * VTMTHY / 60$   
 A  $Z42CAR.K = C42CAR.K + T42CAR.K * VTMTHY / 60$   
 A  $Z21BUS.K = C21BUS.K + T21BUS.K * VTMTHY / 60$   
 A  $Z31BUS.K = C31BUS.K + T31BUS.K * VTMTHY / 60$   
 A  $Z41BUS.K = C41BUS.K + T41BUS.K * VTMTHY / 60$   
 A  $Z22BUS.K = C22BUS.K + T22BUS.K * VTMTHY / 60$   
 A  $Z32BUS.K = C32BUS.K + T32BUS.K * VTMTHY / 60$   
 A  $Z42BUS.K = C42BUS.K + T42BUS.K * VTMTHY / 60$   
 A  $DZ21.K = Z21BUS.K - Z21CAR.K$   
 A  $DZ31.K = Z31BUS.K - Z31CAR.K$   
 A  $DZ41.K = Z41BUS.K - Z41CAR.K$   
 A  $DZ22.K = Z22BUS.K - Z22CAR.K$   
 A  $DZ32.K = Z32BUS.K - Z32CAR.K$   
 A  $DZ42.K = Z42BUS.K - Z42CAR.K$   
 A  $P21BUS.K = 1.0 / (1.0 + EXP(DZ21.K))$   
 A  $P31BUS.K = 1.0 / (1.0 + EXP(DZ31.K))$   
 A  $P41BUS.K = 1.0 / (1.0 + EXP(DZ41.K))$   
 A  $P22BUS.K = 1.0 / (1.0 + EXP(DZ22.K))$   
 A  $P32BUS.K = 1.0 / (1.0 + EXP(DZ32.K))$   
 A  $P42BUS.K = 1.0 / (1.0 + EXP(DZ42.K))$   
 N  $VTMTHY = 2.1536 * VTMT$   
 A  $V21CAR.K = P21CAR.K * V21CH.K$   
 A  $V31CAR.K = P31CAR.K * V31CH.K$   
 A  $V41CAR.K = P41CAR.K * V41CH.K$   
 A  $V22CAR.K = P22CAR.K * V22CH.K$

A V32CAR.K = P32CAR.K\*V32CH.K  
A V42CAR.K = P42CAR.K\*V42CH.K  
A P21CAR.K = 1-P21BUS.K  
A P31CAR.K = 1-P31BUS.K  
A P41CAR.K = 1-P41BUS.K  
A P22CAR.K = 1-P22BUS.K  
A P32CAR.K = 1-P32BUS.K  
A P42CAR.K = 1-P42BUS.K  
A V21BUS.K = P21BUS.K\*V21CH.K + V21CA.K  
A V31BUS.K = P31BUS.K\*V31CH.K + V31CA.K  
A V41BUS.K = P41BUS.K\*V41CH.K + V41CA.K  
A V22BUS.K = P22BUS.K\*V22CH.K + V22CA.K  
A V32BUS.K = P32BUS.K\*V32CH.K + V32CA.K  
A V42BUS.K = P42BUS.K\*V42CH.K + V42CA.K  
NOTE \*  
NOTE 7. DETERMINATION OF PEAK HOUR VEHICLE TRIP DEMANDS  
NOTE \*  
NOTE GLOSSARY  
NOTE -----  
NOTE  
NOTE QIJC-PEAK-HR TRIP DEMAND FROM I TO J USING CAR  
(VEH-TRIP/HR)  
NOTE QIJB-PEAK-HR TRIP DEMAND FROM I TO J USING BUS  
(VEH-TRIP/HR)  
NOTE FDTPH-FRACTION OF DAILY TRIPS DURING PEAK-HR (DIM)  
NOTE ACO-AVERAGE CAR OCCUPANCY (PER/CAR)  
NOTE ABO-AVERAGE BUS OCCUPANCY (PER/BUS)  
NOTE  
NOTE EQUATIONS  
NOTE -----  
NOTE  
A Q21C.K = V21CAR.K\*FDTPH/ACO  
A Q31C.K = V31CAR.K\*FDTPH/ACO  
A Q41C.K = V41CAR.K\*FDTPH/ACO  
A Q22C.K = V22CAR.K\*FDTPH/ACO  
A Q32C.K = V32CAR.K\*FDTPH/ACO  
A Q42C.K = V42CAR.K\*FDTPH/ACO  
A Q21B.K = V21BUS.K\*FDTPH/ABO  
A Q31B.K = V31BUS.K\*FDTPH/ABO  
A Q41B.K = V41BUS.K\*FDTPH/ABO  
A Q22B.K = V22BUS.K\*FDTPH/ABO  
A Q32B.K = V32BUS.K\*FDTPH/ABO  
A Q42B.K = V42BUS.K\*FDTPH/ABO  
C FDTPH = .4  
C ACO = 2  
C ABO = 40  
A Q43CAR.K = Q41C.K + Q42C.K  
A Q43BUS.K = Q41B.K + Q42B.K  
A Q32CAR.K = Q41C.K + Q42C.K + Q31C.K + Q32C.K  
A Q32BUS.K = Q41B.K + Q42B.K + Q31B.K + Q32B.K  
A Q21CAR.K = Q41C.K + Q31C.K + Q21C.K  
A Q21BUS.K = Q41B.K + Q31B.K + Q21B.K  
NOTE \*  
NOTE 8. NETWORK ASSIGNMENT ANALYSIS  
NOTE \*  
NOTE GLOSSARY

NOTE -----

NOTE

NOTE QIJCA-DEMAND OF CARS FROM I TO J ON ARTERIAL  
(VEH-TRIP/HR)

NOTE FADIJ-CARS ASSIGNED TO ARTERIAL WHEN TTIJCA < TTIJCF  
(VEH-TRIP/HR)

NOTE EQIJCA-EQUIVALENT DEMAND OF CARS FROM I TO J ON  
ARTERIAL  
(VEH-TRIP/HR)

NOTE QIJBUS-DEMAND OF BUSES FROM I TO J OBTAINED FROM TRIP  
INTERCHANGE

NOTE MODAL SPLIT (VEH-TRIP/HR)

NOTE QIJCAR-DEMAND OF CARS FROM I TO J OBTAINED FROM TRIP  
INTERCHANGE

NOTE MODAL SPLIT (VEH-TRIP/HR)

NOTE BEF-BUS EQUIVALENT FACTOR TO CARS (CARS/BUS)

NOTE QMA-ARTERIAL LANE CAPACITY (VEH/HR)

NOTE NIJA-NUMBER OF LANES IN ARTERIAL (LANES)

NOTE NAL-NUMBER OF ARTERIAL LANES (LANES)

NOTE ADSAIJ-AUXILIARY FOR CALCULATION OF (1.0-DSAIJ) (DIM)

NOTE DSAIJ-FRACTION OF CAPACITY OCCUPIED BY DEMAND ON  
ARTERIAL (DIM)

NOTE SRIJA-FRACTION OF VFA REACHED, OBTAINED FROM A  
RELATIONSHIP  
BETWEEN SPEED AND CAPACITY (DIM)

NOTE VFA-ARTERIAL FREE FLOW SPEED (MPH)

NOTE VIJCTA-SPEED ON ARTERIAL AT CONGESTED TIME (MPH)

NOTE TTIJCA-TRAVEL TIME FROM I TO J USING CAR ON ARTERIAL (MIN)

NOTE CTIJA-CONGESTED TRAVEL TIME FROM I TO J ON ARTERIAL  
WHEN DEMAND >  
> CAPACITY (MIN)

NOTE XIJA-DISTANCE FROM I TO J ON ARTERIAL (MI)

NOTE QIJCF-DEMAND OF CARS FROM I TO J ON FREEWAY  
(VEH-TRIP/HR)

NOTE QMF-FREEWAY LANE CAPACITY (VEH/HR)

NOTE NIJF-NUMBER OF LANES IN FREEWAY (LANES)

NOTE NFL-NUMBER OF FREEWAY LANES (LANES)

NOTE CTIJF-CONGESTED TRAVEL TIME FROM I TO J ON FREEWAY WHEN  
DEMAND >  
> CAPACITY

NOTE XIJF-DISTANCE FROM I TO J ON FREEWAY (MI)

NOTE ADSFIJ-AUXILIARY FOR CALCULATION OF (1.0-DSFIJ) (DIM)

NOTE DSFIJ-FRACTION OF CAPACITY OCCUPIED BY DEMAND ON  
FREEWAY (DIM)

NOTE SRIJF-FRACTION OF VFF REACHED, OBTAINED FROM A  
RELATIONSHIP  
BETWEEN SPEED AND CAPACITY (DIM)

NOTE VFF-FREEWAY FREE FLOW SPEED (MPH)

NOTE VIJCTF-SPEED ON FREEWAY AT CONGESTED TIME (MPH)

NOTE TTIJCF-TRAVEL TIME FROM I TO J USING CAR ON FREEWAY (MIN)

NOTE TTIJBA-TRAVEL TIME FROM I TO J USING BUS ON ARTERIAL (MIN)

NOTE

NOTE EQUATIONS

NOTE -----

NOTE

L  $Q43CA.K = Q43CA.J + (DT)(FAD43JK)$

L Q32CA.K = Q32CA.J + (DT)(FAD32.JK)  
L Q21CA.K = Q21CA.J + (DT)(FAD21.JK)  
N Q43CA = 0  
N Q32CA = 0  
N Q21CA = 0  
R FAD43.KL = CLIP(EQ43CA.K,0,TT43CF.K,TT43CA.K)  
R FAD32.KL = CLIP(EQ32CA.K,0,TT32CF.K,TT32CA.K)  
R FAD21.KL = CLIP(EQ21CA.K,0,TT21CF.K,TT21CA.K)  
A EQ43CA.K = Q43BUS.K\*BEF + Q43CA.K  
A EQ32CA.K = Q32BUS.K\*BEF + Q32CA.K  
A EQ21CA.K = Q21BUS.K\*BEF + Q21CA.K  
C BEF = 3  
C QMA = 1800  
C NAL = 2  
C N43A = 2  
C N32A = 2  
C N21A = 2  
A SR43A.K = .5 + (.5)(SQRT(ADSA43.K))  
A ADSA43.K = CLIP(1.0-DSA43.K,0,1,DSA43.K)  
A DSA43.K = Q43CA.K/(QMA\*N43A)  
A SR32A.K = .5 + (.5)(SQRT(ADSA32.K))  
A ADSA32.K = CLIP(1.0-DSA32.K,0,1,DSA32.K)  
A DSA32.K = Q32CA.K/(QMA\*N32A)  
A SR21A.K = .5 + (.5)(SQRT(ADSA21.K))  
A ADSA21.K = CLIP(1.0-DSA21.K,0,1,DSA21.K)  
A DSA21.K = Q21CA.K/(QMA\*N21A)  
A V43CTA.K = CLIP(SR43A.K\*VFA,(X43A/CT43A.K)\*60,1,DSA43.K)  
A V32CTA.K = CLIP(SR32A.K\*VFA,(X32A/CT32A.K)\*60,1,DSA32.K)  
A V21CTA.K = CLIP(SR21A.K\*VFA,(X21A/CT21A.K)\*60,1,DSA21.K)  
C VFA = 60  
A TT43CA.K = CLIP((X43A/V43CTA.K)\*60,CT43A.K,1,DSA43.K)  
A TT32CA.K = CLIP((X32A/V32CTA.K)\*60,CT32A.K,1,DSA32.K)  
A TT21CA.K = CLIP((X21A/V21CTA.K)\*60,CT21A.K,1,DSA21.K)  
A CT43A.K = TABXT(CTT43,Q43CA.K/(QMA\*NAL),1,1.2,.2)  
A CT32A.K = TABXT(CTT31,Q32CA.K/(QMA\*NAL),1,1.2,.2)  
A CT21A.K = TABXT(CTT31,Q21CA.K/(QMA\*NAL),1,1.2,.2)  
C X43A = 7  
C X32A = 5  
C X21A = 5  
A Q43CF.K = Q43CAR.K-Q43CA.K  
A Q32CF.K = Q32CAR.K-Q32CA.K  
A Q21CF.K = Q21CAR.K-Q21CA.K  
A CT43F.K = TABXT(CTT43,Q43CF.K/(QMF\*NFL),1,1.2,.2)  
A CT32F.K = TABXT(CTT31,Q32CF.K/(QMF\*NFL),1,1.2,.2)  
A CT21F.K = TABXT(CTT31,Q21CF.K/(QMF\*NFL),1,1.2,.2)  
T CTT43 = 10.5/22.5  
T CTT31 = 7.5/19.5  
A SR43F.K = .5 + (.5)(SQRT(ADSF43.K))  
A ADSF43.K = CLIP(1.0-DSF43.K,0,1,DSF43.K)  
A DSF43.K = Q43CF.K/(QMF\*N43F)  
A SR32F.K = .5 + (.5)(SQRT(ADSF32.K))  
A ADSF32.K = CLIP(1.0-DSF32.K,0,1,DSF32.K)  
A DSF32.K = Q32CF.K/(QMF\*N32F)  
A SR21F.K = .5 + (.5)(SQRT(ADSF21.K))  
A ADSF21.K = CLIP(1.0-DSF21.K,0,1,DSF21.K)  
A DSF21.K = Q21CF.K/(QMF\*N21F)

A V43CTF.K = CLIP(SR43F.K\*VFF,(X43F/CT43F.K)\*60,1,DSF43.K)  
A V32CTF.K = CLIP(SR32F.K\*VFF,(X32F/CT32F.K)\*60,1,DSF32.K)  
A V21CTF.K = CLIP(SR21F.K\*VFF,(X21F/CT21F.K)\*60,1,DSF21.K)  
C VFF = 80  
C QMF = 2400  
C N43F = 2  
C N32F = 2  
C N21F = 2  
A TT43CF.K = CLIP((X43F/V43CTF.K)\*60,CT43F.K,1,DSF43.K)  
A TT32CF.K = CLIP((X32F/V32CTF.K)\*60,CT32F.K,1,DSF32.K)  
A TT21CF.K = CLIP((X21F/V21CTF.K)\*60,CT21F.K,1,DSF21.K)  
C X43F = 7  
C X32F = 5  
C X21F = 5  
A TT43BA.K = TT43CA.K  
A TT32BA.K = TT32CA.K  
A TT21BA.K = TT21CA.K  
NOTE \*  
NOTE 9. EQUILIBRIUM CHECK OF HORIZON YEAR DEMAND FUNCTION  
NOTE \*  
NOTE GLOSSARY  
NOTE -----  
NOTE  
NOTE WTTAIJ-WEIGHTED TRAVEL TIME FROM I TO J (MIN)  
NOTE TTCFIJ-TOTAL TRAVEL TIME FROM I TO J BY CAR ON FREEWAY  
(MIN)  
NOTE CDTIJC-COLLECTION DISTRIBUTION TIME FROM I TO J BY CAR  
OBTAINED FROM DETERMINATION OF TRIP INTERCHANGE MODAL SPLIT  
NOTE PARAMETERS (MIN)  
NOTE TTIJCF-TRAVEL TIME FROM I TO J ON THE FREEWAY BY CAR  
OBTAINED FROM NETWORK ASSIGNMENT ANALYSIS (MIN)  
NOTE TTBAIJ-TOTAL TRAVEL TIME FROM I TO J BY BUS ON ARTERIAL  
(MIN)  
NOTE CDTIJB-COLLECTION DISTRIBUTION TIME FROM I TO J BY BUS  
OBTAINED FROM DETERMINATION OF TRIP INTERCHANGE MODAL SPLIT  
NOTE PARAMETERS (MIN)  
NOTE TTIJBA-TRAVEL TIME FROM I TO J ON ARTERIAL BY BUS  
OBTAINED FROM NETWORK ASSIGNMENT ANALYSIS (MIN)  
NOTE VIJCAR-NUMBER OF TRIPS FROM I TO J BY CAR OBTAINED TRIP  
FROM INTERCHANGE MODAL SPLIT ANALYSIS (PER-TRIP/DAY)  
NOTE VIJBUS-NUMBER OF TRIPS FROM I TO J BY BUS OBTAINED FROM  
TRIP INTERCHANGE MODAL SPLIT ANALYSIS (PER-TRIP/DAY)  
NOTE VIJ-TOTAL NUMBER OF TRIPS FROM I TO J OBTAINED FROM THE  
GRAVITY MODEL (PER-TRIP/DAY)  
NOTE  
NOTE EQUATIONS  
NOTE -----  
NOTE  
A WTTA21.K = (TTCF21.K\*V21CAR.K + TTBA21.K\*V21BUS.K)/V21.K

A WTTA31.K = (TTCF31.K\*V31CAR.K + TTBA31.K\*V31BUS.K)/V31.K  
A WTTA41.K = (TTCF41.K\*V41CAR.K + TTBA41.K\*V41BUS.K)/V41.K  
A WTTA22.K = (TTCF22.K\*V22CAR.K + TTBA22.K\*V22BUS.K)/V22.K  
A WTTA32.K = (TTCF32.K\*V32CAR.K + TTBA32.K\*V32BUS.K)/V32.K  
A WTTA42.K = (TTCF42.K\*V42CAR.K + TTBA42.K\*V42BUS.K)/V42.K  
A TTCF21.K = CDT21C + TT21CF.K  
A TTCF31.K = CDT31C + TT21CF.K + TT32CF.K  
A TTCF41.K = CDT41C + TT21CF.K + TT32CF.K + TT43CF.K  
A TTCF22.K = CDT22C  
A TTCF32.K = CDT32C + TT32CF.K  
A TTCF42.K = CDT42C + TT32CF.K + TT43CF.K  
A TTBA21.K = CDT21B + TT21BA.K  
A TTBA31.K = CDT31B + TT21BA.K + TT32BA.K  
A TTBA41.K = CDT41B + TT21BA.K + TT32BA.K + TT43BA.K  
A TTBA22.K = CDT22B  
A TTBA32.K = CDT32B + TT32BA.K  
A TTBA42.K = CDT42B + TT32BA.K + TT43BA.K  
N TLMF = (X43F\*N43F + X32F\*N32F + X21F\*N21F)\*2  
S TCMT.K = V21CAR.K\*(CDD21 + LHD21) + V31CAR.K\*(CDD31 + LHD31) +  
X V41CAR.K\*(CDD41 + LHD41) + V22CAR.K\*(CDD22 + LHD22) +  
X V32CAR.K\*(CDD32 + LHD32) + V42CAR.K\*(CDD42 + LHD42)  
S FLOS.K = (Q43CF.K\*V43CTF.K + Q32CF.K\*V32CTF.K + Q21CF.K\*V21CTF.K)/  
X (Q43CF.K + Q32CF.K + Q21CF.K)  
NOTE \*  
NOTE 10. ECONOMIC EVALUATION \*  
NOTE \*  
NOTE GLOSSARY  
NOTE -----  
NOTE EQUATIONS  
NOTE -----  
NOTE  
A QACF.K = (Q21CF.K + Q32CF.K + Q43CF.K)/3  
A VACTF.K = (V21CTF.K + V32CTF.K + V43CTF.K)/3  
A RC.K = TABLE(RCT,VACTF.K,50,70,20)  
T RCT = 75/81  
A ERC.K = QACF.K\*RC.K\*2\*365/400  
A FACCT.K = TABLE(FACCT,NFL,2,6,1)  
T FACCT = 4/3/2/1/1  
A NFACCT.K = TABLE(NFACCT,NFL,2,6,1)  
T NFACCT = 16/13/10/8/6  
A PDACCT.K = TABLE(PDACCT,NFL,2,6,1)  
T PDACCT = 30/24/19/15/12  
A EACC.K = (FACCT.K\*287175) + (NFACCT.K\*3185) + (PDACCT.K\*520)  
A FF.K = TABLE(FFT,NFL,2,6,1)  
T FFT = 2.2E6/2.4E6/2.6E6/2.8E6/3.0E6  
A FC1T.K = FC1.K\*.95\*.17  
A QACS.K = QACF.K\*12000\*.33\*.11  
A R.K = QACS.K + FF.K + FC1T.K  
A EF.K = TABLE(EFT,NFL,2,6,1)  
T EFT = 3.6E5/4.4E5/5.2E5/6.0E5/6.8E5  
A E.K = EF.K + ERC.K + EACC.K  
A C.K = TABLE(CT,NFL,2,6,1)  
T CT = 34E6/40E6/45E6/49E6/52E6  
C NFL = 2  
N FRN = (1-EXP(-I\*N))/I

```

C      I = .08
C      N = 30
A      PW.K = (R.K-E.K)*FRN-C.K
A      AC.K = (C.K/FRN)-(R.K-E.K)
A      BC.K = ((R.K-E.K)/C.K)*FRN
A      RE.K = CLIP(1E-6,R.K-E.K,0,R.K-E.K)
A      CRE.K = CLIP(999999,1-(I*C.K/RE.K),I*C.K/RE.K,1)
A      PT.K = (-1/I)*LOGN(CRE.K)
A      FC.K = TABXT(FCT,VACTF.K,50,70,10)
T      FCT = 50/56/63
A      FC1.K = FC.K*QACF.K*31
A      CO.K = TABXT(COT,VACTF.K,50,70,10)
T      COT = 33/36/40
A      CO1.K = CO.K*QACF.K*31
A      HC.K = TABXT(HCT,VACTF.K,50,70,10)
T      HCT = 3.6/3.9/4.4
A      HC1.K = HC.K*QACF.K*31
A      NOX.K = TABXT(NOXT,VACTF.K,50,70,20)
T      NOXT = 10.3/15.2
A      NOX1.K = NOX.K*QACF.K*31
NOTE
NOTE      11. CONTROL STATEMENTS
NOTE
SPEC      DT = .25/LENGTH = 40/PLTPER = 1/PRTPER = 40
PRINT     ERC,E'IT,EACC,EF
PRINT     FC1,CO1,HC1,NOX1
PRINT     R,E,C,RE
PRINT     PW,AC,BC,PT
PLOT      BC
NOTE
NOTE      12. COMPUTER OUTPUT
NOTE
RUN      2-2-2 LANES
C      N43F = 3
C      N32F = 3
C      N21F = 3
C      NFL = 3
RUN      3-3-3 LANES
C      N43F = 4
C      N32F = 4
C      N21F = 4
C      NFL = 4
RUN      4-4-4 LANES
C      N43F = 5
C      N32F = 5
C      N21F = 5
C      NFL = 5
RUN      5-5-5 LANES
C      N43F = 6
C      N32F = 6
C      N21F = 6
C      NFL = 6
RUN      6-6-6 LANES
QUIT

```

The vita has been removed  
from the scanned document