

TRANSPORTATION AND ECONOMIC DEVELOPMENT EVALUATION MODEL

by

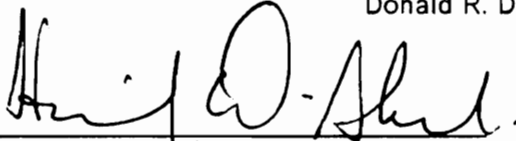
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in
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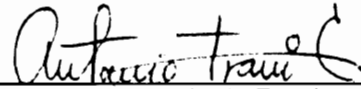
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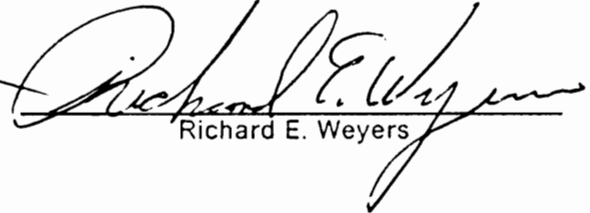
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(ABSTRACT)

The system dynamics methodology is used to develop a computer simulation model to determine whether to add lanes to a congested highway or build a new, more direct, facility. Fundamental to this evaluation is the incorporation of non-user measures of effectiveness to go with the traditional highway user measures of effectiveness, such as the Benefit-Cost Ratio. In the system dynamics methodology three alternative forms of the model of a system are used: verbal, visual, and mathematical. The verbal description is diagrammatic and shows cause-and-effect relationships between many variables in a simple, concise manner. The visual model, or "causal diagram," is translated into a mathematical model, and system equations.

The model is comprised of four sectors:

1. population sector
2. economic sector
3. university sector
4. transportation sector

The model applies to the area of Blacksburg, Christiansburg and Roanoke (city and county), with special treatment to Virginia Tech through the university model. The simulation results of the non-user benefits along with user benefits is used to evaluate the alternatives in the Blacksburg-Christiansburg-Roanoke corridor.

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1.0 Introduction

1.1 Transportation and Economic Development

The better and more complete a nation's infrastructure, the better and more effectively its economic activity can be carried on. The building up of a country's infrastructure, which generally involves projects with a high cost and a very long payoff period, is usually carried out either by government or with its aid. Except for isolated cases of company-town type development, private investment alone cannot finance such development. Indeed, ideas about the nature of the relationship between infrastructure and development, in general, and transportation and development, in particular, have changed considerably over time. Considering the latter, the basic importance of transportation is not in question: transportation is clearly a factor of fundamental importance in all economic activity, and the cost of transportation is one of the most significant variables in the market price of any commodity. But beyond the basic level of infrastructure provision, where transportation (like labor, capital, markets, land and power supplies) is an obvious prerequisite for modern economic growth, it quickly becomes a matter for debate and inquiry whether, as development proceeds, it is advantageous to extend or otherwise improve transportation facilities, or whether limited capital resources available for investment might more efficiently and beneficially be used in other ways. This is a matter of concern to development planners, and it is important to maintain an awareness of the multidimensional nature of the problem: the economic, social, political and spatial di-

mensions of transportation are all important and in some respects complementary--although it may be argued that it is frequently the political dimension in which particular situations and problems are predominantly viewed.

The role of an effective transportation system in building and maintaining a vital economy has been recognized as a critical issue and is currently the subject of renewed interest. The AASHTO-initiated Transportation 2020 program has focused attention on economic development as a significant issue related to surface transportation investment requirements.

AASHTO's June 1988 working draft, "The Bottom Line" includes the following statement:

Transportation has always been a major driver of national economic development and productivity. In the contemporary economy (service oriented, internationally oriented) it is less clear in what ways transportation can support the national economy. New travel patterns and new economic demands are being made and the transportation system must be prepared to respond. In the service economy transportation's role is different rather than decreased. There may well be fewer ton-miles per capita, or per dollar of GNP, in the future economy, but they will be ton-miles of very high value goods, with rigid delivery schedules and rapid travel time requirements. The demands for high quality services with assured reliability will be great. The mobility of our citizens and foreign visitors will be a crucial future economic resource. The economic power of tourism, and the importance of rapid access to all points of the country by business travelers, are just beginning to be appreciated. Recognition of the new roles of transport, and particularly surface transport are only slowly permeating into public policy. The link between transport investment and succeeding economic development and productivity has not yet been generally recognized in policy formation.

1.2 The Problem

The purpose of this research is to identify relationships between highway system supply and highway system performance, benefit-cost, and economic efficiency; and between highway system supply and the states or regions, economic development, and economic productivity. This pulling together of information on the state of the art in terms of data, methods and general concepts is not an end in itself, but a means of eventually developing a methodology that can be used by planners and decision makers at the local, state and national levels for (1) making reliable estimates of the economic health and productivity benefits of potential highway system investments and management actions, and (2) linking highway transport in-

vestments, traffic level of service and succeeding economic development, to provide a basis for rational policy formation.

This research is conceived as three dimensional, consisting of (1) improvement consequences, (2) investment issues and (3) modeling/measuring methodologies. Considering the first orientation, highway improvements may be viewed through four groups of consequences: (1) commodity savings such as construction materials, motor fuel, oil, tires, and spare parts; (2) road user consequences such as travel time reduction and improved level of service; (3) community socio-economic consequences such as business, trade, tourism, national defense, education, utility services, protective services and land values and land use; and (4) impacts on the natural environment such as noise, air pollution, ground and water pollution, and vibration. Referring to the second dimension, four generic problems epitomizing the highway transportation-development process have been identified: (1) prioritizing the programming of highway corridors; (2) the bypass/beltway issue; (3) choosing between the pervasive problem of widening an existing facility or building a new parallel facility; and (4) evaluating the merits of the penetration road for an economically depressed area. Typical approaches to organizing and utilizing data (the third dimension in our conceptual framework) include the steps in the Urban Transportation Planning Process (land use analysis, trip generation, trip distribution, modal split and network assignment); supply-level of service models (the hydrodynamic analogy and stochastic queueing); the classical methods of economic analysis (benefit-cost, present worth, rate-of-return, and annual cost); and economic development methodologies such as input-output, export base, and production functions.

There are many indications that the U.S. is in transition from past exponential growth to equilibrium. It is estimated that 90% of the U.S. highway network is already in place. Because of escalating costs and decreasing budgets, increasing public scrutiny, and requirements imposing higher standards of economic and environmental review to avoid or ameliorate undesirable effects, prioritizing the remainder of our high way system will be a far greater challenge than the planning and programming of the Interstate System.

The major reason for developing a transportation model is not just to forecast the future, but to influence the future and to help the decision-maker to decide which of the candidate alternatives is the preferred one. Models need to be built that are explicitly directed toward particular policy planning issues. This means that variables under the control or sensitive to the policy in question must be included in the model and that the scale of the modeling effort involved with regard to model construction, data collection, calibration, and application must be commensurate with the nature of the decision being considered.

Not surprisingly, some long accepted transportation economic evaluation and project formulation approaches are being reevaluated. Until recently, highway improvement methodologies only considered user benefits explicitly. But a country that is losing its competitive edge cannot continue to treat the effects of transportation investments on economic development subjectively. The 1989 TRB Conference Session on "Transportation and Economic Development" concluded that we should not continue to assume that the economic element of the social, economic and environmental trilogy is covered by highway user impacts such as reduced travel time, travel costs, and accidents.

The relationship between the transportation sector and economic development is the main thrust of this research. A pervasive problem facing all highway departments is whether to add lanes to an existing congested highway or to build a new, more direct highway facility. Fundamental to this evaluation is the selection of a measure of effectiveness. Benefit-cost analysis is used for determining project worthiness, taking into consideration non-user as well as user benefits and impacts. In this research the focus is on non-user benefits which traditionally have been handled subjectively because of the obvious difficulty in modeling transportation induced development. In addition to the transportation sector the problem is conceived as containing population, economic, and university sectors. Finally some alternative solutions to the problem will be presented and examined.

1.3 The Current Transportation Problem

U.S. Rt. 460 is a four-lane roadway connecting Blacksburg with I-81 via Christiansburg. The current road has a speed limit ranging from 45mph to 55mph. Rt. 460 is the only arterial roadway linking Blacksburg with the Interstate; thus, the condition of the road and its effectiveness are vital to the transportation needs of the area.

Currently, there are daily traffic jams on Rt. 460 during peak traffic hours. As Virginia Tech and the Blacksburg area expand, so will the volume of traffic to and from the area. A reliable and efficient link with I-81 is a major concern of Virginia Tech and therefore of Blacksburg. A research institution such as Tech requires easy access to the interstate system as well as to larger cities such as Roanoke.

1.4 Alternatives

The Virginia Department of Transportation and the consultant team identified 21 potential alignments for a new roadway. From these, several were eliminated early primarily because of their impact on the natural and man-made features identified from the preliminary meetings. Ten alternatives were recommended for traffic testing. Seven alternatives were then selected, as shown in Fig.1, for more detailed study, namely Alternatives 2, 3A, 5, 6, 7, 10, and 12. Table 1.1 summarizes the cost of each alternative [62].

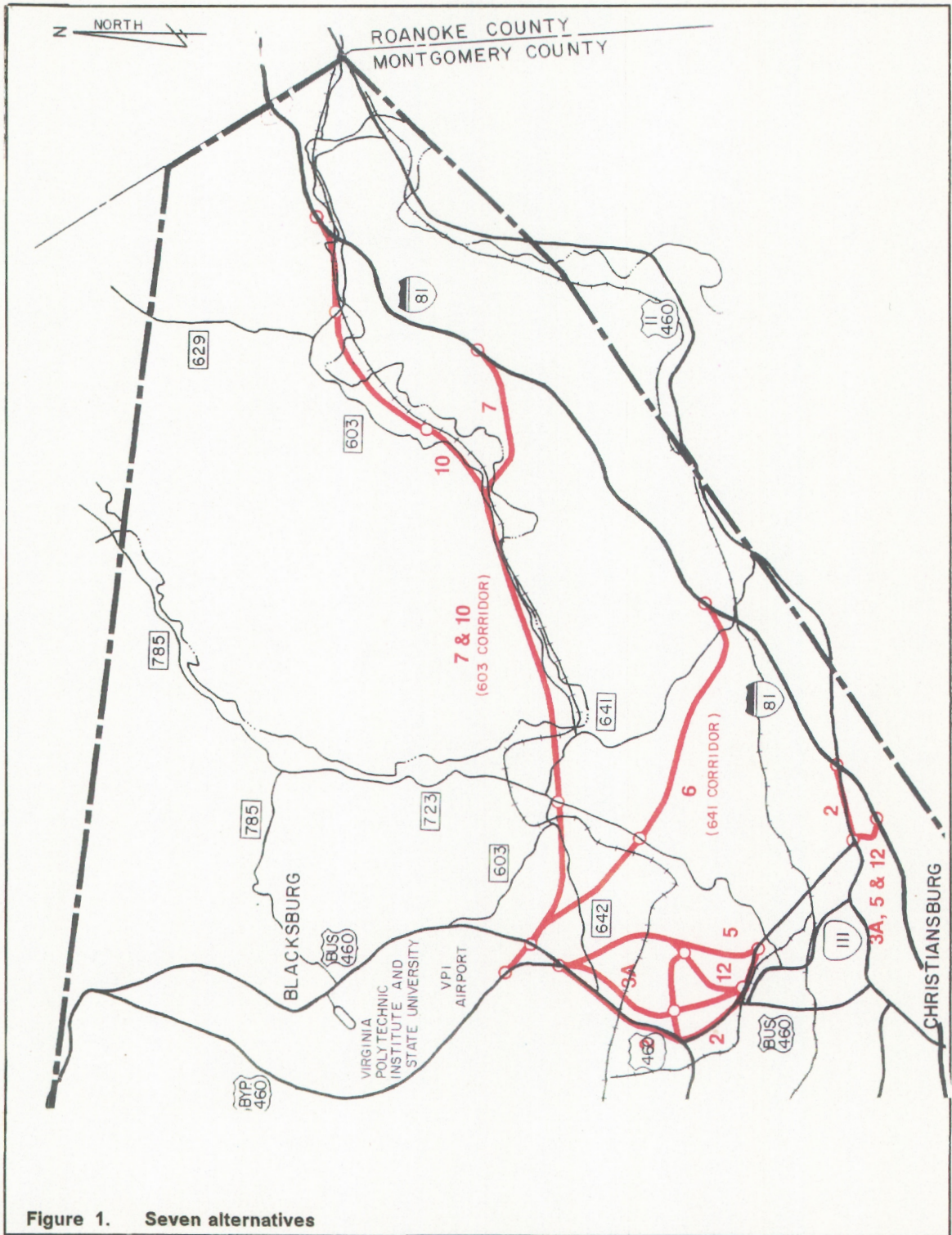


TABLE 1.1

SUMMARY OF PROJECT COSTS
(MILLIONS OF DOLLARS)

In this matrix, the costs for preliminary engineering, right of way (R/W) and construction for each alternative are shown. Several of the alternatives also require improvements to existing Route 460. These costs are also shown along with an estimated total cost for the full improvement.

Alternative	Preliminary Engineering Costs	New Alignments		Existing Route 460		Estimated Total Costs
		Right Of-Way Costs	Construc- tion Costs	Right Of-Way Costs	Construc- tion Costs	
2	5.7	---	---	13.7	56.5	75.9
3A	8.4	13.6 ¹	83.6 ¹	---	---	105.6
5	9.0	12.6	70.8	11.0	19.5	122.9
6	11.3	11.6 ²	93.7 ²	11.0	19.5	147.1
7	12.8	14.2 ²	108.5 ²	11.0	19.5	166.0
10	15.0	17.1 ²	130.3 ²	11.0	19.5	192.9
12	9.2	13.9 ¹	89.3 ¹	1.0	2.3	115.7

¹Includes R/W and construction costs for flyover ramp at Route 114 and existing Route 460.

²Includes R/W and construction costs for flyover ramp from S. Main Street to southbound existing Route 460.

Source: Reference [62]

1.4.1 Alternative 1 (Do Nothing)

As its name implies, deals with a condition in which the improvement of transportation facilities are not undertaken. Under this condition, the development of the population, university and economic sectors for the projection year will be investigated. The traffic demand will undoubtedly increase over the year and will sooner or later exceed the lane capacity. This alternative will be used as a basis for evaluating other alternatives.

1.4.2 Alternative 2

Alternative 2, as shown in Fig.2, widens the existing Route 460 to eight lanes from a point beginning at the south end of the Blacksburg Bypass to its connection with the Christiansburg Bypass at North Franklin Street. Alternative 2 includes a section of East Roanoke Street, which would be widened to eight lanes from the Christiansburg Bypass to its connection with I-81. A grade separation is required at Route 114, and flyover ramps are required at North Franklin Street, the south end of the Christiansburg Bypass, the East Roanoke Street/I-81 interchange, and South Main Street over the Blacksburg Interchange. This alternative has a length of 3.5 miles.

1.4.3 Alternative 3A

Alternative 3A, as shown in Fig.3, begins at the south end of the Blacksburg Bypass, and parallels Route 460 to a connection with the Christiansburg Bypass at North Franklin Street. This alternative requires six lanes to accommodate traffic and for geometrics. An extension of the Christiansburg Bypass, beginning at its intersection with East Roanoke Street and

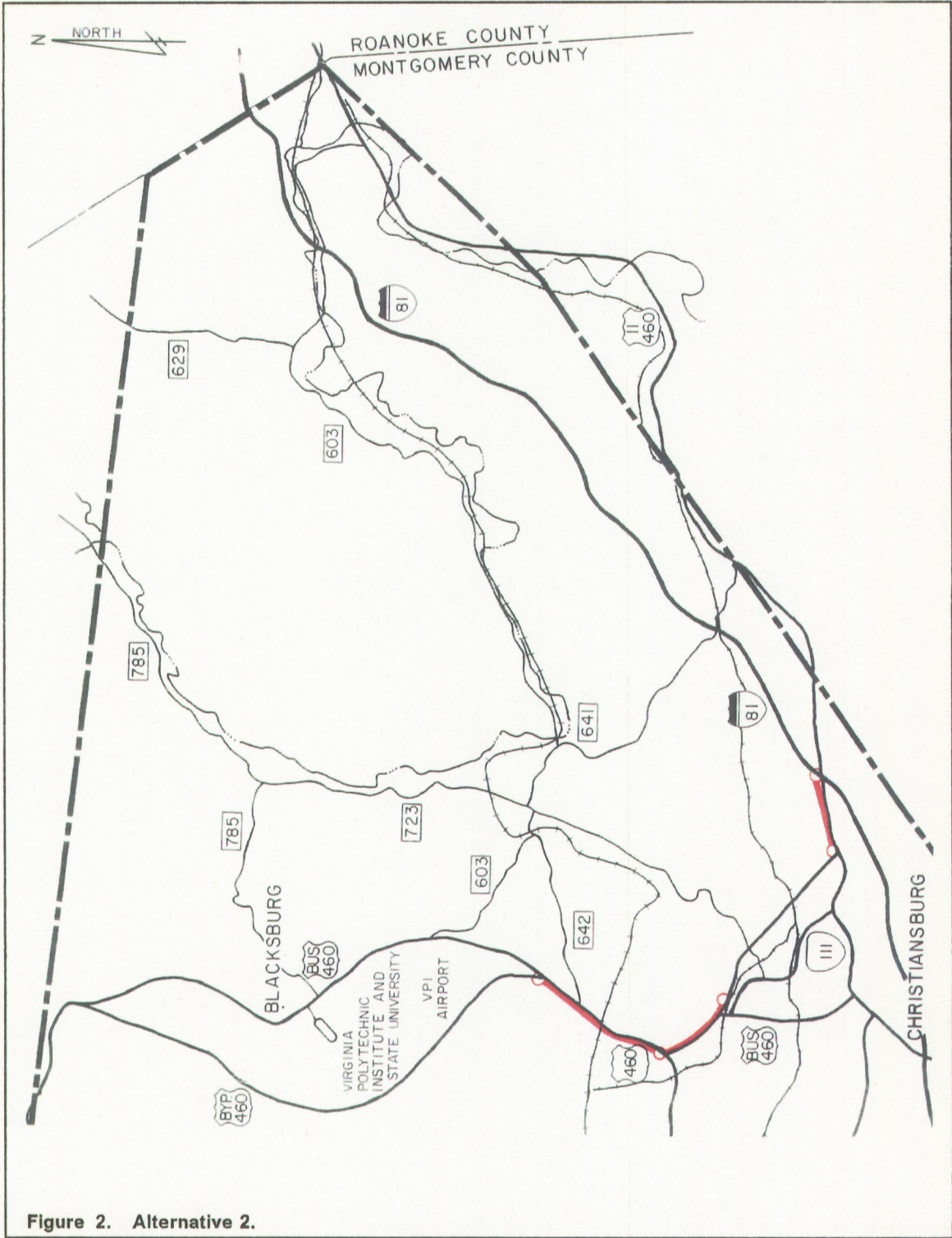


Figure 2. Alternative 2.

ending at a connection with I-81, is included in this alternative. An interchange at the Route 114 extension, and a flyover ramp are required at the intersection of existing Routes 460 and 114. This alternative has a length of 3.2 miles.

1.4.4 Alternative 5

Alternative 5, as shown in Fig.4, begins at the south end of the Blacksburg Bypass. This alignment requires four lanes and proceeds in a general southeasterly direction and passes west of the Yellow Sulphur Springs historic site, crosses the Norfolk Southern Railroad, and passes east of the Mid-County Landfill. It curves to the southwest, connecting to the Christiansburg Bypass. The extension of the Christiansburg Bypass, which provides a connection to I-81, is also included in Alternative 5. With this alternative, existing U.S. 460 between the bypasses would have to be widened to eight lanes, including a grade separation at Route 114 and improvements to several interchanges. This alternative has a length of 3.2 miles.

1.4.5 Alternative 12

Alternative 12, as shown in Fig.5, requires four lanes, begins at the south end of the Blacksburg Bypass, at the same point as Alternatives 3A and 5. This alignment proceeds southward, the same as Alternative 5, to a point south of the railroad. From here Alternative 12 departs from Alternative 5, and proceeds southwest to meet the Christiansburg Bypass at North Franklin Street. Alternative 12 includes an interchange with the Route 114 extension. The extension of the Christiansburg Bypass to I-81 is included in Alternative 12. Existing U.S. 460 south of Route 114 would be widened to six lanes under this alternative, including a flyover ramp at the Route 114 intersection. This alternative has a length of 4.3 miles.

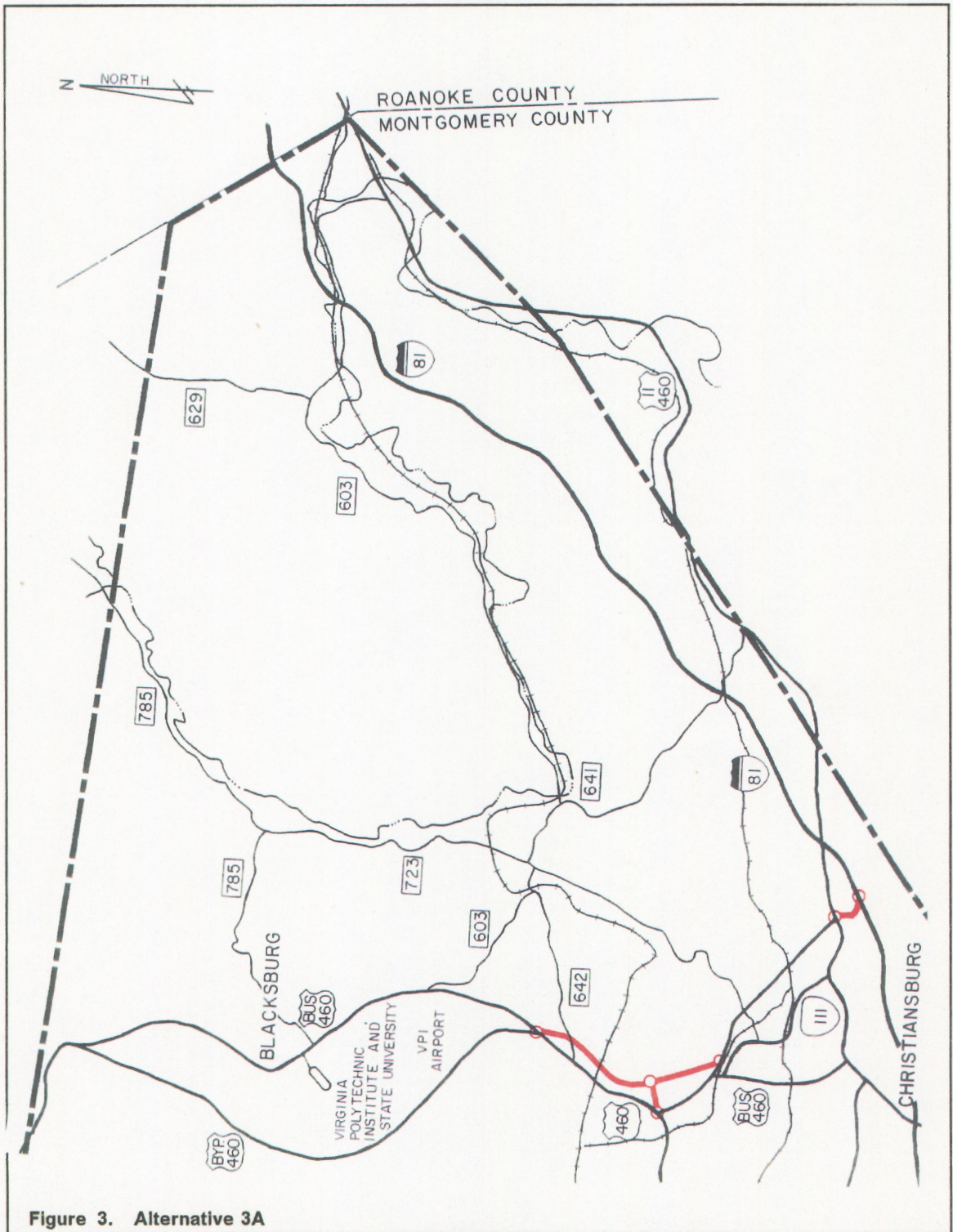


Figure 3. Alternative 3A

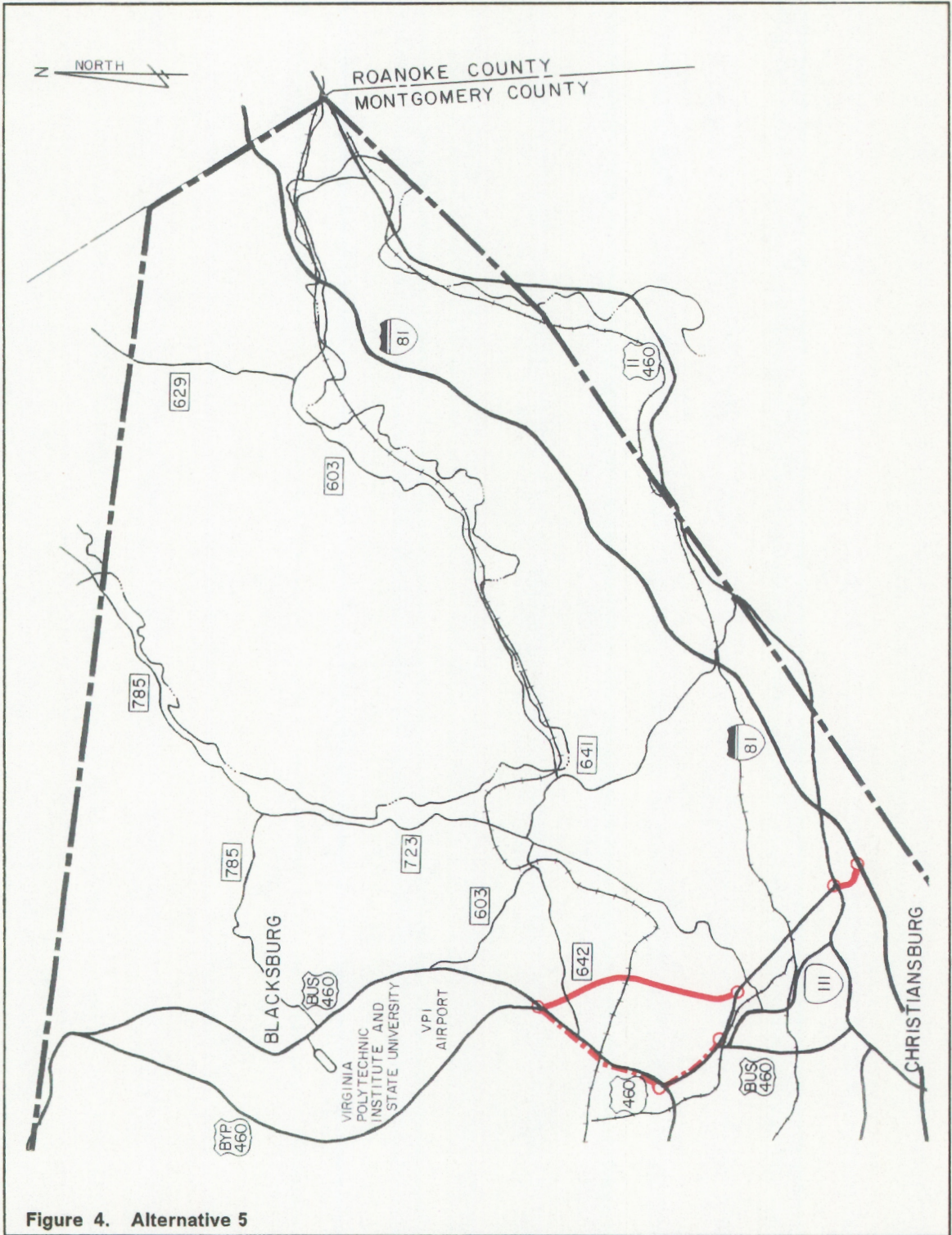


Figure 4. Alternative 5

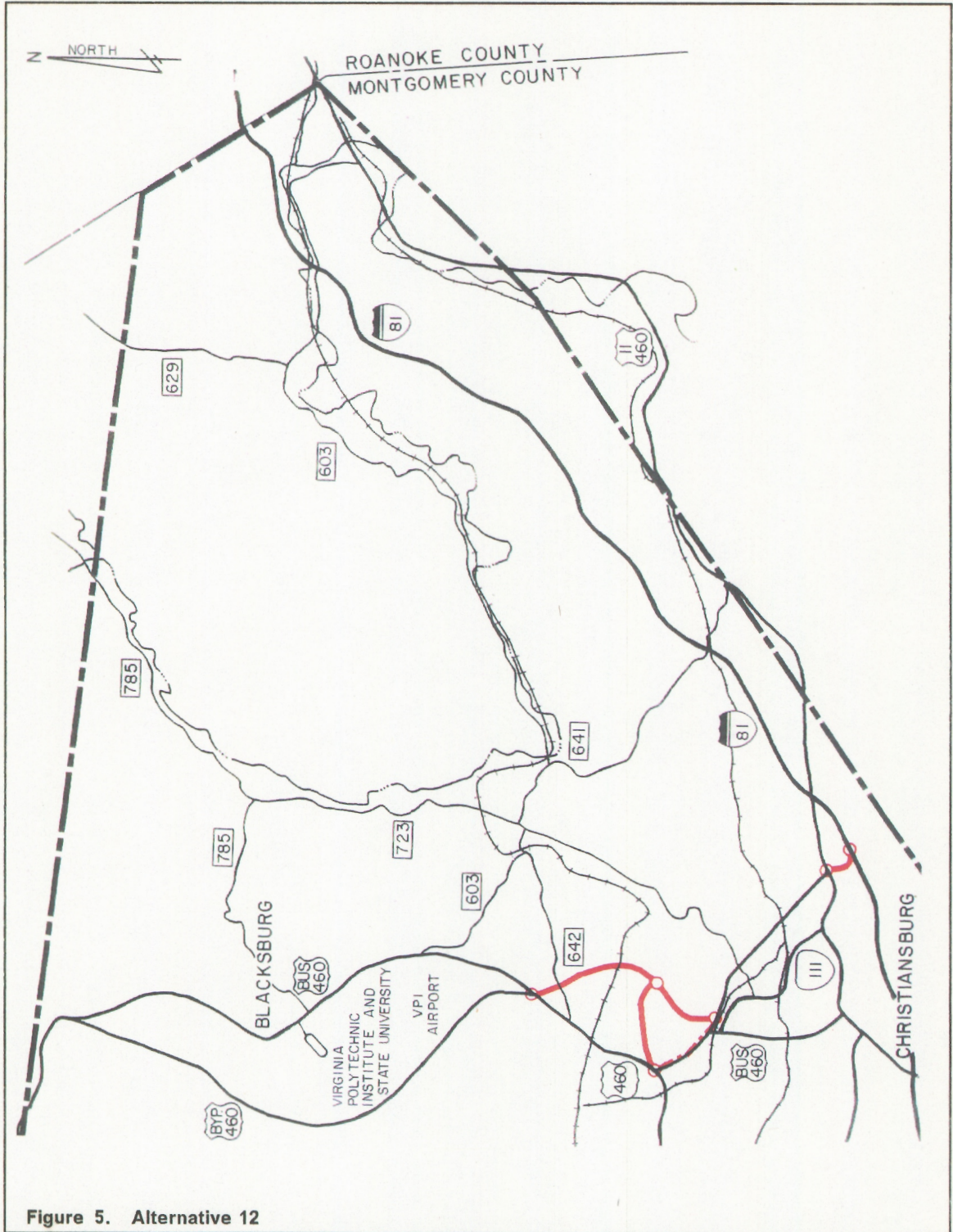


Figure 5. Alternative 12

1.4.6 Alternative 6

Alternative 6, as shown in Fig.6, begins at a point on the Blacksburg Bypass near the southern end of the Virginia Tech Corporate Research Park. This alignment requires four lanes and proceeds generally in a southeast direction and crosses over South Main Street. Alternative 6 spans the Ellett Valley and includes an interchange with Route 723. It enters the mountainous region adjacent to and generally paralleling Route 641, and connects to I-81 north of the Route 641 underpass. With this alternative, existing U.S. 460 between the bypasses would have to be widened to eight lanes, including a grade separation at Route 114 and improvements to the existing Blacksburg and Christiansburg Bypass interchanges. This alternative has a length of 5.7 miles.

1.4.7 Alternative 7

Alternative 7, as shown in Fig.7, like Alternative 6, requires four lanes and begins at a point on the Blacksburg Bypass near the southern end of the Virginia Tech Corporate Research Park. From here it proceeds south of the Blacksburg Industrial Park, spans the Ellett Valley and includes an interchange with Route 723, and follows the Route 603 corridor in the Roanoke Valley. It curves to the south and crosses Route 603 and the north fork of the Roanoke River. Alternative 7 runs through Pedlar Hills and intersects I-81 approximately two miles southwest of the Route 603 interchange. With this alternative, existing U.S. 460 between the bypasses would have to be widened to eight lanes, including a grade separation at Route 114 and improvements to the existing Blacksburg and Christiansburg Bypass interchanges. This alternative has a length of 8.5 miles.

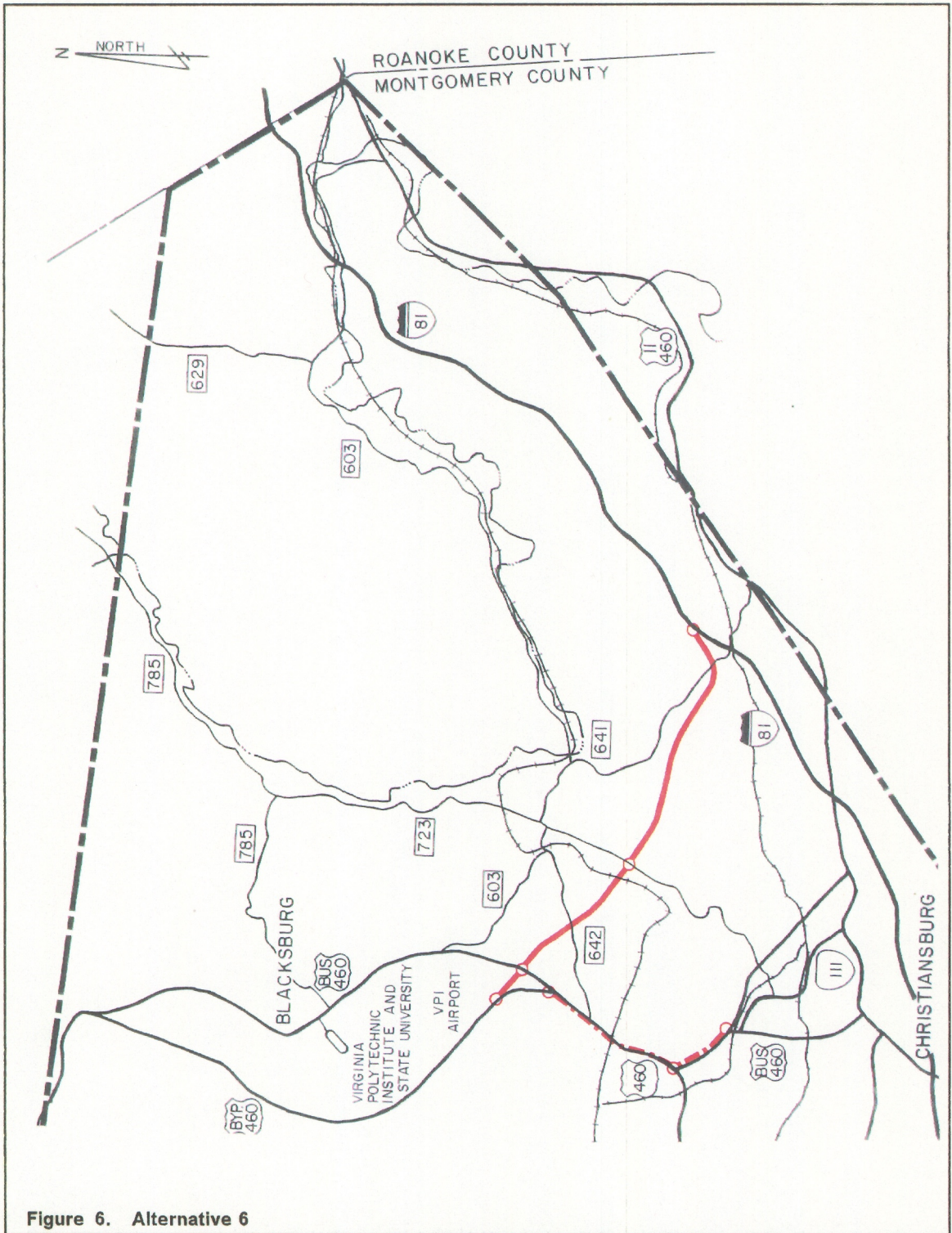
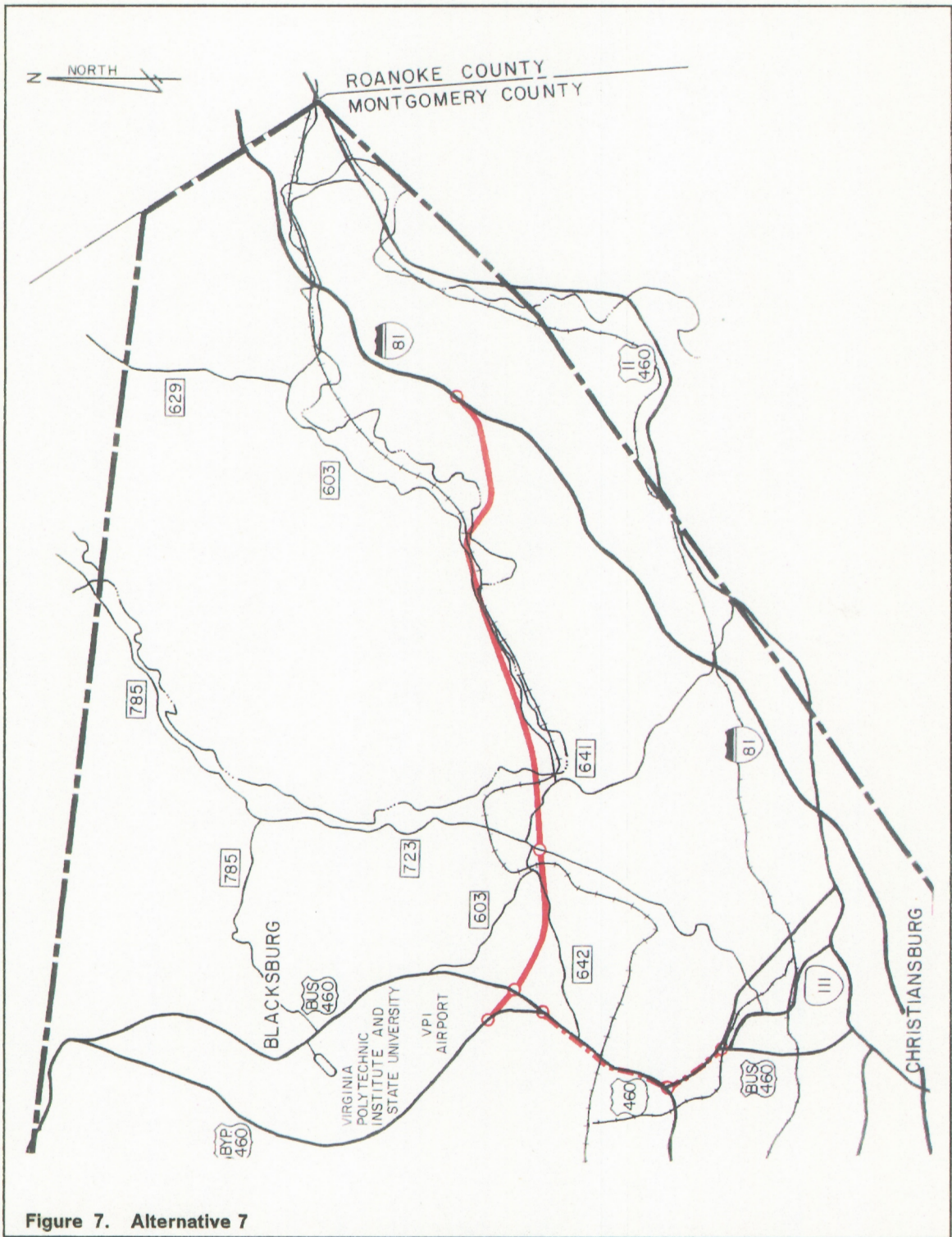


Figure 6. Alternative 6



1.4.8 Alternative 10

Alternative 10, as shown in Fig.8, also requires four lanes and begins at the same point on the Blacksburg Bypass where Alternatives 6 and 7 start. It is the same as Alternative 7, except that it continues to follow the Route 603 corridor along the north fork of the Roanoke River, connecting to I-81 at the existing interchange with Route 603. Interchanges are included with Route 723 in the Ellett Valley, Routes 622/647 near Ironto, and Route 603 west of I-81. With this alternative, existing U.S. 460 between the bypasses would have to be widened to eight lanes, including a grade separation at Route 114 and improvements to the existing Blacksburg and Christiansburg Bypass interchanges. This alternative has a length of 10.6 miles.

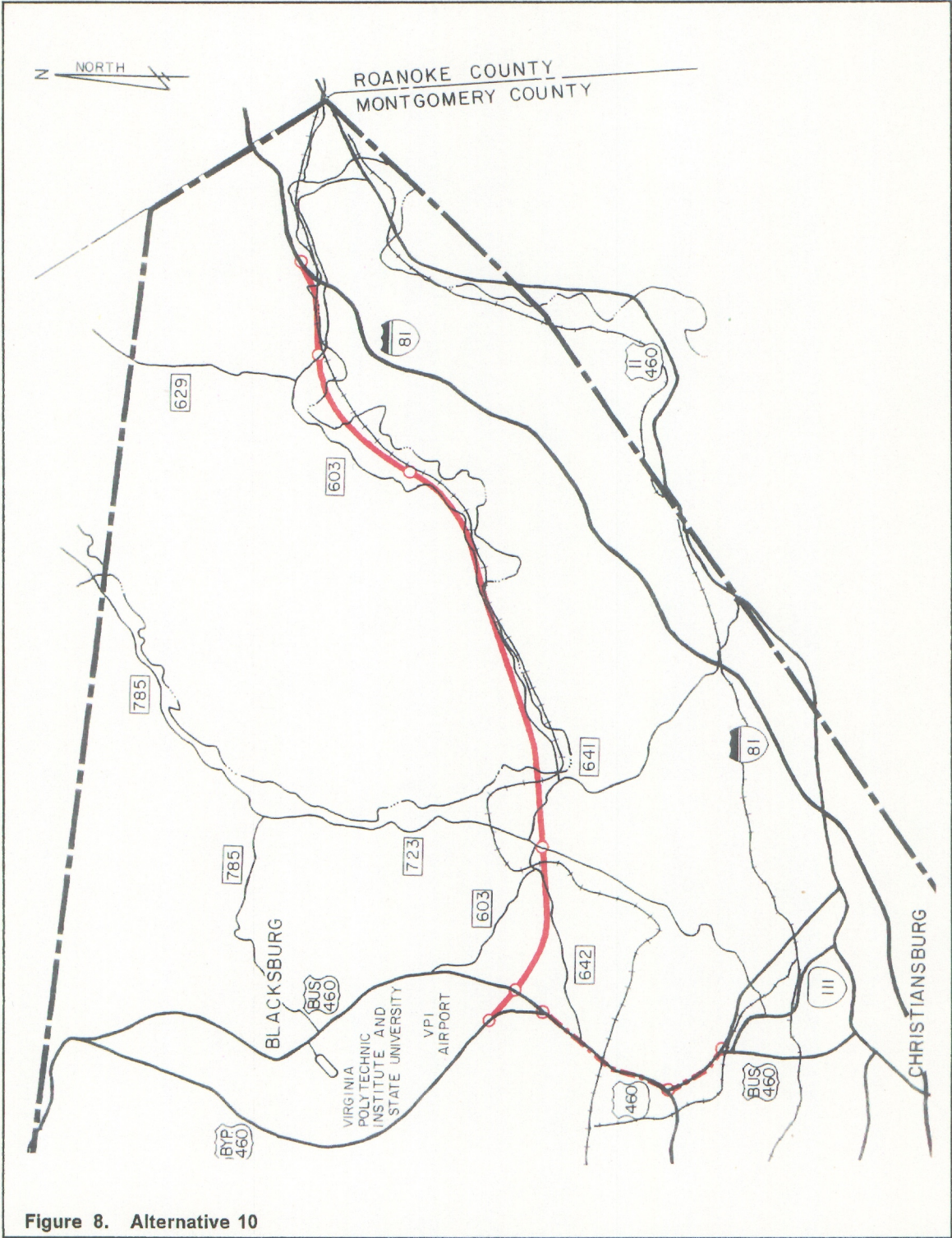


Figure 8. Alternative 10

1.5 Goals and Objectives

The objectives of this research is to develop a methodology for generating models that can be used by planners and decision makers at the state and local levels instrumentations for accomplishing the following:

1. making reliable estimates of the economic health and productivity benefits of potential transportation investments and management actions;
2. linking transport investment and succeeding economic development to provide a basis rational policy formation.

To accomplish the objective of this project, the plan of research is envisaged as consisting of the following steps:

1. To identify and describe the methodology and the regional setting in which it is to be applied.
2. To develop relationships between variables in causal streams from policy parameters to measures of effectiveness and express them in the form of a computer model.
3. To describe the model in detail focusing on the causal statements representing the causal hypotheses upon which the model outputs are based; and
4. To show how the model can be applied by using it to evaluate transportation attractions being considered by the Virginia Department of Transportation in terms of user benefits and socio-economic impacts.

2.0 An Overview of the Study Area

2.1 Introduction

The study area, as shown in Fig.9, is a part of Southwest Virginia. It is composed of Blacksburg and Christiansburg, the two major towns of Montgomery County, and Roanoke (city and county). In this overview, some socio-economic and transportation statistics of the study area will be presented.

2.2 Town of Blacksburg

Blacksburg, Montgomery County's largest town, was founded in 1798 by William and Jane Black, who deeded approximately 35 acres of land to a group of local trustees so the new locality could qualify as an incorporated town. Blacksburg was incorporated in 1871. The following year, Montgomery County residents contributed \$20,000 to the

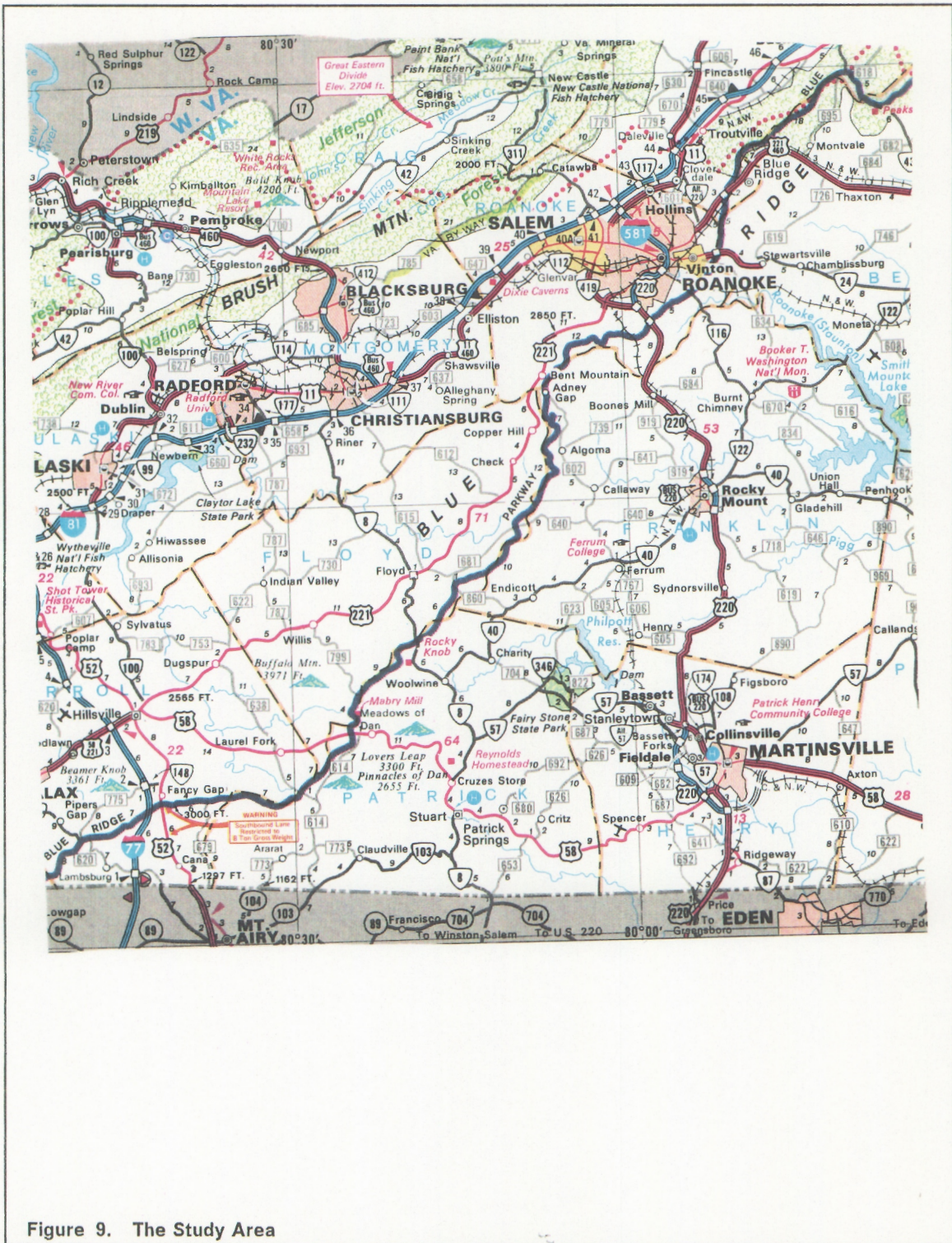


Figure 9. The Study Area

state to help establish Virginia Agricultural and Mechanical College, which later became Virginia Tech. Blacksburg's growth has been directly linked to the growth of Tech, the largest university in Virginia. Blacksburg's area is 18.7 square miles with a population of 33,320.

2.3 Virginia Tech

Blacksburg is the home of Virginia Tech, Virginia's largest university and one of the country's leading research institutions. Tech, which numbers students from all over the United States and the world among its 22,000 enrollment, was founded as a land grant college in 1872. Today, the University has 118 buildings on a 2,500-acre campus in Blacksburg.

Tech offers a comprehensive curriculum of 79 bachelor's and 124 master's and doctoral degree programs in its eight colleges: Agriculture and Life Sciences, Architecture and Urban Studies, Arts and Sciences, Business, Education, Engineering, Human Resources, and Veterinary Medicine. In 1989, the University had more than 2,000 faculty members, 4,000 graduate students, and 22,000 undergraduates with a budget of 400 million dollars.

Virginia Tech is widely known in the business and academic worlds for the excellence of its programs and the quality of its students. Although the University's enrollment has increased by 200% since 1966, the competition for admission is still very high. More than 14,000 students apply for the fewer than 4,000 openings in its freshman class each year, and the SAT score of the average Tech freshman is 200 points above the national average [56].

2.3.1 The Virginia Tech Corporate Research Center

The Virginia Tech Corporate Research Center is designed to attract corporate research and development operations to locate adjacent to the university, which offers excellent research facilities and a wealth of faculty expertise in scientific and technological fields.

The close interaction between corporate scientists and university researchers will foster a wide variety of creative activities: basic research, applied studies, engineering, product development, and closely allied efforts.

The research center consists of 120 acres which include:

1. Two 20,000 square foot laboratory/office buildings, with space for start-up firms and specialized Virginia Tech programs.
2. One 20,000 square foot laboratory building for mixed use.
3. One 49,000 square foot computing and information sciences building.

2.4 Town of Christiansburg

The Town of Christiansburg was incorporated in 1833 by special act of the General Assembly. As a result of its consolidation with the former Town of Cambria in 1964 and two subsequent annexations, Christiansburg has a population of 15,050 [66].

In terms of the nature of its population, the evidence reveals that the Town's populace is somewhat older and generally has lower income than that of the State as a whole. Data indicate that, as of 1980, the median age of Christiansburg's residents was 31.3 years, a statistic above that for the state overall (29.8 years). In terms of personal

earnings, statistics reveal that, as of 1979 (the latest year for which such data are available), the median family income in Christiansburg was \$16,668, or 83.3% of that for the Commonwealth as a whole (\$20,018).[66]

2.5 Roanoke (County and City)

Natural forests, trading routes and natural beauty initiated the settlement in this region during 1740. The area soon started to grow in agriculture and forest products. The area, now known as Roanoke Valley, was initially a part of Botetourt County. In 1838 Roanoke County was formed. The village of Old Lick was formed in this valley in the year 1825. In 1835 the Town of Big Lick was officially incorporated in the Roanoke County. By 1881 the town of Big Lick became the main connecting point for the two important railroads of that time, namely the Shenandoah Valley Railroad and the Norfolk & Western Railroad. The importance of this Town thus started to grow rapidly. In 1882 the village of Old Lick and the Town of Big Lick were merged to form the town of Roanoke. The Town got city status in 1884.

2.6 Socio-economic Characteristics

Table A.1 to Table A.24 in appendix A show some relevant socio-economic statistics that are used both explicitly and subjectively in developing the regional development model that is the basis for the evaluation methodology.

2.7 Transportation Characteristics

Interstate 81 bisects Montgomery County. I-81 is a major artery connecting the northeastern and southern United States. Interstate 77 intersects I-81 40 miles southwest of Christiansburg, the Montgomery County seat, providing a major artery into the mid-western and southeastern states. Another four-lane highway, US Highway 460, also runs through Montgomery County. US 460 links Virginia's coalfields with the port cities on its east coast, and intersects with I-81 and US Highway 11 in Christiansburg. Table A.25 to A.40 in Appendix A show some transportation statistics for the Study area.

3.0 Methodology

3.1 Systems Approach and Systems Methodology

A methodology is a system of rules which guides scientific inquiry. A methodology is usually comprised of procedures (orders of action for defining problems in terms of variables); tools, or elements of communication in the form of verbal, graphical and mathematical constructs, that aid in the execution of the procedures; and techniques which are formal approaches to obtaining solutions to "models" representing the problems [29]. A model is an idealized representation of reality developed with the aid of a methodology. Three components of a methodology for creating and utilizing a model are: (1) a substantive component which specifies how the model's variables and relations are selected (2) a set of criteria that can be used to determine whether the results generated by the model are acceptable; and (3) a scheme for structuring and manipulating the model for performing policy analysis.

3.2 System Dynamics Modeling

Systems dynamics is a relatively new methodology for policy modeling. It is based on the foundations of (1) decision making, (2) feedback systems analysis, and (3) simulation. Decision making is stating how action is to be taken. Feedback deals with the way information is to be used for decision making. Simulation permits decision makers to view the implications of their decisions over the future.

The difficulty in solving the problem of the interrelationships between regional development and transportation investment is that the problem is the object of two different disciplines, development planning and transportation economics, using different languages. The system dynamics methodology is used to bridge the gap between the two disciplines by establishing chains of causality from variables within decision makers' control (levels of investment, resource allocations, and regulatory actions) to socio-economic development indicators (industrial growth, job creation, unemployment, in and out migration rates, population, population density, land use intensity and per capita income).

A model of this process can be very complex and can consist of hundreds of variables. Because of the necessary feedbacks, the determination of the optimal transport system to maintain a desired level of development can be, to say the least, elusive. System dynamics, a field which extends from the work begun by Professor Jay Forrester of MIT, is a methodology devised to handle causal processes by constructing computer models to do what the human mind cannot do—rationally analyze the structure, interactions, and modes of behavior of large scale socio-economic systems. The steps in the procedure are: (1) the formulation of a mental model of the problem in the form of a verbal description, (2) the identification and display of control variables and impact variables in table form, (3) the incorporation of additional key variables in the causal chains from control variables to impact variables and the display of all the interactions graph-

ically in the form of a "causal diagram," and (4) the development of the mathematical model from the causal diagram.

3.3 Causal Diagrams

A causal diagram simplifies the transformation of verbal description into feedback structure. The first step in developing the causal diagram of the model is to identify the key variables which describe the problem situation and record the way the system to be analyzed works. These key variables which are deduced from the mental model or verbal description of the system, are arranged on a sheet of paper. Cause-effect relationships between pairs of variables are depicted by arrows in the second step. The third step in developing a causal diagram is giving each link or arrow a plus or minus directional sign usually placed near the arrow head. Two types of arrows (solid and dashed) and two types of signs (+ and -) are used. The solid arrows denote physical flows, dashed information flows. The types of sign tell us of the variables added or subtracted from this causal diagram.

3.4 System Dynamics Equations

Integration (or accumulation) is the basis of the level and rate structure used in systems dynamics. A level variable $L(t)$ denotes the accumulation of of some physical entity at time t . RI and RO represent the rate variables, rate-in and rate-out, denoting the

change in the level variable over the interval from $t - 1$ to t . The relationships between the level $L(t)$ and the rates can be expressed mathematically as:

$$L(t) = L(t - 1) + \int_{t-1}^t (RI - RO)dt \quad 3.1$$

$$L.K = L.J + (DT)(RI.JK - RO.JK) \quad 3.2$$

In difference equation terminology, any level variable L_i is expressed as functions of rate variables R_j and the previous value of the level,

$$L_i(t) = L_i(t - 1) + (dt) \sum_{j=1}^n R_j(t) \quad i = 1, \dots, m \quad 3.3$$

with the R_j is assumed to be constant over the interval from $t - dt$ to t . The rate variables are of the form

$$R_j(t) = f[L_i(t), E_k(t), A_{ij}(t), A_{kj}(t)] \quad 3.4$$

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

DYNAMO (DYNAMIC MOdels) is a computer program which compiles and executes system dynamic models. Because the inability of this computer program to handle subscripts, DYNAMO uses a postscript notation in which $.K$ stands for the present time t , $.J$ stands for the past time $t - dt$, and $.L$ stands for the future time $t + dt$. As in all computer programming upper case letters are used and DT is called the simulation interval, the

TYPE OF EQUATION	TYPE OF VARIABLE							
	Dependent (Left-Hand Side)	Level	Rate	Auxiliary	Independent (Right-Hand Side)	Constant	Initial	Table Name
L: Level	.K	.J	.JK	.J	none	none	none	n.p.
R: Rate	.KL	.K	.JK	.K	none	none	none	n.p.
A: Auxiliary	.K	.K	.JK	.K	none	none	none	none
C: Constant	none	n.p.*	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
N: Initial	none	none	none	none	none	none	none	n.p.
T: Table Name	none	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.

* n.p. = not permitted

Figure 10. Summary of DYNAMO postscript convention

MAX(A,B) A if $A \geq B$
 B if $A < B$

MIN(A,B) A if $A \leq B$
 B if $A > B$

furthermore, the function MAX can be used to compute the absolute value of a variable specifying the variable and its negative inside the two parenthesis positions.

MAX(A,-A)

3.4.2 Table Functions

A very important part of many simulation models is the use of tabular data, either empirically or theoretically derived. DYNAMO is able to handle data by means of several types of table functions. TABLE, TABXT, TABHL, and TABPL are all invoked in the same manner though there are significant changes in their respective interpolating schemes. Two statements are required to describe a table function. The first one involves five ordered elements inside a parenthesis to specify the dependent variable name, the independent variable name, the lowest, highest values of the independent variable, and the interval between each independent variable. A general definition of a table is given below

TABHL (Y-variable, x-variable, low x, high x, x-interval)

Y-variable = numerical values

The main use of these table functions relies on the fact that every time the variable represented by the table function is invoked in the code the value of that variable will be interpolated or extrapolated from the known function values. TABLE, TABHL, and TABXT interpolate linearly between declared elements while TABPL performs cubic interpolation. TABHL upgrades TABLE by assigning the extreme point function values to the desired function if extrapolation is required. TABXT performs linear extrapolation at the desired value of the function. A last remark in the definition of the numerical values for TABPL is the fact that a zero must be added for each numerical value defined for the Y-variable.

The analyst must determine through logical relationships and statistical data analyses the values for constants and the multipliers which relate the rates to the levels. Once the model has been calibrated and validated, the DYNAMO model can be used for a variety of applications, including: forecasting and prediction, sensitivity analysis, and testing of various scenarios.

3.5 Arrays

DYNAMO provides the modeler with the capability to write variable names with subscripts. Instead of simply writing WF.K to represent a workforce, for example, one can write WF.K(S,T), where S could represent, say, the skill level of the workforce and T the task to which it is assigned. S and T are called subscripts. Although the notation may initially appear cumbersome, there is a dramatic advantage to being able to write variable names using subscripts. It means that one variable name can represent more than one quantity, and one equation can represent more than one element of model structure. The capability to write variables with subscripts enables the modeler to duplicate an entire sector of a model, with different parameters, any number of times with-

out writing more equations. It allows complex, disaggregated models to build up from small, conceptually aggregate sectors. A subscripted variable such as $WF.K(S,T)$ actually represents an array of numbers.

4.0 Non-User Benefit Analysis

4.1 System Dynamic Model of the Study Area

This chapter will present a detailed description of the model. In this description, every element of the model is presented including all assumptions, relationships and numerical values of the parameters used. The model has been divided into:

1. Population sector,
2. Economic sector,
 - Basic industry
 - Business services
 - Household services
3. University sector
4. Transportation sector

Fig. 11 shows the key variables relation between sectors, while the program is listed in Appendix B.

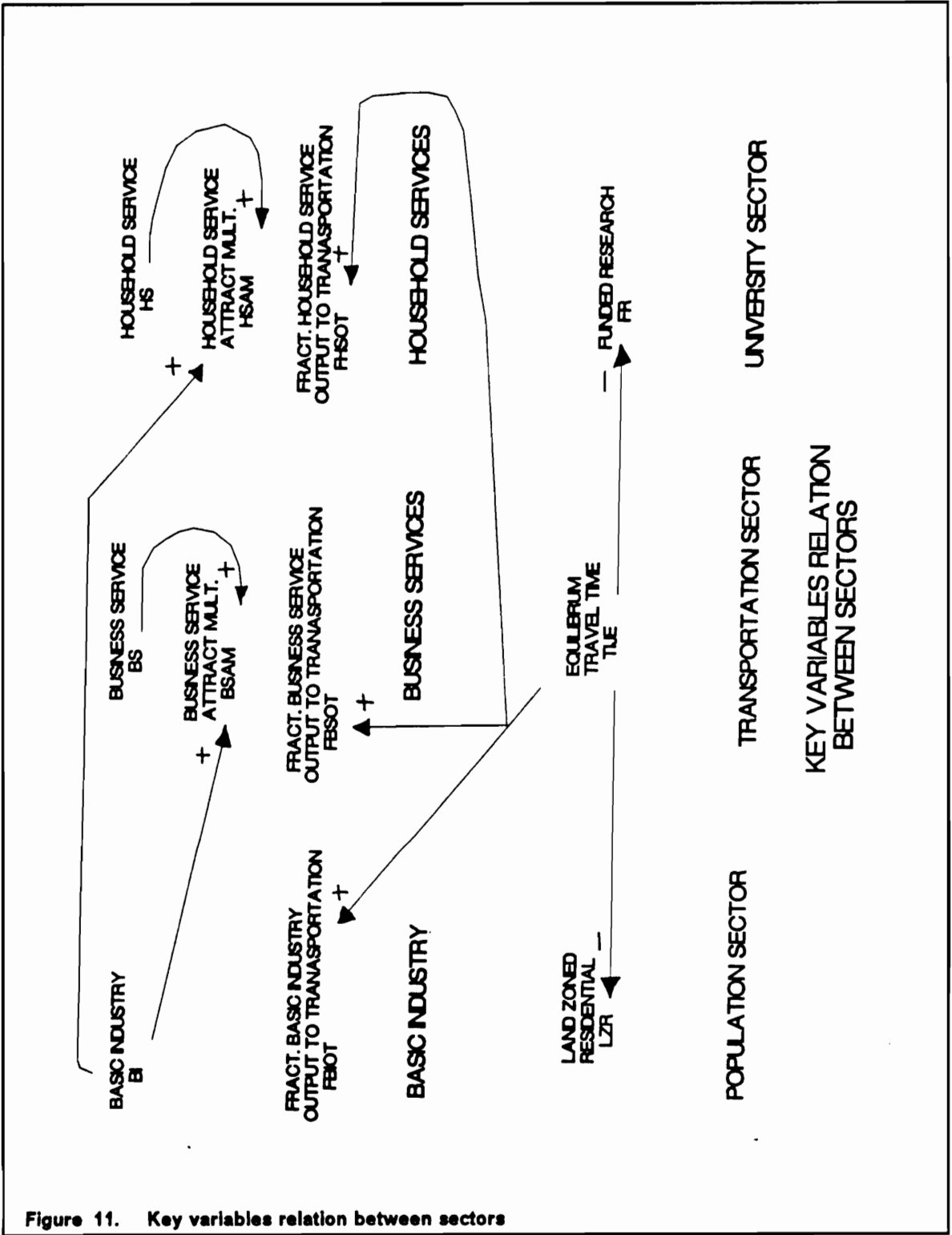


Figure 11. Key variables relation between sectors

4.2 Role of Data

Most social science methodologies are oriented toward gathering and testing data; system dynamics is a methodology that is philosophically committed to serve as a guide to action. Social science methodologies do not possess the grounding for experimenting with large, whole systems. System dynamics provides a framework within which to see operation of the total system in a coherent and orderly manner. An important benefit of the system approach embodied in the system dynamics methodology is the potential of increasing communication between social scientists and policy makers [Drew,(29)]. The model's assumptions were derived from three means:

1. Data that were presented in Appendix A, assuming that Montgomery County area would represent 50% of it from Blacksburg, 25% of it from Christiansburg, and the last 25% for the rest of the County.
2. Through interviews with number of official in planning and economic development department.
3. Personal judgment in those cases where no relevant information was available.

4.3 Population Sector

Population growth is among the most important issues the world faces. Experts agree that it can be met only if there is a great deal of advance planning and that the time for such planning is growing very short. At the micro-level population growth influences both public and private investment decisions. In the case of health, education, transportation and public utility planning depend on population more than any other variable. In the private sector, the level of production in industries serving local markets depends on population growth as well as the supply of labor to sustain industrialization.

Population takes an important part, because it ties economic growth or decay and transportation. It represents both the supply of labor force and the demand of number of trips they make. Fig. 12 shows a causal diagram for the population sector used in the model.

The following paragraphs present an explicit definition of relevant model variables.

Population, P

Population, P is represented as a level variable, P. A system level represents the process of accumulation. Mathematically speaking, the process is one of integration. Population at any point in time is calculated as the population at the preceding point in time, plus the people who have been added by the birth rate in the intervening interval, minus the people removed by the death rate. The population variable is in persons per year. Each level variable requires an initial value, for the population's initial value is population at 1990 in Blacksburg, Christiansburg and Roanoke respectively, and it's estimated to be 33,320, 15,050 and 181,100 respectively. The equation for P is written as

$$P.K(A) = P.J(A) + (DT)(NPG.JK(A) + IM.JK(A) - OM.JK(A))$$

$$P(A) = PN(A)$$

$$PN (*) = 33320/15050/181100$$

where

P - population (persons)

PN - population of Blacksburg, Christiansburg and Roanoke respectively
in 1990 in (persons)

DT - simulation time interval (years)

NPG - net population growth (persons/year)

IM - in-migration (dim)

OM - out-migration (dim)

Net Population Growth, NPG

Net Population Growth, NPG, represents a lump sum of yearly births and deaths all expressed in persons per year. The net population growth depends on the current population in each city.

$$NPG.KL(A) = P.K(A)*NGF(A)$$

where

NPG - Net population growth (persons/year)

NGF - Net growth factor (dim)

Net Growth Factor, NGF

Net Growth Factor, NGF, is a constant representing the difference between the death rate and birth rate, and is assumed to be 0.0024, 0.0073, and 0.0035 for Blacksburg, Christiansburg and Roanoke, respectively.

Out-Migration, OM

Out-Migration, OM, is a rate variable in persons per year and it is dependent on the population of each city and the out-migration normal, and it has been assumed the out-

migration normal is 0.14, 0.015 and 0.024 for Blacksburg, Christiansburg and Roanoke respectively. The out-migration equation can be written as

$$OM.KL(A) = P.K(A)*OMN(A)$$

where

OM - out-migration rate in (persons per year)

P - population in (persons)

OMN - out-migration normal (dim)

In-migration, IN

In-migration, IN, is a rate variable in persons per year, and it is depend on the population, in-migration normal and resident land availability multiplier. The in-migration rate equation can be written as

$$IM.KL(A) = P.K(A)*IMN(A)*RLAM.K(A)$$

where

IM - in-migration rate in (persons per year)

P - population (persons)

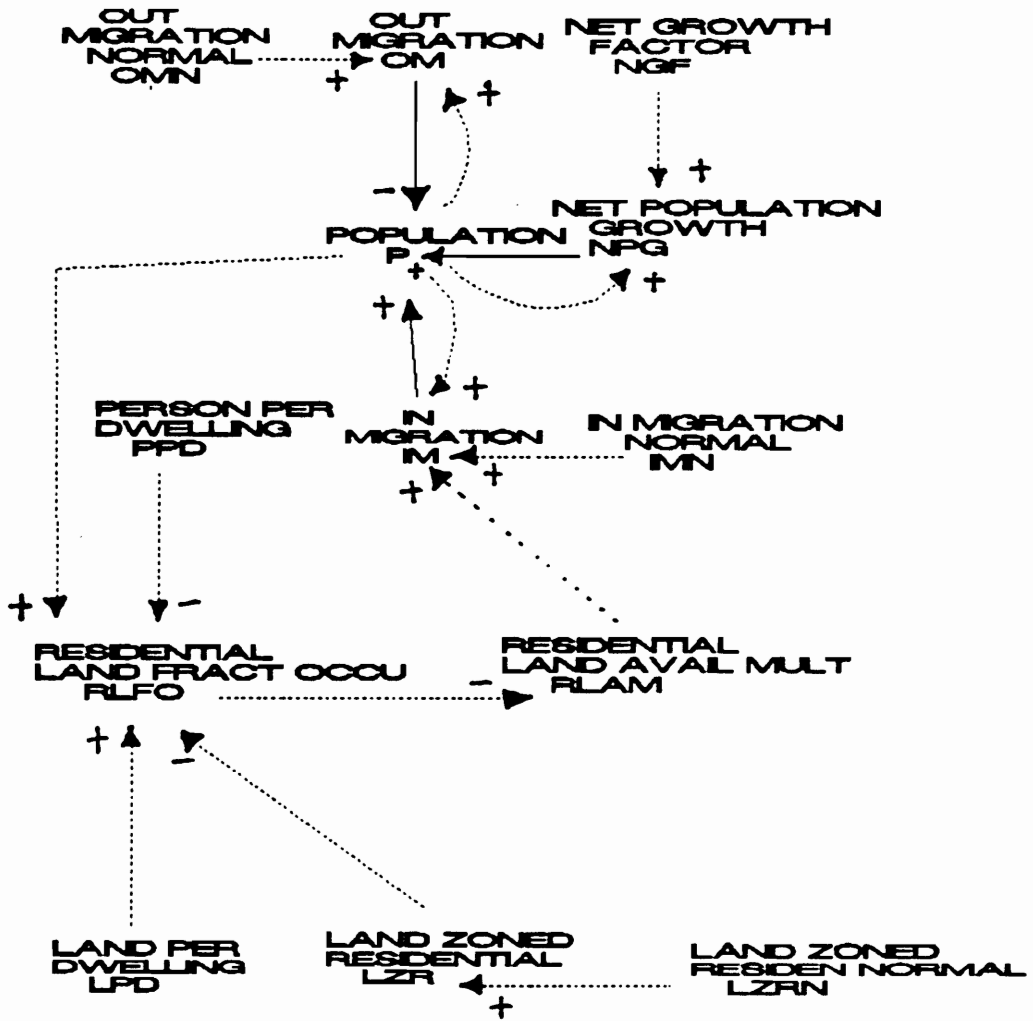
IMN - in-migration normal (dim)

RLAM - resident land availability multiplier (dim)

It has been assumed that in-migration normal is 0.29, 0.075 and 0.059 in Blacksburg, Christiansburg and Roanoke respectively.

Residential land availability multiplier, RLAM

The residential land availability multiplier, RLAM, is a dimensionless auxiliary assumed to be (1-RLFO), where RLFO is residential land fraction occupied and has been used to represent the availability of housing to the population movement.



POPULATION SECTOR

Figure 12. Causal Diagram of Population Sector

Residential land fraction occupied, RLFO

Residential land fraction occupied, RLFO, is a dimensionless auxiliary dependent on the population of each city, area of dwelling, number of persons in the dwelling and the land zoned for residents. It can be written as

$$RLFO.K(A) = P.K(A)*LPD(A)/(PPD(A)*LZR.K(A))$$

where

RLFO - Residential land fraction occupied (dim)

P - population (persons)

LPD - land per dwelling (acres/unit)

PPD - persons per dwelling (persons/unit)

LZR - land zoned residential (acres)

Land per dwelling, LPD

Land per dwelling, LPD, is a constant variable in acres per unit representing the average area required for dwelling. It has been found that the land per dwelling for Blacksburg, Christiansburg and Roanoke is 0.09, 0.14 and 0.13 acres per dwelling respectively.

Persons per dwelling, PPD

Persons per dwelling, PPD, is a constant variable representing the average household size. It has been found that the average is 2.01, 2.51 and 2.7 for Blacksburg, Christiansburg and Roanoke respectively.

Land zoned residential, LZR

Land zoned residential, LZR, is an auxiliary variable in acres. The demand for more land is generated from an increase in urban activities. Since there are many activities in an urban area, it would be impractical to quantify all of them just for the pur-

pose of determining the magnitude of the demand for land. Therefore, in this study, only population is selected as a parameter used in determining this demand. To illustrate, an increase in industrial activities, for example, will attract more people to the area, leading to an increase in housing demand. The population size thus implies the intensity of urban activities, which is needed to estimate the demand for land. The equation can be written as

$$LZR.K(1) = LZR.N(1) \cdot (TN31/T31E)$$

$$LZR.K(2) = LZR.N(2) \cdot (TN12/T12E)$$

$$LZR.K(3) = LZR.N(3) \cdot (TN13/T13E)$$

where

LZR.K(1), LZR.K(2) and LZR.K(3) are the land areas zoned residential in Blacksburg, Christiansburg and Roanoke respectively.

LZR.N(1) - land zoned residential of Blacksburg normal which has been found 3845 acres.

LZR.N(2) - land zoned residential normal in Christiansburg, which has been found to be 2123 acres.

LZR.N(3) - land zoned residential normal of Roanoke which has been found 22000 acres.

TN31 - Travel time from area 3 to area 1 normal = 40 min.

TN13 - Travel time from area 1 to area 3 normal = 40 min.

TN31 - Travel time from area 3 to area 1 normal = 40 min.

TN12 - Travel time from area 1 to area 2 normal = 16 min.

TijE - Travel time from area i to area j at equilibrium to be obtained from the user benefit analysis.

4.4 Economic Sector

The Economic Sector is divided into three sectors: basic industry, business serving industries, and household serving industries. Fig 13 shows the relation between economic sectors.

4.4.1 Basic Industry

Basic industry is defined as those industries whose products and services are exported outside of the region and depend on markets external to the region under study.

Typical of industries that might be considered as basic are the various primary industries, manufacturing, and university employment. A causal diagram of the basic industry sector appear in Fig. 14.

Basic industry BI_i is a level variable BI in (\$). Each level variable requires an initial value for the basic industry. The initial value has been assumed 5.36e8, 4.1e8 and 4.42e9 for Blacksburg, Christiansburg, and Roanoke, respectively. It is dependent on new basic industry attracting rate, basic industry investment and basic industry depreciation. The basic industry equation can be written

$$BI.K(A) = BI.J(A) + (DT)(NBIAR.JK(A) + BII.JK(A) - BID.JK(A))$$

$$BI(A) = BIN$$

$$BIN(*) = 5.36e8/4.1e8/4.42e9$$

where

BI - Basic industry in (\$)

BIN - Basic industry in 1990 at: Blacksburg, Christiansburg and Roanoke, respectively in (\$).

NBIAR - New basic industry attract rate (dim)

BII - Basic industry investment in (\$/year)

BID - Basic industry depreciation in (\$/year)

Basic Industry Depreciation, BID

Basic industry depreciation, BID is a rate variable in \$ per year and it is dependent on the basic industry on each city and the life expectancy of each industry in a year. The equation can be written as

$$BID.KL(A) = BI.K(A)/LBI(A)$$

where

BID - basic industry depreciation in \$ per year

BI - basic industry in \$

LBI - lifetime of basic industry in year

It has been assumed that the basic industry lifetime is 25 years for Blacksburg, Christiansburg, and Roanoke.

New Basic Industry Attraction Rate, NBIAR

New basic industry attraction rate is a rate variable in \$ per year. It is dependent upon the basic industry in each city, basic industry attract factor and basic industry attraction multiplier. The equation can be written as

$$NBIAR.KL(A) = BI.K(A) * BIAF(A) * BIAM.K(A)$$

where

NBIAR - new basic industry attraction rate (dim)

BI - basic industry in \$

BIAF - basic industry attraction factor (dim)

BIAM - basic industry attraction multiplier (dim)

Basic Industry Attraction Factor, BIAF

Basic industry attraction factor is a dimensionless constant representing the industry attraction rate and has been assumed for Blacksburg, Christiansburg, and Roanoke to be 0.02 based on the study of the area.

Basic Industry Attraction Multiplier - BIAM

Basic industry attraction multiplier is a dimensionless auxiliary representing the increase in basic industry. The equation of basic industry attract multiplier is written as

$$\text{BIAM.K(A)} = 1 - (\text{FBIOI.K(A)})$$

where

BIAM - basic industry attract multiplier (dim)

FBIOI - fraction basic industry output to input (dim)

Basic Industry Product - BIP

Basic industry product BIP, is an auxiliary variable in \$ per year. This is the value added by industry after deducting the value of inputs such as rows materials, electricity, water and transportation. The basic industry product equation can be written as

$$\text{BIP.K(A)} = \text{BIO.K(A)} * (1 - \text{FBIOI.K(A)})$$

where

BIP - basic industry product (\$/yr)

BIO - basic industry output (\$/yr)

FBIOI - fraction basic industry output to input (dim)

Basic Industry Output, BIO

Basic industry output, BIO, is an auxiliary variable in \$ per year. This variable defines the selling price. It depends on the amount of the basic industry capital and the efficiency of that capital as measured by the basic industry capital output ratio. The basic industry output equation can be written as

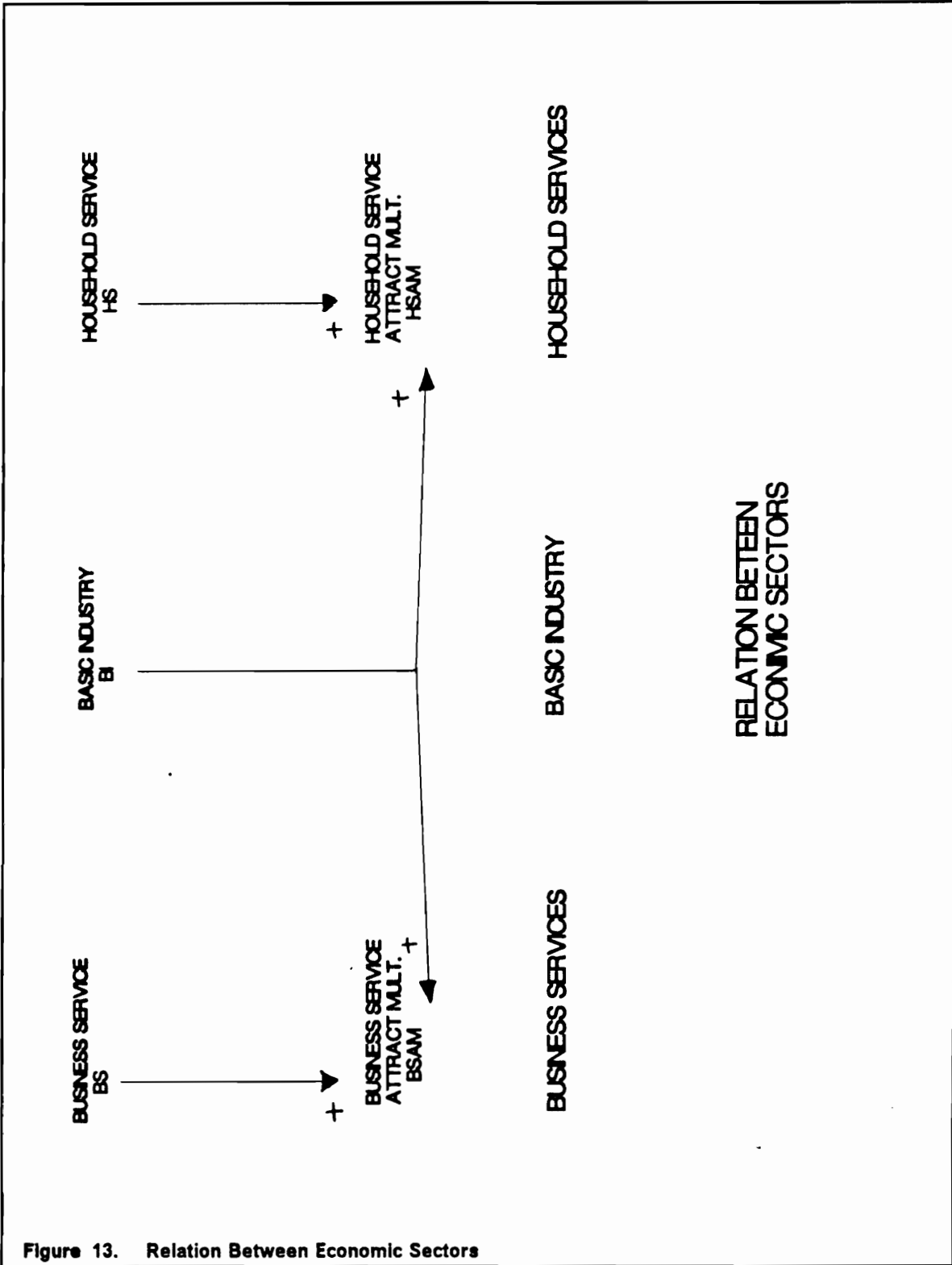


Figure 13. Relation Between Economic Sectors

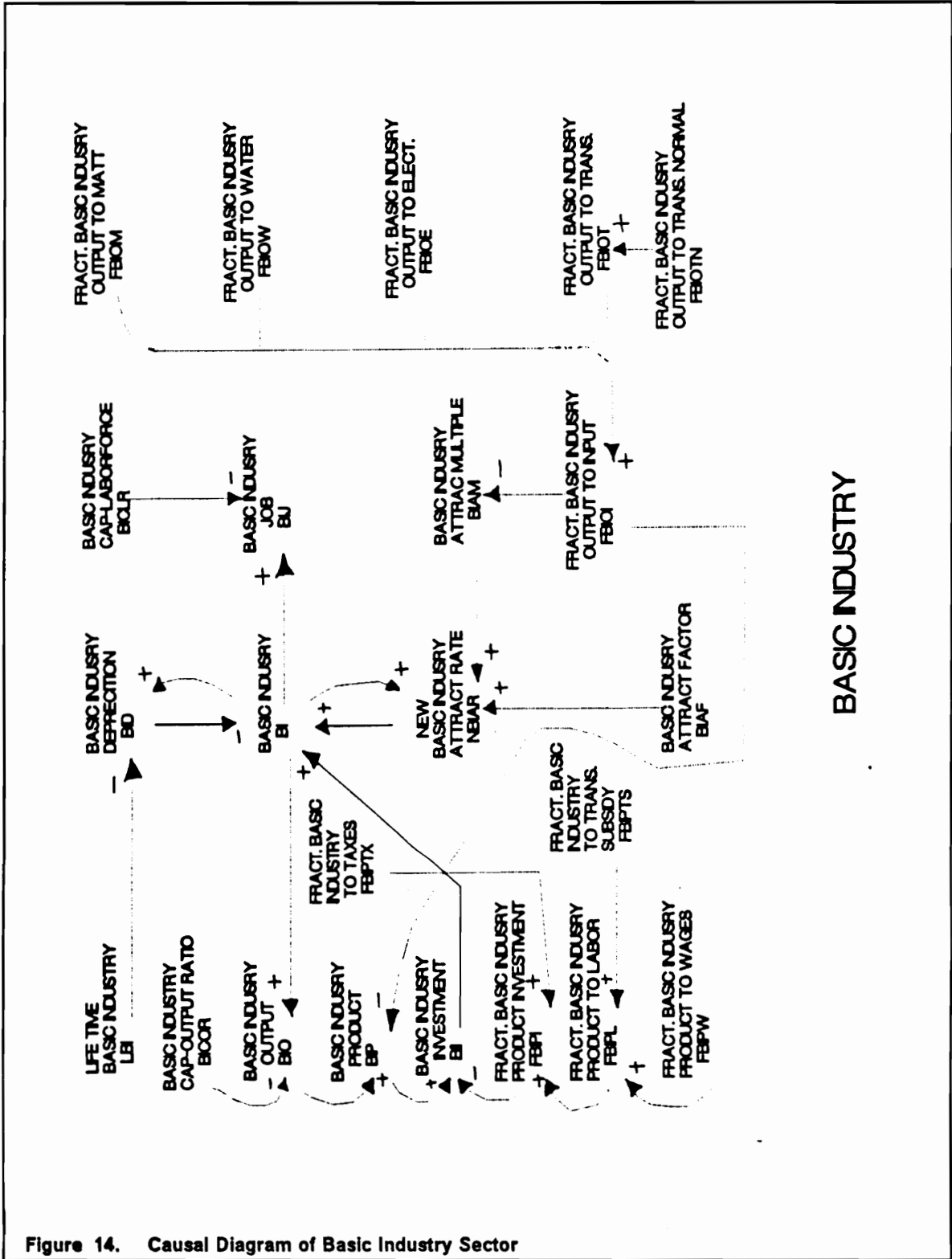


Figure 14. Causal Diagram of Basic Industry Sector

$$BIO.K(A) = BI.K(A)/BICOR(A)$$

where

BIO - basic industry output (\$/year)

BI - basic industry (\$)

BICOR - basic industry capita output ratio (years)

The average small basic industry capital-output ratio for Blacksburg, Christiansburg, and Roanoke is assumed to be 1.8 years.

Fraction Basic Industry Output to Input, FBIOI

Fraction basic industry output to input, FBIOI, is dimensionless. This fraction includes cost of transportation, electricity, water and materials. The equation can be written as

$$FBIOI.K(A) = FBIOT.K(A) + FBIOE(A) + FBIOW(A) + FBIOM(A)$$

The fraction basic industry output to electricity has been assumed as 0.08 based on the study of the area. The fraction basic industry output to water has been assumed as 0.02 based on the study of the area. The fraction basic industry output to material has been assumed as 0.2 based on the study of the area.

Fraction Basic Industry Output to Transportation - FBIOT

Fraction basic industry output to transportation, FBIOT, is a dimensionless constant equal to the usual allocations to the transportation called the fraction basic industry output to transportation normal and the travel time. The equations for fractions basic industry outputs to transportation can be written as

$$FBIOT.K(1) = FBIOTN(1) * \text{Exp} (-(1-T31E/TN31))$$

$$FBIOT.K(2) = FBIONT(2) * \text{Exp} (-(1-T12E/TN12))$$

$$FBIOT.K(3) = FBIONT(3) * \text{Exp} (-(1-T13E/TN13))$$

where

FBIOT - fract. basic industry output to transportation (dim)

FBIOTN - fract. basic industry output to transportation normal (dim)

and fraction output to transportation normal has been assumed as 0.2 based on the study of the area.

Basic Industry Jobs, BIJ

Basic industry jobs, BIJ, is an auxiliary variable representing the number of jobs in basic industry. The equation of basic industry jobs can be written as

$$BIJ.K(A) = BI.K(A)/BICLR(A)$$

where

BIJ - basic industry jobs (persons)

BI - basic industry in (\$)

BICLR - basic industry capital labor ratio (\$/person)

The basic industry capital labor ratio is the amount of capital per labor force, and it has been assumed as 110,000 for Blacksburg, Christiansburg, and Roanoke.

Basic Industry Investment, BII

Basic industry investment, BII, is a rate variable in \$ per year. The amount reinvested in basic industry each year is the product of the basic industry, BIP and the fraction of BIP invested (FBIPI). The equation of basic industry investment, BII, can be written as

$$BII.KL(A) = BIP.K(A) * FBIPI(A)$$

where

BII - basic industry investment (\$/yr)

BIP - basic industry product (\$/yr)

FBIPI - fraction of basic industry product investment (dim)

Fraction Basic Industry Product Investment, FBIPI

Fraction basic industry product investment, FBIPI, is a dimensionless constant dependent on the fraction basic industry product to labor and fraction basic industry product to taxes.

The fraction of basic industry product to taxes has been assumed to be 0.2 for Blacksburg, Christiansburg, and Roanoke.

Fraction Basic Industry Product to Labor - FBIPL

Fraction basic industry product to labor, FBIPL, is a dimensionless constant representing the amount which is paid for labor, it is dependent on the amount of wages and the amount paid for transportation subsidy. The equation of fraction basic industry product to labor, FBIPL can be written as

$$\text{FBIPL} = \text{FBIPS} + \text{FBIPW}$$

where

FBIPL - fraction basic industry product to labor (dim)

FBIPS - fraction basic industry product to transportation subsidy (dim)

FBIPW - fraction basic industry product to wages (dim)

The fraction basic industry to transportation subsidy has been assumed to be 0.1 for Blacksburg, Christiansburg, and Roanoke. The fraction basic industry to wages has been assumed to be 0.4, 0.4, and 0.5 for Blacksburg, Christiansburg and Roanoke respectively.

4.4.2 Business Services

Business serving industry includes the industries that serve the region, for example, personal services, elementary and high school, and repair shops. Fig 15 shows a causal diagram for this sector.

Business services, BS, is a level variable expressed in (\$). Each level variable requires an initial value for the business services. The initial value has been assumed to be 1.53E8, 0.72E8 and 1.068E9 for Blacksburg, Christiansburg and Roanoke, respectively. It is depend on

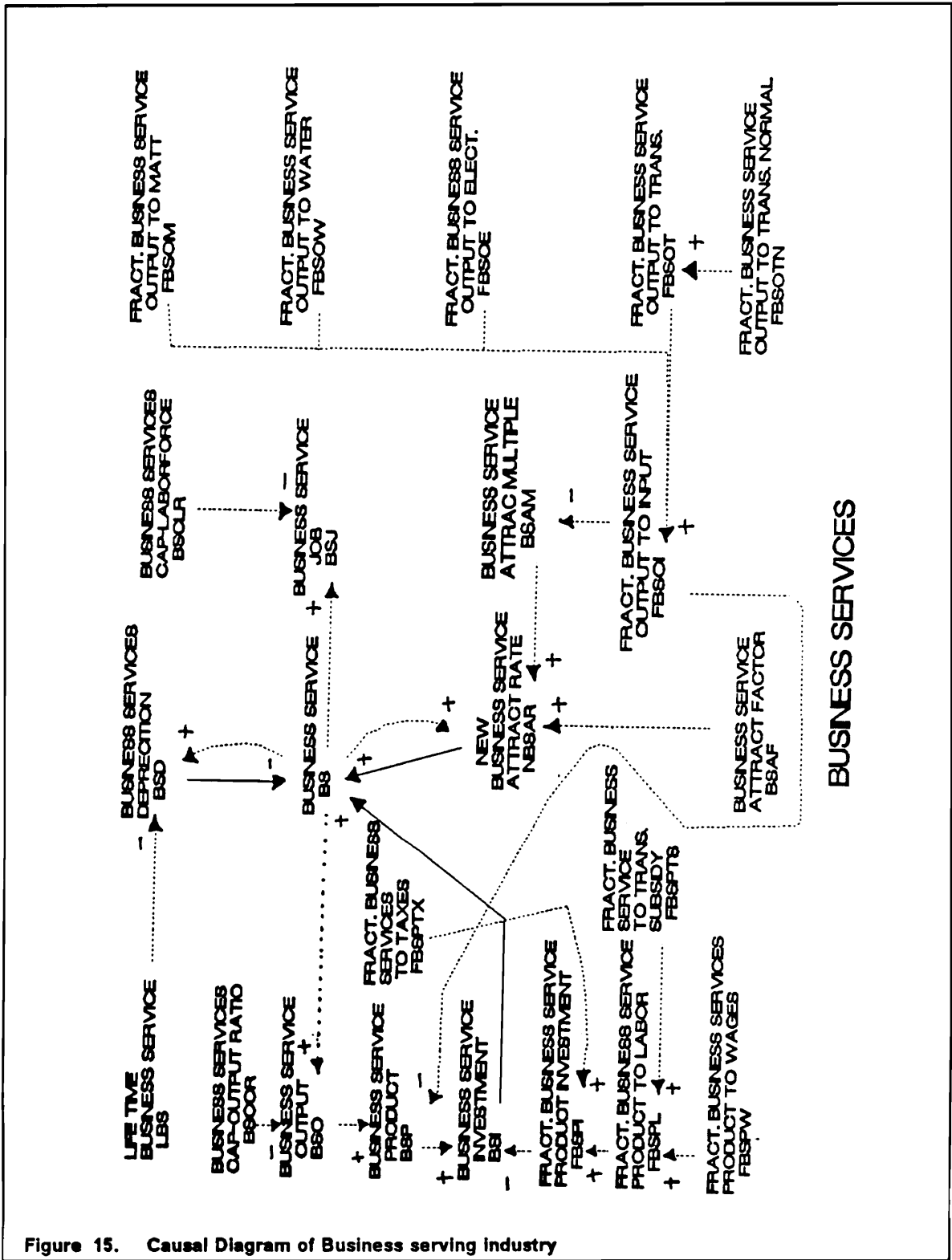


Figure 15. Causal Diagram of Business serving industry

new business services attract rate, business services investment and business services depreciation. The business services can be written as

$$BS.K (A) = BS.J (A) + (DT) (NBSAR.JK (A) + BS1.JK (A) - BSD.JK (A))$$

$$BS (A) = BSN$$

$$BSN (*) = 1.5388/0.72E8/1.068E9$$

where

BS - Business services in (\$)

BSN - Business services in 1990 at: Blacksburg, Christiansburg and Roanoke, respectively (\$).

NBSAR - New business services attract rate (dim) .

BSI - Business services investment in \$ per year

BSD - Business services depreciation in \$ per year

Business services depreciation, BSD

Business services depreciation, BSD is a rate variable in \$ per year and its dependence on the business services on each city and the expectation lifetime of each industry in year.

The equation can be written as

$$BSD.KL (A) = BS.K (A)/LBS (A)$$

where

BSD - Business services depreciation in \$ per year

BS - Business services in (\$)

LBS - Lifetime of business service in year.

It is been assumed that the business services lifetime is 50 years for Blacksburg, Christiansburg and Roanoke.

New business services attraction rate, NBSAR

New business services attraction rate is a rate variable in \$ per year. It is dependent on the business services in each city, business services attract factor and business services attract multiplier. The equation can be written as

$$NBSAR.KL(A) = BS.K (A) * BSAF (A) * BSAM.K (A)$$

where

NBSAR - New business services attraction rate (dim)

BS - Business services in (\$)

BSAF - Business service attraction factor (dim)

BSAM - Business service attraction Multiplier (dim)

Business services attraction factor, BSAF

Business services attraction factor is a dimensionless constant representing the attraction rate to the industry and it is being assumed to be 0.02 for Blacksburg, Christiansburg and Roanoke.

Business services attraction multiplier BSAM

Business services attraction multiplier is a dimensionless for auxiliary to represent the increase in business services. The equation of business services attraction multiplier is written as

$$BSAM.K(A) = (BI.K(A)/BIN(A))*(1-FBSOI.K(A))$$

where

BSAM - Business service attraction multiplier (dim)

FBSOI - Fraction business service output to input (dim)

Business services product BSP

Business services product, BSP, is an auxiliary variable in \$ per year. This is the value added by industry after deducting the value of such inputs as materials, electricity, water and transportation. Business services product equation can be written as

$$BSP.K(A) = BS0.K(A) * (1 - FBSOI.K(A))$$

where

BSP - Business service product (\$/yr)

BS0 - Business service output (\$/yr)

FBSOI - Fraction business service output to input (dim)

Business services output, BSO

Business services output, BSO is an auxiliary variable in \$ per year. This variable defines the value of the selling price. It is dependent on the amount of the business services capital and the efficiency of that capital as measured by the business services capital output ratio the business services output equation can be written as

$$BSO.K(A) = BS.K(A)/BSCOR(A)$$

where

BSO - Business service output (\$/year)

BS - Business service industry (\$)

BSCOR - Business service capital output ratio (years)

It has been assumed that the business services output ratio for Blacksburg, Christiansburg and Roanoke is 1.8 years based on the study of the area.

Fraction business services output to input, FBSOI

Fraction business services output to input, FBSOI is a dimensionless. This fraction includes cost of transportation, electricity, water and materials. The equation can be written as

$$FBSOI.K(A) = FBSOT.K(A) + FBSOE(A) + FBSOW(A) + FBSOM(A)$$

The fraction business services output to electricity has been taken as 0.08 based on the study of the area. The fraction business services output to water has been taken as 0.002 based on the study of the area. The fraction business services output to materials has been taken as 0.2 based on the study of the area.

Fraction business services output to Transportation, FBSOT

Fraction business services output to Transportation, FBSOT, is a dimensionless constant equal to the usual allocation to the transportation. The fraction business services output to

transportation normal and the travel time, the equations for fractions business services output to transportation can be written as

$$\text{FBSOT.K (1)} = \text{FBSOTN (1)} * \text{Exp} (-(1-\text{T31E}/\text{TN31}))$$

$$\text{FBSOT.K (2)} = \text{FBSONT (2)} * \text{Exp} (-(1-\text{T12E}/\text{TN12}))$$

$$\text{FBSOT.K (3)} = \text{FBSONT (3)} * \text{Exp} (-(1-\text{T13E}/\text{TN13}))$$

where

FBSOT - fract. business service output to transportation (dim)

FBSOTN - fract. business service output to transportation normal (dim)

and Fraction output to Transportation normal has been assumed as 0.2 based on the study of the area.

Business Services Jobs, BSJ

Business Services jobs, BSJ is an auxiliary variable representing the number of jobs in business services the equation of business services job can be written as

$$\text{BSJ.K (A)} = \text{BS.K (A)}/\text{BSCLR (A)}$$

where

BSJ - Business service job (person)

BS - Business service in (\$)

BSCLR - Business service capital labor (\$/person)

The business services capital labor ratio is the amount of capital per labor price, and it has been taken as 130,000 for Blacksburg, Christiansburg and Roanoke, respectively.

Business Service Investment, BSI

Business service investment, BSI is a rate variable in \$ per year. The amount reinvested in business services each year is the product of the business services, BSP and the fraction of BSP invested FBSPI. The equation of business services investment BSI can be written as

$$\text{BSI.KL (A)} = \text{BSP.K (A)} * (1-\text{FBSPI(A)})$$

where

- BSI - Business service investment (\$/yr)
- BSP - Business service product (\$/yr)
- FBSPI - Fraction of business service product investment (dim)

Fraction business services product investment, FBSPI

Fraction business services product investment, FBSPI is a dimensionless constant dependent on the fraction business services product to labor and fraction business services product to taxes. The fraction of business services product to taxes is been taken as 0.2 for Blacksburg, Christiansburg and Roanoke.

Fraction business services product to labor FBSPL

Fraction business services product to labor, FBSPL is a dimensionless constant representing the amount which is paid for labor, it is dependent on the amount of wages and the amount which is paid for transportation subsidy. The equation of fraction business services product to labor, FBSPL can be written as

$$FBSPL = FBSPTS + FBSPW$$

where

- FBSPL - Fraction business service product to labor (dim)
- FBSPTS - Fraction business service product to transportation subsidy (dim)
- FBSPW - Fraction business service product to wages (dim)

The fraction business service to transportation subsidy has been taken as 0.1 for Blacksburg, Christiansburg and Roanoke. The fraction business service to wages has been taken as 0.5 for Blacksburg, Christiansburg and Roanoke.

4.4.3 Household Services

Household services are aimed to serve both basic and business industry, retailers and real state business are examples of such industry. The magnitude of household services are depending on the number of jobs available and the inhabitants of that region. Their location is depending upon the population distribution of the region and their products are assumed to be consumed within the region. Fig. 16 shows a causal diagram for this sector.

Household services, HS, is a level variable HS expressed in (\$). Each level variable requires an initial value for the household services the initial value has been assumed as 2.3E8, 2.02E8 and 2.36E9 for Blacksburg, Christiansburg and Roanoke, respectfully. It is dependent on New household services attraction rate, household services investment and household services depreciation. The household services equation can be written as

$$HS.K (A) = HS.J (A) + (DT) (NHSAR.JK (A) + HSIJK (A) - HSD.JK (A))$$

$$HS (A) = HSN$$

$$HSN (A) = 2.3E8/2.02E8/2.364E9$$

where

HS - Household service in (\$)

HSN - Household service 1990 at Blacksburg, Christiansburg and Roanoke, respectively in (\$)

NHSAR - New household service attraction rate (dim)

HS1 - Household service investment in \$ per year

HSD - Household service depreciation in \$ per year

Household services depreciation, HSD

Household services depreciation, HSD, is a rate variable in \$ per year and it is dependent on the household services in each city and the expectation lifetime of each industry in years. The equation can be written as

$$HSD.KL (A) = HS.K (A)/LHS (A)$$

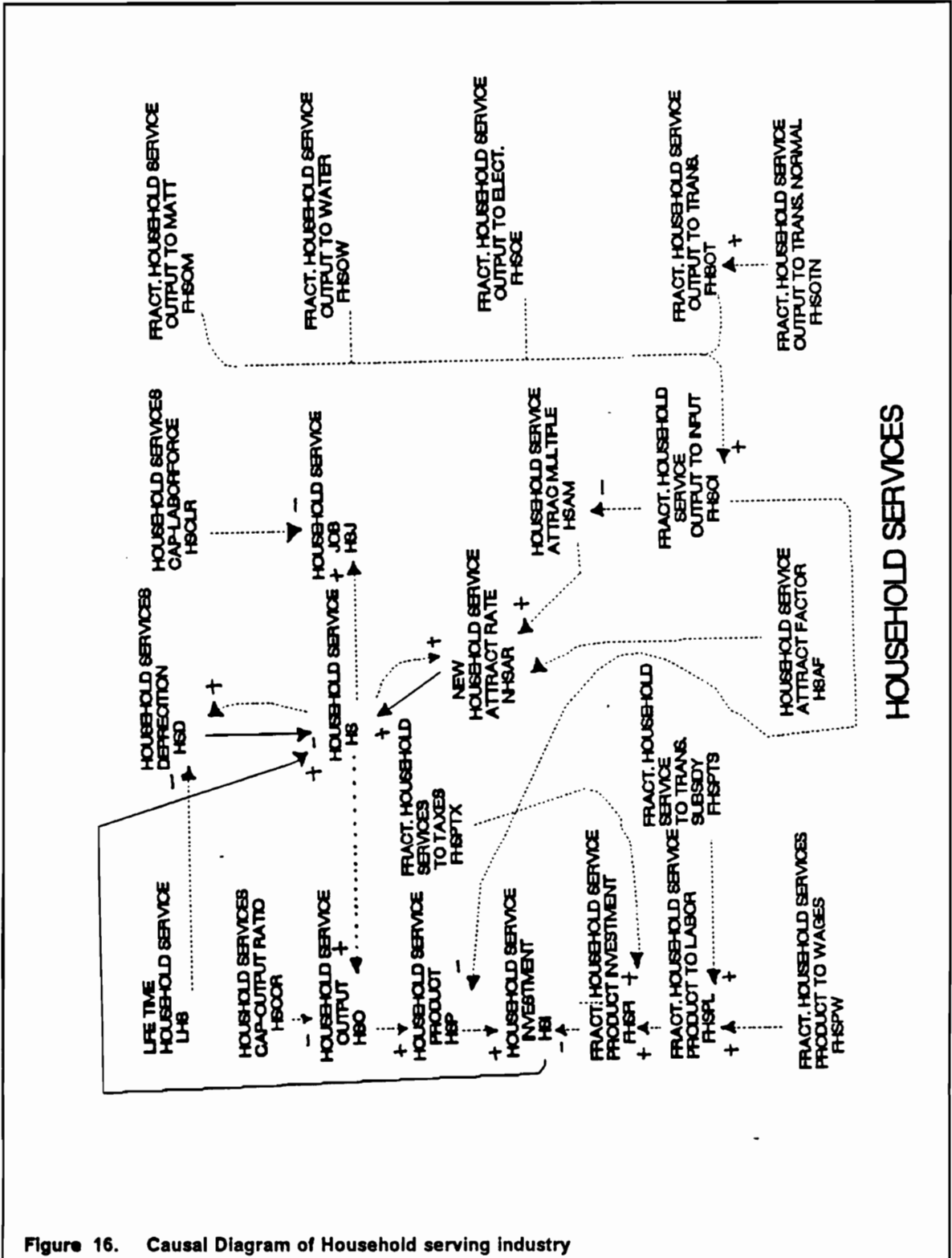


Figure 16. Causal Diagram of Household serving industry

where

HSD - household service depreciation in \$ per year

HS - household service industry in \$

LHS - Lifetime of household service industry in years

It is been assumed that the household services lifetime is 50 years for Blacksburg, Christiansburg and Roanoke.

New Household Services Attraction Rate, NHSAR

New household services attraction rate is a rate variable in \$ per year. It is dependent on the household services in each city, household services attraction factor and household services attraction multiplier. The equation can be written as

$$\text{NHSAR.KL (A)} = \text{HS.K (A)} * \text{HSAF (A)} * \text{HSAM.K (A)}$$

where

NHSAR - New household service attraction rate (dim)

HS - Household service industry in \$

HSAF - Household service attraction factor (dim)

HSAM - Household service industry attraction multiplier (dim)

Household services attraction factor, HSAF

Household services attraction factor is a dimensionless constant represents the attraction rate to the industry and it has been assumed for Blacksburg, Christiansburg and Roanoke as 0.02 based on the study of the area.

Household services attraction multiplier, HSAM

Household services attraction multiplier is a dimensionless for auxiliary to represent the increase in the industry. The equation of household services attraction multiplier is written as

$$\text{HSAM.K (A)} = (\text{BI.K(A)}/\text{BIN(A)}) * (1 - \text{FHSOI.K(A)})$$

where

HSAM - Household service attraction multiplier (dim)

FHSOI - Fraction household service output to input (dim)

Household services product, HSP

Household services product, HSP, is an auxiliary variable in \$ per year. This is the value added by industry's after deducting the value of such inputs as materials, electricity, water and transportation. The household services product equation can be written as

$$\text{HSP.K (A)} = \text{HSO.K (A)} * (1 - \text{FHSOI.K (A)})$$

where

HSP - Household service product (\$/yr)

HSO - Household service output (\$/yr)

FHSOI - Fraction household service industry output to input (dim)

Household services output, HSO

Household services output, HSO is an auxiliary variable in \$ per year. This variable defines the value of the selling price. It is dependent on the amount of the household services capital and the efficiency of that capital as measured by the household services capital output ratio. The household services output equation can be written as

$$\text{HSO.K (A)} = \text{HS.K (A)} / \text{HSCOR (A)}$$

where

HSO - Household service output (\$/year)

HS - Household service industry (\$)

HSCOR - Household service industry output ratio (years)

It has been assumed that the household services output ratio for Blacksburg, Christiansburg and Roanoke is 1.8 years based on the study of the area.

Fraction household services output to input, FHSOI

Fraction household services output to input, FHSOI is dimensionless. This fraction includes cost of transportation, electricity, water and materials. The equation can be written as

$$FHSOI.K(A) = FHSOT.K(A) + FHSOE(A) + FHSOW(A) + FHSOM(A)$$

The fraction household services output to electricity has been taken as 0.08 based on the study of the area. The fraction household services output to water has been taken as 0.02 based on the study of the area. The fraction household services output to materials has been taken as 0.2 based on the study of the area.

Fraction household services output to transportation, FHSOT

Fraction household services output to transportation, FHSOT is a dimensionless constant equal to the usual allocation to the transportation called the fraction household services output to transportation normal and the travel time. The equations for fraction household services output to transportation can be written as

$$FHSOT.K (1) = FHSOTN (1) * \text{Exp} (-(1-T31E/TN31))$$

$$FHSOT.K (2) = FHSOTN (2) * \text{Exp} (-(1-T12E/TN12))$$

$$FHSOT.K (3) = FHSOTN (3) * \text{Exp} (-(1-T13E/TN13))$$

where

FHSOT - fract. household service output to transportation (dim)

FHSOTN - fract.household service output to transportation normal (dim)

Fraction output to transportation normal has been assumed as 0.2 based on the study of the area.

Household services jobs, HSJ

Household services jobs, HSJ, is an auxiliary variable representing the number of jobs in the industry. The equation of household services job can be written as

$$HSJ.K (A) = HS.K (A)/HSCLR (A)$$

where

HSJ - Household service industry jobs (persons)

HS - Household service industry in (\$)

HSCLR - Household service industry capital labor (\$/person)

The household services capital labor ratio is the amount of capital per labor price, and it has been assumed as 130,000 for Blacksburg and Christiansburg and 120,000 for Roanoke.

Household services investment, HSI

Household services investment, HSI is a rate variable in \$ per year. The amount reinvested in the industry each year is the product of the household services, HSP and the fraction of HSP invested (FHSPI). The equation of household services investment, HSI can be written as

$$HSI.KL (A) = HSP.K (A) * (1 - FHSPI (A))$$

where

HSI - Household service investment (\$/yr)

HSP - Household service industry product (\$/yr)

FHSPI - Fraction of household service product investment (dim)

Fraction household services product investment, FHSPI

Fraction household services product investment, FHSPI is a dimensionless constant dependent on the fraction household services product to labor and fraction household services product to taxes. The fraction of household services product to taxes is been taken as 0.2 for Blacksburg, Christiansburg and Roanoke.

Fraction household services product to labor, FHSPL

Fraction household services product to labor, FHSPL is a dimensionless constant representing the amount which is paid for labor, it is dependent on the amount of wages and the

amount which paid for transportation subsidy. The equation of fraction household services product to labor, FHSPL can be written as

$$\text{FHSPL} = \text{FHSPTS} + \text{FHSPW}$$

where

FHSPL - Fraction household service product to labor (dim)

FHSPTS - Fraction household service product to transportation subsidy (dim)

FHSPW - Fraction household service product to wages (dim)

The fraction household services to transportation subsidy has been assumed as 0.1 for Blacksburg, Christiansburg and Roanoke. The fraction basic industry to wages has been taken 0.5 for Blacksburg, Christiansburg and Roanoke.

4.5 University Sector

When universities were initiated, their main task was to preserve knowledge and pass it on to the next generation. The increasing complexity of technological society has imposed new demands on the university, calling forth a variety of new services, training program and research rolls; the strains of rapid social change have induced the faculty to participate more activity in social guidance. So, university education systems become complex problems of management and coordination. They are linked on the one hand to the source of the cultural and scientific. On the other hand, they represent a main avenue of opportunities towards which individuals aspire for their personal and professional development and through which social equity and social mobility can be achieved.

A special treatment of Virginia Tech is performed through the university sector. Fig.17 shows a causal diagram for the university sector.

Faculty, F

Faculty, F, is an auxiliary variable in persons representing the number of faculty in the university. It is equal to the summation of assistant professors, associate professors and full professors. The equation can be written as

$$F.K = ASST.K + ASSOC.K + FULL.K$$

where

F - faculty (persons)

ASST - assistant professors (persons)

ASSOC - associate professors (persons)

FULL - full professors (persons)

Assistant Professors, ASST

Assistant professors, ASST, is a level variable representing the total number of assistant professors. It is dependent on assistant professor hiring rates, assistant professor departure rates, and assistant to associate promotion rates. Each level variable has an initial value, the initial value has been taken as the number of assistant professors at Virginia Tech in 1990 which is 379. The equation can be written as

$$ASST.K = ASST.J + (DT) (ATHR.JK - ATDR.JK - ATAPR.JK)$$

$$ASST = ASSTN$$

$$ASSTN = 379$$

where

ASST - no. of asst. professors (persons)

ATHR - asst. professor hiring rate (person/yr)

ATDR - asst. professor departure rate (person/yr)

ATAPR - asst. to assoc. promotion rate (person/yr)

ASSTN - no. of asst. professors at Virginia Tech in 1990 (persons)

Associate Professors, ASSOC

Associate professors, ASSOC, is a level variable representing the total number of associate professors. It is dependent on the associate professor hiring rate, associate professor departure rate, associate to full promotion rate and assistant to associate promotion rate. Each level variable has an initial value, the initial value has been taken as the number of associate professors at Virginia Tech in 1990 which is 550. The equation can be written as

$$ASSOC.K = ASSOC.J + (DT)(ACHR.JK - ACDR.JK - ATFPR.JK + APR.JK)$$

$$ASSOC = ASSOCN$$

$$ASSOCN = 550$$

where

ASSOC - no. of assoc. professors (persons)

ASSOCN - no. of assoc. professors at Virginia Tech in 1990 (persons)

ACHR - assoc. professor hiring rate (persons/yr)

ACDR - assoc. professor departure rate (persons/yr)

ATFPR - assoc. to full promotion rate (persons/yr)

ATAPR - asst. to assoc. promotion rate (persons/yr)

Full Professor, FULL

Full professor, FULL, is a level variable representing the total number of full professors. It is dependent on full professor hiring rate, full professor departure rate, and associate to full promotion rate. The initial value of level has been taken as the number of full professors in 1990 which is 568. The equation can be written as

$$\text{FULL.K} = \text{FULL.J} + (\text{DT})(\text{FHR.JK} - \text{FPDR.JK} + \text{ATFPR.JK})$$

$$\text{FULL} = \text{FULLN}$$

$$\text{FULLN} = 568$$

where

FULL - no. of full professors (persons)

FULLN - no. of full professor in 1990 (persons)

FHR - full professor hiring rate (person/yr)

FPDR - full professor departure rate (person/yr)

ATFPR - assoc. to full promotion rate (person/yr)

Faculty Hiring, FH

Faculty hiring, FH, is an auxiliary variable in person per year. It is dependent on the number of faculty positions, number of faculty and hiring delay. The equation can be written as

$$\text{FH.K} = \text{Smooth}(\text{FP.K} - \text{F.K})/\text{HD,HD}$$

where

FH - faculty hiring (person/yr)

FP - faculty position (persons)

F - faculty (persons)

HD - hiring delay (yrs)

Assistant Professor Hiring Rate, ATHR

Assistant professor hiring rate, ATHR, is a rate variable expressed in persons per year. It is dependent on faculty hiring and the assistant professor hiring fraction. The equation can be written as

$$\text{ATHR.KL} = \text{FH.K} * \text{ATHF}$$

where

ATHR - asst. professor hiring rate (persons/yr)

FH - faculty hiring (persons/yr)

ATHF - asst. professor hiring fractions (dim)

Associate Professor Hiring Rate, ACHR

Associate professor hiring rate, ACHR, is a rate variable in persons per year. It is dependent on faculty hiring and associate professor hiring fraction. The equation can be written as

$$\text{ACHR.KL} = \text{FH.K} * \text{ACHF}$$

where

ACHK - assoc. professor hiring rate (person/yr)

FH - faculty hiring (persons/yr)

ACHF - assoc. professor hiring fraction (dim)

Full Professor Hiring Rate, FHR

Full professor hiring rate, FHR, is a rate variable in persons per year. It is dependent on faculty hiring and full professor hiring fraction. The equation can be written as

$$\text{FHR.KL} = \text{FH.K} * \text{FHF}$$

where

FHR - full professor hiring rate (persons/yr)

- FH - faculty hiring (persons/yr)
- FHF - full professor hiring fraction (dim)

Assistant to Associate Promotion Rate, ATAPR

Assistant to associate promotion rate, ATAPR, is a rate variable in persons per year. It is dependent on the number of assistant professors and assistant to associate promotions factor. The equation can be written as

$$ATAPR.KL = ASST.K * ATAPF$$

where

- ATAPR - asst. to assoc. promotion rate (person/yr)
- ASST - no. of asst. professors (persons)
- ATAPF - asst. to assoc. promotion factor (fraction/yr)

Associate to Full Promotion Rate, ATAFPR

Associate to full promotion rate, ATAFPR is a rate variable in persons per year. It is dependent on the number of associate professors and associate to full promotion factor. The equation can be written as

$$ATFPR.KL = ASSOC.K * ATFPPF$$

where

- ATFPR - assoc. to full promotion rate (person/yr)
- ASSOC - no. of assoc. professors (persons)
- ATFPPF - assoc. to full promotion factor (fraction/yr)

Faculty Position, FP

Faculty position, FP, is an auxiliary variable in persons. The number of faculty position is dependent on fraction operation budget to faculty, teaching salary and operating budget. The equation can be written as

$$FP.K = FOBF * OB.K/TS.K$$

where

- FP - faculty positions (persons)
- FOBF - fraction operating budget to faculty (dim)
- OB - operating budget (\$/yr)
- TS - teaching salary (\$/person/yr)

Teaching Salaries, TS

Is an auxiliary variable in (\$/person/yr). The equation can be written as

$$TS.K = TSN + RAMP(TSI, 1990)$$

where

- TS - teaching salaries (\$/person-yr)
- TSN - teaching salaries normal at Virginia Tech (\$/person-yr)
- TSI - teaching salaries increase (\$/person-yr)

Operating Budget, OB

Operating budget, OB, is an auxiliary variable in \$ per year. It is dependent on research overhead to budget, discretionary funds to budget, state support per student and number of students. The equation can be written as

$$OB.K = ROB.K + SSPS.K * CLIP(S.K, SSS, TIME.K, SSPCT)$$

where

- OB - operating budget (\$/yr)
- ROB - research overhead to budget (dim)
- SSPS - state support per student (\$/student/yr)

State Support per Student, SSPS

State support per student is an auxiliary variable in (\$/person-yr) The equation can be written as

$$SSPS.K = (SSPSN + RAMP(SSPSI, 1990)) * SSPSM.K$$

$$\begin{aligned} \text{SSPSN} &= 2500 \\ \text{SSPSM.K} &= \text{TABHL}(\text{SSPSMT}, \text{SSS}/\text{S.K}, 0, 2, 0.2) \\ \text{SSPSMT} &= 1/1/1/1/1/1/1/1/1/1 \\ \text{SSS} &= 5200 \\ \text{SSPSI} &= 150 \end{aligned}$$

where

- SSPS - state support per student (\$/person/yr)
- SSPSN - state support per student normal and it is being assumed as 2,500 \$/person/yr
- SSPSI - state support per student increase (\$/person-yr)

Student, S

Student, S, is an auxiliary variable representing the total undergraduate students in the University. The equation can be written as

$$\text{S.K} = \text{FRES.K} + \text{SOPH.K} + \text{JUN.K} + \text{SEN.K}$$

where

- S - total no. of undergraduate students (persons)
- FRES - no. of freshmen students (persons)
- SOPH - no. of sophomore students (persons)
- JUN - no. of junior students (persons)
- SEN - no. of senior students (persons)

Freshmen, FRES

Freshmen, FRES, is a level variable representing the total number of freshmen students in the University. It is dependent on student admissions each year and number of students passed each year from freshmen to sophomores. The initial value for this level variable is the number of freshmen students in 1990 which is 5,673. The equation can be written as

$$\text{FRES.K} = \text{FRES.J} + (\text{DT})(\text{SA.JK} - \text{FTSP.JK})$$

$$FRES = FRESN$$

$$FRESN = 5,673$$

where

FRES - no. of freshmen students (persons)

FRESN - no. of freshmen students in 1990 (persons)

SA - student admissions (persons/yr)

FTSP - freshmen to sophomores passing (persons/yr)

Sophomores, SOPH

Sophomores, SOPH, is a level variable representing the total no. of sophomore students in the University. It depends on the number of students passed from freshman to sophomore each year and number of students passed each year from sophomore to juniors. The initial value for this level variable is the number of sophomore students in 1990 which is 4,524. The equation can be written as

$$SOPH.K = SOPH.J + (DT)(FTSP.JK - STJP.JK)$$

$$SOPH = SOPHN$$

$$FRESN = 4,524$$

where

SOPH - no. of sophomore students (persons)

SOPHN - no. of sophomore students in 1990 (persons)

FTSP - freshmen to sophomores passing (persons/yr)

STJP - sophomores to juniors passing (persons/yr)

Juniors, JUN

Juniors, JUN, is a level variable representing the total number of junior students in the University. It is dependent on students passing from sophomores to juniors each year and number of students passed each year from juniors to seniors. The initial value for this level

variable is the number of junior students in 1990 which is 4,572. The equation can be written as

$$\text{JUN.K} = \text{JUN.J} + (\text{DT})(\text{STJP.JK} - \text{JTSP.JK})$$

$$\text{JUN} = \text{JUNN}$$

$$\text{JUNN} = 4,572$$

where

JUN - no. of junior students (persons)

JUNN - no. of junior students in 1990 (persons)

STJP - no. of sophomores to juniors passing (persons/yr)

JTSP - no. of juniors to seniors passing (persons/yr)

Seniors, SEN

Seniors, SEN, is a level variable representing the total number of senior students in the University. It is dependent on the number of students passing from juniors to seniors and the number of student graduates each year. The initial value for this level is the number of senior students in 1990 which is 3,657. This equation can be written as

$$\text{SUN.K} = \text{SUN.J} + (\text{DT})(\text{JTSP.JK} - \text{SG.JK})$$

$$\text{SUN} = \text{SUNN}$$

$$\text{JUNN} = 3,657$$

where

SUN - no. of seniors students (persons)

SUNN - no. of seniors students in 1990 (persons)

JTSP - no. of juniors to seniors passing (persons/yr)

SG - student graduating (person/yr)

Student Admissions, SA

Student admissions, SA, is a rate variable in persons per year, representing the number of students admitted to the undergraduate program in the University each year. It is de-

pendent on the number of students, number of student positions, and admission change delay.

The equation can be written as

$$SA.KL = CLIP ((SP.K - S.K)/ACD, S.K * SAN, Time .K, APCT)$$

where

SA - tudent admissions (persons/yr)

SP - student positions (persons)

S - student (persons)

ACD - admission change delay (yr)

SAN - student admission normal (fract/yr)

Time - 1990

APCT - admission policy change time (yr)

in other words, if time is greater than or equal to APCT

$$SA.KL = (SP.K - S.K)/ACD$$

and if time < APCT

$$SA.KL = SA.K * SAN$$

Freshman to Sophomores, FTSP

Freshman to sophomores passing, FTSP, is a rate variable in person per year. It represents the number of students passing from freshman to sophomores. It is dependent on the number of freshmen students and fraction freshmen passing. The equation can be written as

$$FTSP.KL = FRES . K * FFP$$

where

FTSP - fresh.to soph. passing (persons/yr)

FRES - freshman student (persons)

FFP - fract.freshman passing (dim)

Sophomores to Juniors Passing, STJP

Sophomores to juniors passing, STJP is a rate variable in person per year. It represents the number of students passed from sophomore to junior. It is dependent on the number of sophomore students and fraction sophomores passing. The equation can be written as

$$STJP.KL = SOPH . K * FSP$$

where

STJP - soph. to jun. passing (person/yr)

SOPH - sophomores (persons)

FSP - fract. soph. passing (dim)

Juniors to Seniors Passing, JTSP

Juniors to seniors passing, JTSP is a rate variable in person per year. It represents the number of students passed from juniors to seniors. It is dependent on the number of juniors students and fraction juniors passing. The equation can be written as

$$JTSP.KL = JUN . K * FJP$$

where

JTSP - junior to soph. passing (person/yr)

JUN - junior (persons)

FJP - fract. jun. passing (dim)

Student Position, SP

Student position, SP, is an auxiliary variable. It is dependent on class lab space and space per student. The equation can be written as

$$SP.K = CLS.K/SPS$$

where

SP - Student position (student)

CLS - class lab space (sq. ft.)

SPS - space per student (sq. ft./student)

where the class lab space equals the total area minus the area of offices, and the equation can be written as

$$CLS = TOT.K - O.S.K$$

where

TOT - Total space area (sq. ft.)

OS - Office space (sq. ft.)

Office Space, OS

Office space, OS, is an auxiliary variable in square feet, it represents the area of the offices. It depends on the number of faculty, number of research faculty positions, space per faculty, total graduate student number, number of staff positions and space per staff. The equation can be written as

$$OS.K = (F.K + RFP.K) * SPF + TGS.K * SPG + STFP.K * SPSF$$

where

OS - office space (sq.ft)

Assistant Professor Departure Rate, ATDR

Assistant professor departure rate, ATDR, is a rate variable representing the number of assistant professors that have left each year. It depends on the number of assistant professors and employment duration of assistant professor. The equation can be written as

$$ATDR.KL = ASST.K / EDATP$$

Associate Professor Departure Rate, ACDR

Associate professor departure rate, ACDR, is a rate variable representing the number of associate professors which quit each year. It depends on the number of associate professors and employment duration of associate professor. The equation can be written as

$$ACDR.KL = ASSOCT.K / EDACP$$

Full Professor Departure Rate, FPDR

Full professor departure rate, FPDR, is a rate variable representing the number of full professors which quit each year. It depends on the number of full professors and employment duration of full professor. The equation can be written as

$$FPDR.KL = FULL.K/EDFP$$

Student Graduation, SG

Student Graduation, SG, is an auxiliary variable representing the number of student graduations. It is dependent on the number of senior students and fraction seniors graduating. The equation can be written as

$$SG.K = SEN.K * FSG$$

where

SG - number of students graduating (persons/yr)

SEN - number of senior students (persons)

FSG - Fraction senior students graduating (dim)

Research Overhead to Budget, ROB

Research overhead to budget, ROB, is an auxiliary variable in dollars per year. It depends on the amount of research overhead and the fraction of research overhead to budget.

The equation can be written as

$$ROB.K = RO.K * FROB$$

where

ROB - research overhd to budget (\$/yr)

RO - research overhd (\$/yr)

FROB - fract. research overhd to budget (dim)

Research Overhead, RO

Research overhead, RO, is an auxiliary variable in dollars per year. It depends on the amount of funded research and fraction research to overhead. The equation can be written as

$$RO.K = FR.K * FRO$$

RO - research overhd (\$/yr)

FR - funded research (\$/yr)

FRO - fract. research to overhd (dim)

Funded Research, FR

Funded research, FR, is an auxiliary variable in dollars per year. It represents the amount of money obtained from the research every year. It depends on the number of faculty, number of proposals per faculty, faction of proposals funded, value of each proposal and the travel time from Roanoke to Blacksburg. The equation can be written as

$$FR.K = F.K * PPF * FPF.K * VPP.K * (TN31/T31E)$$

where

FR - funded research (\$/yr)

F - faculty (persons)

PPF - proposal per faculty (proposal/person)

FPF - fract. proposals funded (dim)

VPP - value per proposal (\$/proposal)

TN31 - travel time from area 3 to area 1 normal (min)

T31E - travel time from area 3 to area 1 at equilibrium (min)

Value per proposal, VPP

Value per proposal, VPP, is an auxiliary variable in dollars per proposal. The equation can be written as

$$VPP.K = VPPN + RAMP (VPPI, 1990)$$

VPP - value per proposal (\$/proposal)

VPPN - value per proposal normal (\$/proposal)

VPPI - value per proposal increase (\$/proposal)

Research Faculty Positions, RFP

Research faculty positions, RFP is dependent on fraction funded research faculty salary, funded research and teaching salary. The equation can be written as

$$RFP.K = (FFRFS * FR.K)/TS.K$$

where

RFP - research faculty positions (persons)

FFRFS - fract. funded research to faculty salaries (dim)

FR - funded research (\$/yr)

TS - teaching salaries (\$/person-yr)

Graduate Research Assistants, GRA

Graduate research assistants, GRA, represents the number of graduate students who have support from the research fund. It is dependent on fraction funded research student salaries, funded research and student salary. The equation can be written as

$$GRA.K = (FFRSS * FR.K)/SS.K$$

where

GRA - graduate research asst. (persons)

FFRSS - fract.funded research to student salaries (dim)

FR - funded research (\$/yr)

SS - student salaries (\$/person-yr)

Student Salaries, SS

Student salaries, SS, is an auxiliary variable in (\$/person/yr.). The equation can be written as

$$SS.K = SSN + RAMP (SSI, 1990)$$

where

SS - student salaries (\$/person-yr)

SSN - student salaries normal at Virginia Tech = 12,000 (\$/person-yr)

SSI - student salaries increase = 400 (\$/person-yr)

Unsupported Graduate Student, UGS

The number of unsupported graduate students, UGS, is dependent on the number of graduate students and ratio of unsupported graduate students. The equation can be written as

$$UGS.K = RUGSTS * S.K$$

where

UGS - unsupported graduate student (person)

RUGSTS - ratio unsupported graduate to student (dim)

S - student (persons)

Graduate Assistants, GA

Graduate assistants, GA, represents the number of graduate students who worked as teaching assistants and paid by the University directly. It is dependent on the fraction operating budget to graduate assistance, operating budget and student salary. The equation can be written as

$$GA.K = RGATS * S.K$$

where

GA - graduate asst. (persons)

RGATS - ratio graduate asst. to student (dim)

S - student (persons)

Staff Positions, STFP

Staff positions, STFP is an auxiliary variable representing the number of staff in the University. It depends on fraction of operating budget to staff, operating budget, fraction funded research to staff support, funded research and staff salary. The equation can be written as

$$\text{STFP.K} = (\text{FOBS} * \text{OB.K} + \text{FFRSFS} * \text{FR.K})/\text{STFS.K}$$

where

- STFP - staff positions (persons)
- FOBS - fract. operation budget to staff (dim)
- OB - oper. budget (\$/yr)
- FFRSFS - fract. funded research to staff support (dim)
- FR - funded research (\$/yr)
- STFS - staff salaries (\$/person-yr)

Staff Salaries, STFS

Staff salaries is an auxiliary variable in (\$/person - yr) the equation can be written as

$$\text{STFS} = \text{STFFSN} + \text{RAMP}(\text{STFSI}, 1990)$$

where

- STFS - staff salaries (\$/person-yr)
- STFFSN - staff salaries normal at Virginia Tech = 14,000 (\$/person-yr)
- STFSI - teaching salaries increase = 500 (\$/person-year)

TABLE 4.1

Structure of University Model

Varameter	Verbal	Value	Unit
Hiring delay	HD	2	years
Asst. Prof. Hiring Factor	ATHF!0.5	Dim	
Assoc. Prof. Hiring Factor	ACHF	0.33	Dim
Full Prof. Hiring Factor	FHF	0.17	Dim
Asst. to Assoc. Promotion Factor	ATAPF	0.1	Fract/yr
Assoc. to Full Promotion Factor	ATFPF	0.1	Fract/yr
Fraction open budget to faculty	FOBF	0.6	DIM
Admission change delay	ACD	2	Years
Student admission normal	SAN	0.235	Fract/yr
Fraction freshman passing	FFP	0.8	DIM
Fraction sophomore passing	FSP	0.85	DIM
Fraction junior passing	FJP	0.9	DIM
Space per student	SPS	170	Sq ft/person
Space per graduate student	SPG	25	Sq ft/person
Space per faculty	SPF	500	Sq ft/person
Space per staff	SPSF	300	Sq ft/person
Employment duration Asst. Prof.	EDATP	6	Years
Employment duration Assoc. Prof.	EDACP	8	Years
Employment duration Full Prof.	EDFP	10	Years
Fract. research overhead to budget	FROB	0.6	DIM
Fract. research to overhead	FRO	0.5	DIM
Fract. proposals funded	FPF	0.6	DIM
Proposals per faculty	PPF	3	proposal/ person
Fract. funded research faculty salaries	FFRFS	0.15	DIM
Fract. funded research student salaries	FFRSS	0.25	DIM
Ratio unsupported graduate to student	RUGSTS	0.05	DIM
Ratio graduate assistants to student	RGATS	0.1	DIM
Fract. open budget to staff	FOBS	0.1	DIM
Fract. funded research to staff	FFRSFS	0.05	DIM
Total space	TOT	6,500,000	Sq. ft.
Fract. serious graduating	FSG	0.95	DIM

Jobs (J)

Jobs J is representing the total basic industry job, business service job and household job in Blacksburg. We add number of faculty positions and staff positions for the total number of jobs. The equation can be written as

$$J.K (1) = BIJ.K (1) + BSJ.K (1) + HSJ.K (1)$$

$$J.K (2) = BIJ.K (2) + BSJ.K (2) + HSJ.K (2)$$

$$J.K (3) = BIJ.K (3) + BSJ.k (3) + HSJ.K (3)$$

where

J (1) - total number of jobs in Blacksburg

J (2) - total number of jobs in Christiansburg

J (3) - total number of jobs in Roanoke

BIJ (1) - basic industry jobs in Blacksburg

BIJ (2) - basic industry jobs in Christiansburg

BIJ (3) - basic industry jobs in Roanoke

BSJ (1) - business services jobs in Blacksburg

BSJ (2) - business services jobs in Christiansburg

BSJ (3) - business services jobs in Roanoke

HSJ (1) - household services jobs in Blacksburg

HSJ (2) - household services jobs in Christiansburg

HSJ (3) - household services jobs in Roanoke

Labor force, LF

Labor force, LF is a variable, and it is equal to a proportion from the total population. In Blacksburg, 0.1 of the population considers a labor force and 40% from the population of each Christiansburg and Roanoke. The equation can be expressed as

$$LF.K (A) = P.K (A) * LPF (A)$$

where

- LF - labor force (persons)
- P - population
- LPF - labor force participation fraction

Unemployment rate, UR

Urban unemployment is defined as the ratio between the labor forces less the number of jobs available in the city, divided by the labor force. Labor forces greater than the jobs available result in a high unemployment rate.

$$UR.K = (LF.K - J.K)/LF.K$$

- UR - Unemployment rate (Percentage)
- LF - Labor Force (Persons)
- J - Jobs (Job Units)

Per Capita Income, PCI

Per capita income is an auxiliary variable in (\$/person) and the equation can be written as

$$PCI.K (1) = BIP.K (1) + BSP.K (1) + HSP.K (1) + RO.K /P.K (1)$$

$$PCI.K (2) = BIP.K (2) + BSP.K (2) + HSP.K (2)/P.K (2)$$

$$PCI.K (3) = BIP.K (3) + BSP.K (3) + HSP.K (3)/P.K (3)$$

where

- PCI (1) - per capita income in Blacksburg (\$/person-yr)
- PCI (2) - per capita income in Christiansburg (\$/person-yr)
- PCI (3) - per capita income in Roanoke (\$/person-yr)
- BIP (1) - basic industry product in Blacksburg (\$/year)
- BIP (2) - basic industry product in Christiansburg (\$/year) -
- BIP (3) - basic industry product in Roanoke (\$/year)
- BSP (1) - business service product in Blacksburg (\$/year)
- BSP (2) - business service product in Christiansburg (\$/year)

- BSP (3) - business service product in Roanoke (\$/year)
- HSP (1) - household service product in Blacksburg (\$/year)
- HSP (2) - household service product in Christiansburg (\$/year)
- HSP (3) - household service product in Roanoke (\$/year)
- RO - research overhead in Virginia Tech (\$/year)

4.6 Transportation Sector

The transportation sector is the primary focus of the model's design. In the transportation sector many parameters are changed from each alternative to another one, so we will explain the auxiliaries only. Fig.18 shows a causal diagram for the transportation sector.

Travel demand, V

Travel demand, V, is an auxiliary variable in persons per hour. It is dependent on the population of each city and trip generation factor. The equation can be written as

$$V_{ijK} = TGF(i) * P(i)$$

where

- Vij - Demand from area i to area j (person/day)
- TGF_i - trip generation factor (dim)
- P_i - population (persons)

Volume on link, KL QKL

Volume on link KL, QKL is an auxiliary variable in veh per hour. The equation can be written as

$$QKL.K = (FDTPH/ACO)*VKL + QKLT$$

where

QKL - volume on link KL (veh/hr)

FDTPH - fraction daily traffic in peak hour (dim)

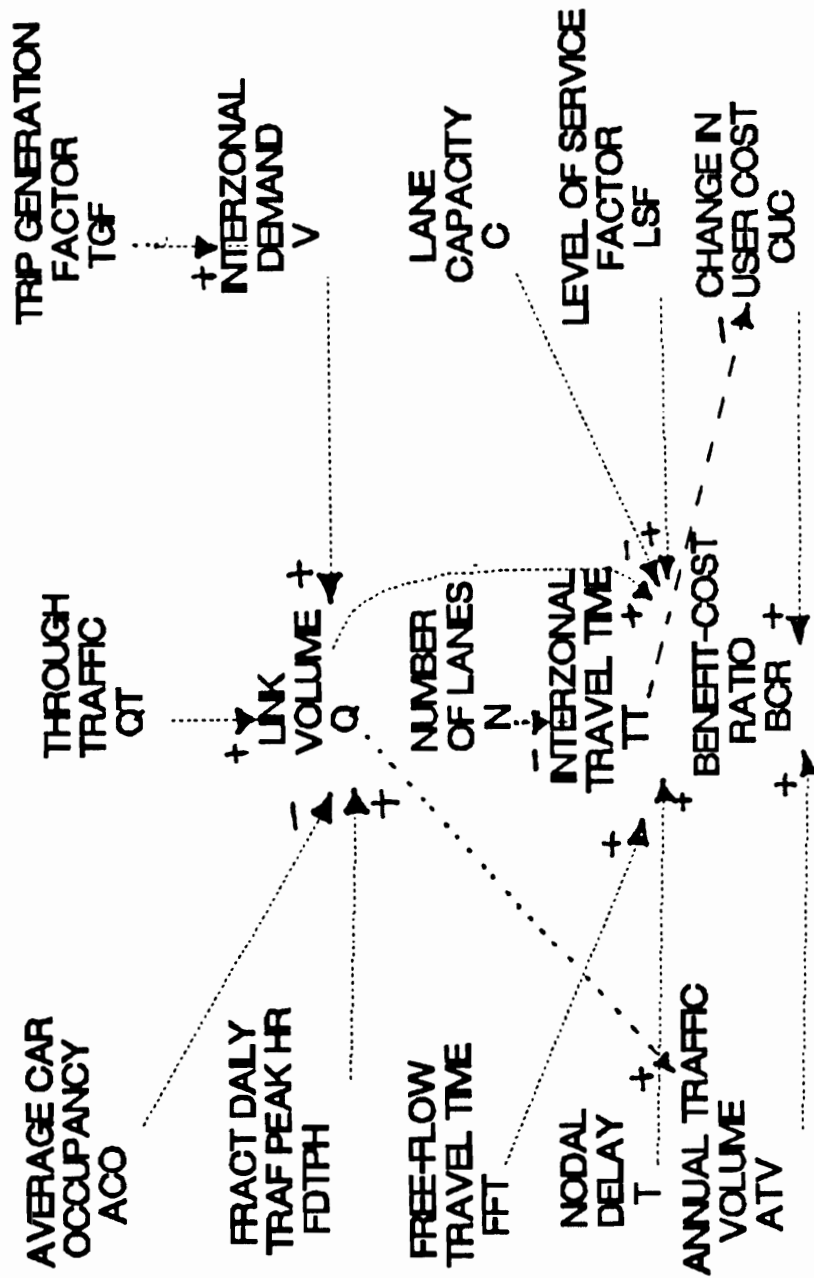
ACO - average car occupancy (person/hr)

VKL - demand from area k to l (person/hr)

QKLT - through traffic on link KL (veh/hr)

Travel Time, TKL

Travel time, TRL in minutes is dependent on free flow travel time on link KL, level of service on link KL, volume on link KL, number of lanes on link KL and capacity of link KL.



TRANSPORTATION SECTOR

Figure 18. Causal Diagram of Transportation Sector

5.0 User Benefit Analysis

5.1 Introduction

An important component of the benefits of highway improvements is saving 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. A unit value of time is selected and multiplied by the amount of travel time saved among the different alternative. In order to find the user benefits for all traffic including induced and diverted as well as through traffic, we have to:

1. Plot the demand function and the supply function for each alternative for the link from Blacksburg to Roanoke.
2. Calculate the benefit-cost ratio for each alternative using

$$BC = \frac{R - E}{Cr} (1 - e^{-r})$$

where

BC - Benefit-cost ratio

R - Annual revenue

E - Annual expenses

C - Initial cost

r - Interest rate (10%)

t - Economic useful life (25 years)

This is explicitly stated in sections 5.9 to 5.15.

5.2 Benefit/Cost Ratio Analysis

The benefit/cost ratio method is one that is found mainly in the public works field, through it is as applicable to industrial application as is any of the other methods. The benefit/cost ratio method has been used almost exclusively since 1952 in the application of economic analysis in highway field [Winfrey,(13)].

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 = present sum

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

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

Assuming that interest is compounded annually at a rate r,

$$F = P(1 + r)^n = P [SPCAF] \qquad 5.1$$

Where SPCAF is the single-payment compounded factor. Solving for P, the present-worth of future sum P, gives :

$$P = F(1 + r)^{-n} = F [SPPWF] \quad 5.2$$

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

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

$$F = \sum_{i=0}^{n-1} A(1 + r)^i = A \left[\frac{(1 + r)^n - 1}{r} \right] = A[EPSCAF] \quad 5.3$$

Where EPSCAF stands for the equal-payment series compound amount factor,

Solving Eq.5.3 for A yields

$$A = F \left[\frac{r}{(1 + r)^n - 1} \right] = \frac{F}{R} [EPSSFF] \quad 5.4$$

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

Substituting Eq. 5.1 in Eq. 5.3 and then solving for A gives

$$A = P \left[\frac{r(1 + r)^n}{(1 + r)^n - 1} \right] = P [EPSCRF] \quad 5.5$$

With EPSCRF standing for the equal-payment series capital-recovery factor

Solving Eq. 5.5 for P defines the equal-payment series present-worth factor EPSPWF as follows:

$$P = A \left[\frac{(1 + r)^n - 1}{r(1 + r)^n} \right] = A [EPSPWF] \quad 5.6$$

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 the 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. 5.6 , gives the present worth of future benefits B as:

$$B = (R - E)[EPSPWF] \quad 5.7$$

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

$$PW = B - C \quad 5.8$$

The annual cost criterion has appeal because by expressing all cost, revenues and expenses as equivalent annual costs, budget planning and control can be facilitated. Applying Eq. 5.5, the annual cost AC of a project alternative is

$$PW = C [EPSCRF] - (R - E) \quad 5.9$$

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 expression

$$B = \sum_{t=0}^n \frac{b_t \Delta t}{(1 + r/x)^{xt}} \quad 5.10$$

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 Δt approaches zero yields the continuous formulation of Eq.5.10 which is

$$B = \int_0^n \frac{b_t dt}{(1 + r/x)^{xt}} \quad 5.11$$

Benefits b_t , are equal to annual revenues R, minus annual expenses E Rewriting Eq. 5.11 gives

$$B = (R - E) \frac{dt}{\int_0^n \left[\left[1 + \frac{1}{x/r} \right]^{x/r} \right]^{rt}} \quad 5.12$$

Since,

$$\lim_{x/r \rightarrow \infty} \left[1 + \frac{1}{(x/r)} \right]^{x/r} = e \quad 5.13$$

Eq 5.12 becomes

$$B = (R - E) \int_0^n e^{-rt} dt \quad 5.14$$

Integrating and applying the limits of integration yields

$$B = (R - E) \frac{1 - e^{-rn}}{r} \quad 5.15$$

If the net present worth is represented by PW and project cost by C, it gives

$$PW = (R - E) \frac{1 - e^{-rn}}{r} - C \quad 5.16$$

The annual cost represented by AC, is

$$AC = C \frac{r}{1 - e^{-rn}} - (R - E) \quad 5.17$$

The rate of return, ROR, is based on solving Eq.5.17 when AC=0, as

$$\frac{r}{1 - e^{-rn}} = \frac{(R - E)}{C} \quad 5.18$$

The benefit-cost is simply B over C. It turns

$$BC = \frac{(R - E)}{C} \times \frac{1 - e^{-rn}}{r} \quad 5.19$$

Sources: References [64,50,49,45]

5.3 Demand Function

Traffic is a medium of activity. It is all too often considered to be synonymous with transportation facilities and this has led to a variety of one-sided criteria for assessing the needs for, and performance of, transportation systems. This notion often sets the traffic engineer in opposition to the urban planner, the sociologist and economist and all too often leads to the fertile "chicken-and-egg" argument as to which comes first – transportation or land use [1].

The truth is that traffic is the joint consequence of land-use potential and transportation capability. Neither land use or highway capacity can generate traffic on its own; traffic is, in fact, the medium in which both find expression, land use and transport form a closed-loop system. Traditionally, however, analysts have opened the loop to study the effect on traffic of imposing changes on one or the other. The transportation planning process has been conceptualized as consisting of a demand function and supply function. When they are combined and the loop is closed, the system like any other physical as economic system, will in the long term settle down into a state of equilibrium. In this section we consider the demand function and in the next section the supply function.

From Transportation sector

$$Q31_t = (FDTPH/ACO) \times V31_t + Q31T \quad 5.20$$

Where:

FDTPH = constant

ACO = constant

Q31T = constant

and

$$V31_t = P_t \times TGF31 \quad 5.21$$

Where:

TGF31 = constant

Hence,

$$Q31_t = f(P_t) \quad 5.22$$

from Population Sector $P.K = P.J + (DT)(NPG.JK + IM.JK - OM.JK)$

at equilibrium

$$P.K = P.J = P_e$$

$$NPG_e + IM_e - OM_e = 0$$

$$P_e \times NGF + P_e \times IMN \times RLAM_e - P_e \times OMN = 0$$

$$P_e \times NGF + P_e \times IMN \times (1 - RLFO_e) - P_e \times OMN = 0$$

$$RLFO_e = P_e \times \frac{LPD}{PPD} \times LZR_e$$

$$LZR_e = LZR_N \times (TN31/T31E)$$

$$P_e \times NGF + P_e \times IMN \times (1 - P_e \times LPD \times T31E / PPD \times LZRN \times TN31) - P_e \times OMN = 0$$

$$NGF + IMN - P_e \times (IMN \times LPD \times T31E / PPD \times LZRN \times TN31) - OMN = 0$$

$$P_e = \left(\frac{PPD \times LZRN \times TN31}{IMN \times LPD \times T31E} \right) (NGF - OMN + IMN) \quad 5.23$$

Where:

PPD = constant

LZRN = constant

TN31 = constant

IMN = constant

LPD = constant

NGF = constant

OMN = constant

Hence,

$$P_e = f(T31E) \quad 5.24$$

$$V31_t = P_t \times TGF31$$

from Population Sector P.K = P. J + (DT)(NPG.JK + IM.JK - OM.JK)

$$\frac{dp_t}{dt} = NPG_t + IM_t - OM_t$$

$$= P_t \times NGF + P_t \times IMN \times RLAM_t - P_t \times OMN$$

$$= P_t [NGF - OMN + IMN(1 - RLFO_t)]$$

$$= P_t [NGF - OMN + IMN \times (P_t \frac{\times LPD \times T31E}{PPD \times LZRN \times TN31})]$$

$$\begin{aligned}
&= P_t \left[(NGF - OMN + IMN) \left(\frac{PPD \times LZRN \times TN31}{IMN \times LPD \times T31E} \right) - P_t \right] \times \left(\frac{IMN \times LPD \times T31E}{PPD \times LZRN \times TN31} \right) \\
&= P_t (P_e - P_t) \left(\frac{IMN \times LPD \times T31E}{PPD \times LZRN \times TN31} \right)
\end{aligned} \tag{5.25}$$

$$\int_{P_0}^{P_t} \frac{dp_t}{P_t} (P_e - P_t) = \int_0^t \left(\frac{IMN \times LPD \times T31E}{PPD \times LZRN \times TN31} \right) dt$$

$$\begin{aligned}
\ln P_t - \ln(P_e - P_t) \Big|_{P_0}^{P_t} &= P_e \times \left(\frac{IMN \times LPD \times T31E}{PPD \times LZRN \times TN31} \right) \times t \\
&= (NGF - OMN + IMN) \times t
\end{aligned}$$

$$\ln \left[\frac{P_t / (P_e - P_t)}{P_0 / (P_e - P_0)} \right] = (NGF - OMN + IMN) \times t$$

$$\frac{P_t}{(P_e - P_t)} = \left(\frac{P_0}{(P_e - P_0)} \right) \times [e^{(NGF - OMN + IMN)t}]$$

$$P_t = \frac{P_e}{\{1 + (P_e/P_0 - 1)e^{-(NGF - OMN + IMN)t}\}} \tag{5.26}$$

By substituting Eq.5.24 and Eq.5.26 into Eq.5.22 we get

$$Q_{31,t} = f(T31) \tag{5.27}$$

Using the trail and error procedure, we derive the demand curve

5.4 Supply Function

The diversity of patterns of socioeconomic interaction and the resulting complexity in the evolution of transportation needs indicate that formal and systematic analyses are essential for understanding the relationships between the spatial distribution of activities and transportation. This is handled in past using transportation demand analysis described, in the context of this model, in the previous section.

In the celebrated four-step urban transportation planning process consisting of trip generation, trip distribution, model split and traffic assignment, the supply function is considered at the traffic assignment stage. What we are interested in is the average, perceived user cost function. In order to construct such a function, we make use of basic speed-volume relationships derived from theory of traffic flow research and end up with travel time-volume relationship. Since the demand function can also be expressed using the same variables, equilibrium analysis is made feasible.

From transportation sector

$$T_{31,t} = (FFT_{31} \times (1 - ((1 - LSF_{31}) \times Q_{31,t}) / (N_{31} \times C_{31}))) / (1 - Q_{31,t} / (N_{31} \times C_{31}))$$

Where:

FFT_{31} = constant

N_{31} = constant

LSF_{31} = constant

C_{31} = constant

Hence,

$$T_{31,t} = f(Q_{31,t})$$

5.28

Through the trail and error procedure, we derive the supply curve

5.5 Annual Revenue, R

For non-toll type transport facilities, there are no annual revenues per se to use to substitute for R. Therefore, a more detailed discussion of the benefit item "perceived user travel benefit" will be helpful. For this purpose it is necessary to introduce supply-demand concepts. A basic premise of economics is the intimate relationship between price and demand on the one hand and price and supply on the other. A demand function or demand curve is a statement of the number of trips which will be made or "purchased" at different levels of overall trip price, where the perceived price of travel is the total payment in expense, time, and effort that the traveller perceives or thinks about in making a trip. It is necessary to know how the unit price of travel will change as more and more tripmaking is made and as system design and operation is changed. On the other hand, it is necessary to know what price different volumes of tripmakers will be willing to pay for the trip in question. The interplay between these two relationships will permit determination of the actual use which a facility will experience and of the benefit or value accruing to its user. Once the equilibrium point (V, P) or intersection between supply and demand curves has been determined, the total system costs can be computed. The value of time is assumed to be \$0.2/min. The revenue can be computed as an area under the curve with the volume multiplied by 8,760 to change it from veh/hr. to veh/yr.

5.6 Annual Expenses, E

Annual expenses includes the following:

1. The annual cost of maintenance (surface and base, roadside, drainage, snow and ice re-

moval, etc.)

2. Annual operation and administration (lighting, traffic operation, etc.)
3. Vehicle running cost which is affected by distance, vertical grades, horizontal curvature, roadway surface, speed and traffic control devices. The vehicle running cost includes fuel, engine oil, tires, maintenance, and depreciation.
4. Accident cost - it is very difficult to assign a value to accident casualties. There has been a lot of research that has given values for fatalities, nonfatal personal injuries, and property damage.

The data for each alternative was assumed based on figures in "A Manual on User Benefits Analysis of Highway and Bus-transit Improvement," AASHTO [12].

5.7 Construction Cost, C

C represents the total construction cost including engineering, right-of-way, and construction Table 1.1 shows the estimated cost for each alternative.

5.8 Economic Useful Life, t

The key in determining economic life, t , 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, and it has been assumed here to be 25 years.

The following seven sections quantify the Uses/Benefit for all alternatives explored in this research.

5.9 Alternative 2

Fig.19 shows the user benefits analysis for alternative 2 where

$$\text{Cost } C = 75,900,000$$

$$\begin{aligned} \text{Revenue } R &= \frac{(P_1 - P_2)(Q_1 + Q_2)}{2} \\ &= \frac{(40 \times 0.2 - 35.9 \times 0.2)(1,182 \times 8,760 + 1,561 \times 8,760)}{2} \end{aligned}$$

$$= 9,851,758$$

$$\text{Expenses } E = 3,663,640$$

$$\begin{aligned} \text{BC} &= \frac{R - E}{Cr} (1 - e^{-r}) \\ &= \frac{9,851,758 - 3,663,640}{75,900,000 \times 0.1} (1 - e^{-0.1 \times 25}) \end{aligned}$$

$$= 0.7$$

USER BENEFITS ANALYSIS
 BLACKSBURG TO ROANOKE
 EQUILIBRIUM ANALYSIS FOR ALT 2

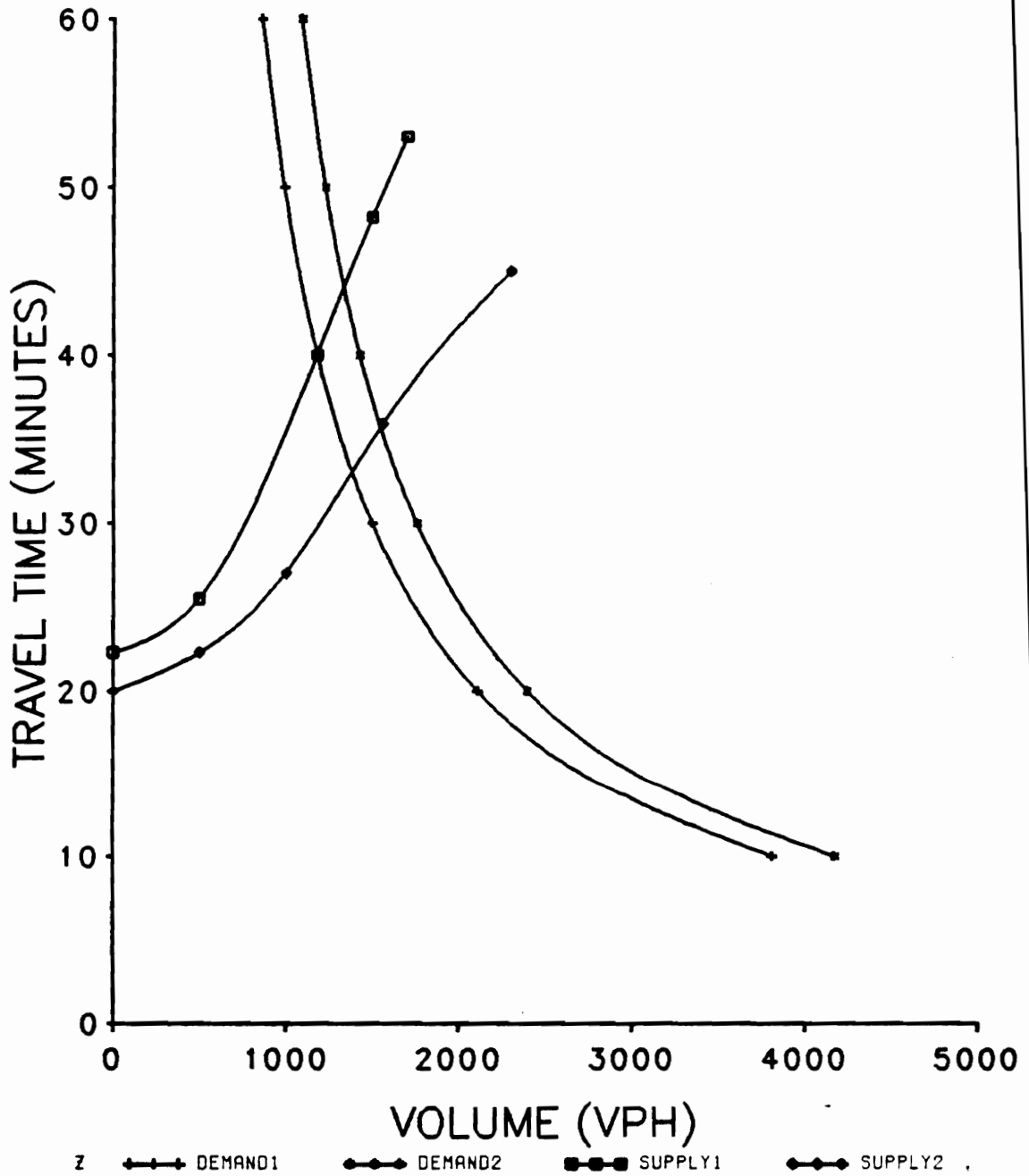


Figure 19. Equilibrium Analysis for Alternative 2

5.10 Alternative 3A

Fig.20 shows the user benefits analysis for Alternative 3A where

$$\text{Cost } C = 105,600,000$$

$$\begin{aligned} R &= \frac{(P_1 - P_{3a})(Q_1 + Q_{3A})}{2} \\ &= \frac{(40 \times 0.2 - 34.8 \times 0.2)(1,182 \times 8760 + 1,579 \times 8,760)}{2} \\ &= 12,576,907 \end{aligned}$$

$$\text{Expenses } E = 980,000$$

$$\begin{aligned} BC &= \frac{R - E}{Cr} (1 - e^{-r}) \\ &= \frac{12,576,907 - 980,000}{105,600,000 \times 0.1} (1 - e^{-0.1 \times 25}) \\ &= 1.0 \end{aligned}$$

**USER BENEFITS ANALYSIS
BLACKSBURG TO ROANOKE
EQUILIBRIUM ANALYSIS FOR ALT 3A**

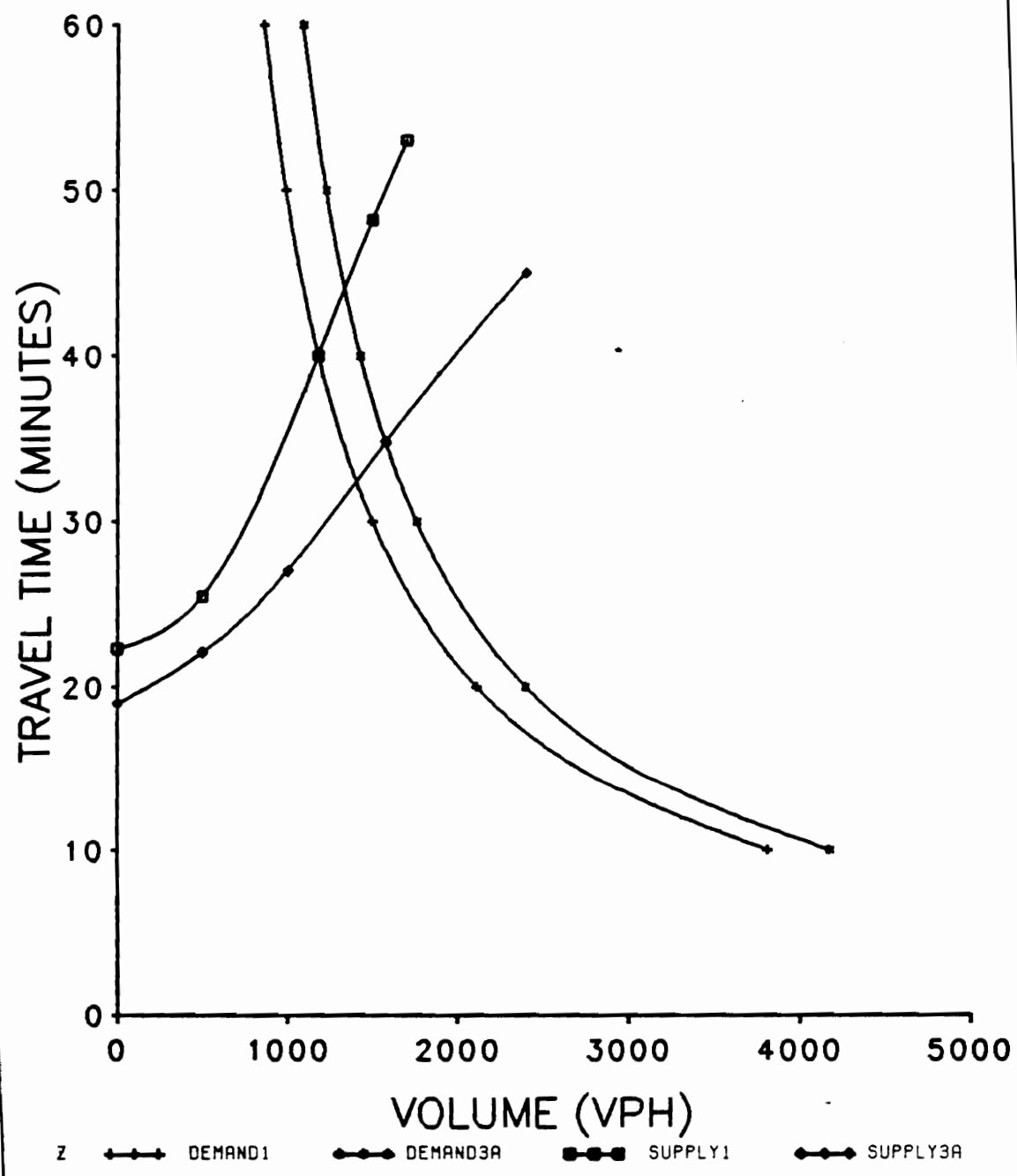


Figure 20. Equilibrium Analysis for Alternative 3A

5.11 Alternative 5

Fig.21 shows the user benefits analysis for Alternative 5 where

$$\text{Cost } C = 122,900,000$$

$$\begin{aligned}\text{Revenue } R &= \frac{(P_1 - P_2)(Q_1 + Q_2)}{2} \\ &= \frac{(40 \times 0.2 - 34.68 \times 0.2)(1,182 \times 8,760 + 1,602 \times 8,760)}{2} \\ &= 12,974,331\end{aligned}$$

$$\text{Expenses } E = 924,195$$

$$\begin{aligned}\text{BC} &= \frac{R - E}{Cr} (1 - e^{-r}) \\ &= \frac{12,974,331 - 924,195}{122,900,000 \times 0.1} (1 - e^{-0.1 \times 25}) \\ &= 0.9\end{aligned}$$

**USER BENEFITS ANALYSIS
BLACKSBURG TO ROANOKE
EQUILIBRIUM ANALYSIS FOR ALT 5**

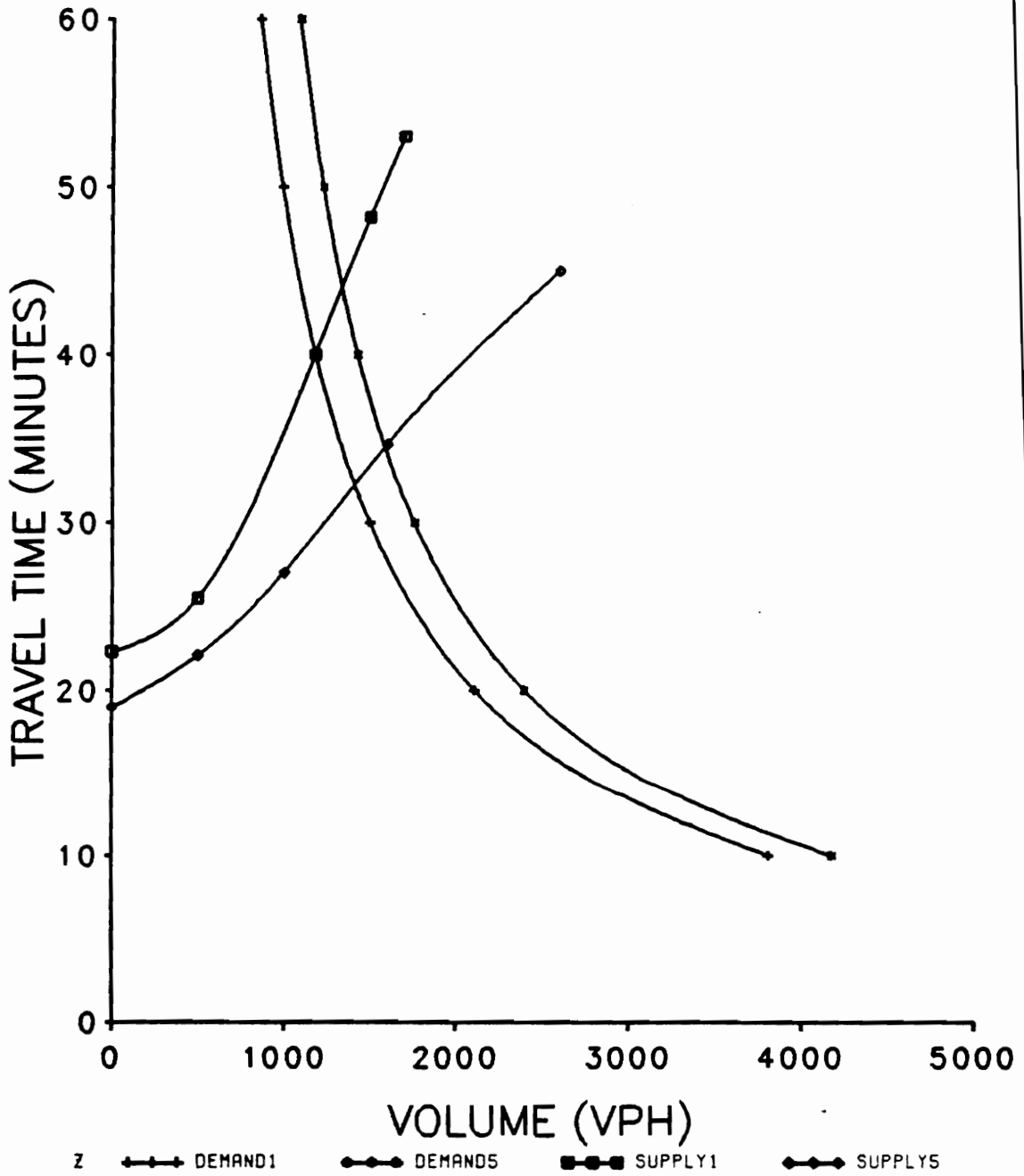


Figure 21. Equilibrium Analysis for Alternative 5

5.12 Alternative 12

Fig.22 shows the user benefits analysis for Alternative 12 where

$$\text{Cost } C = 115,700,000$$

$$\begin{aligned}\text{Revenue } R &= \frac{(P_1 - P_{12})(Q_1 + Q_{12})}{2} \\ &= \frac{(40 \times 0.2 - 35.49 \times 0.2)(1,182 \times 8,760 + 1,575 \times 8,760)}{2} \\ &= 10,892,245\end{aligned}$$

$$\text{Expenses } E = 1,400,000$$

$$\begin{aligned}\text{BC} &= \frac{R - E}{Cr} (1 - e^{-r}) \\ &= \frac{10,892,245 - 1,400,000}{115,700,000 \times 0.1} (1 - e^{-0.1 \times 25}) \\ &= 0.75\end{aligned}$$

**USER BENEFITS ANALYSIS
BLACKSBURG TO ROANOKE
EQUILIBRIUM ANALYSIS FOR ALT 12**

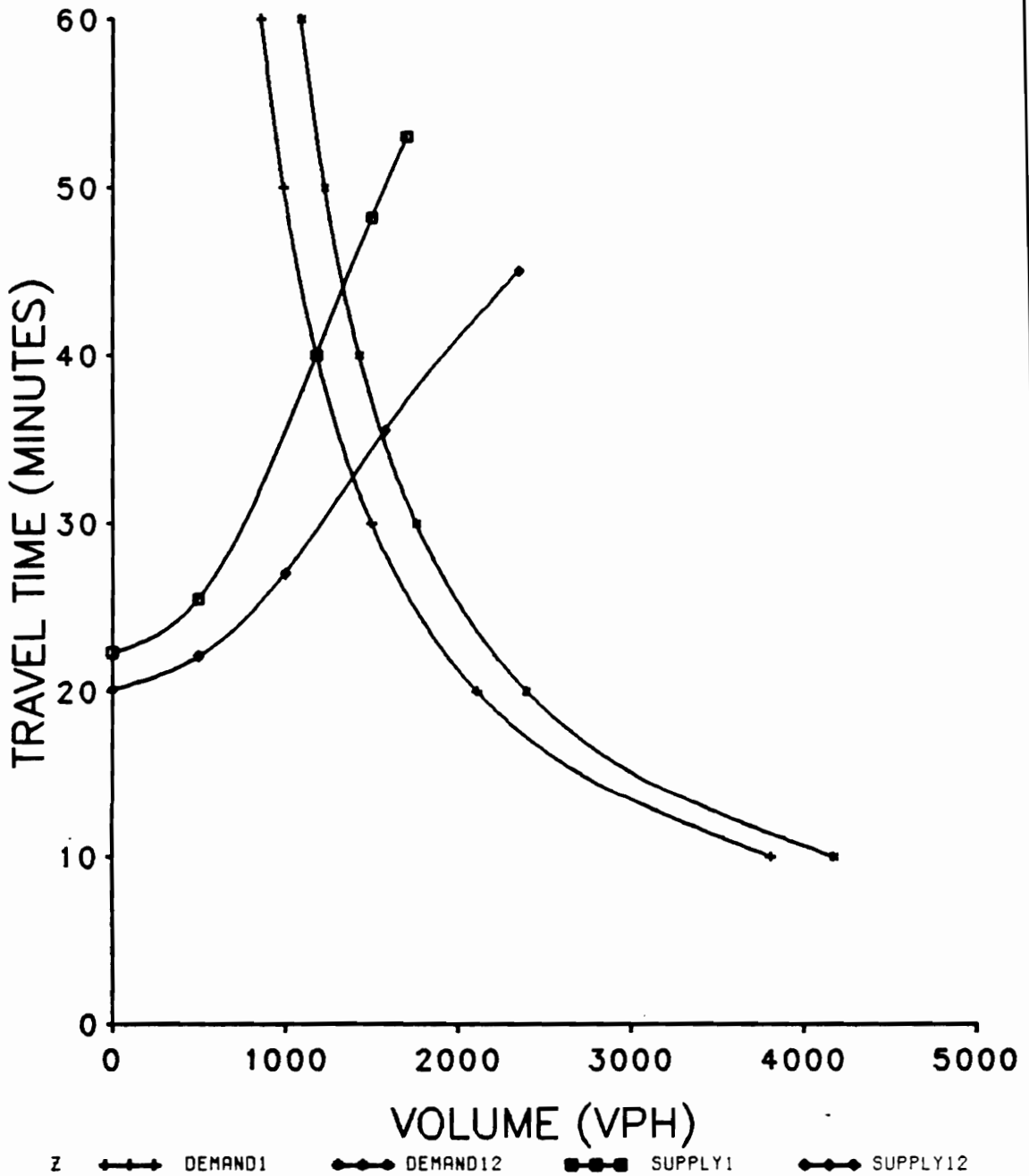


Figure 22. Equilibrium Analysis for Alternative 12

5.13 Alternative 6

Fig.23 shows the user benefits analysis from Alternative 6 where

$$\text{Cost } C = 147,100,000$$

$$\begin{aligned}\text{Revenue } R &= \frac{(P_1 - P_2)(Q_1 + Q_2)}{2} \\ &= \frac{(40 \times 0.2 - 29.88 \times 0.2)(1,182 \times 8,760 + 2,015 \times 8,760)}{2} \\ &= 28,341,789\end{aligned}$$

$$\text{Expenses } E = 2,701,070$$

$$\begin{aligned}\text{BC} &= \frac{R - E}{Cr} (1 - e^{-r}) \\ &= \frac{28,341,789 - 2,701,770}{147,100,000 \times 0.1} (1 - e^{-0.1 \times 25}) \\ &= 1.6\end{aligned}$$

USER BENEFITS ANALYSIS
 BLACKSBURG TO ROANOKE
 EQUILIBRIUM ANALYSIS FOR ALT 6

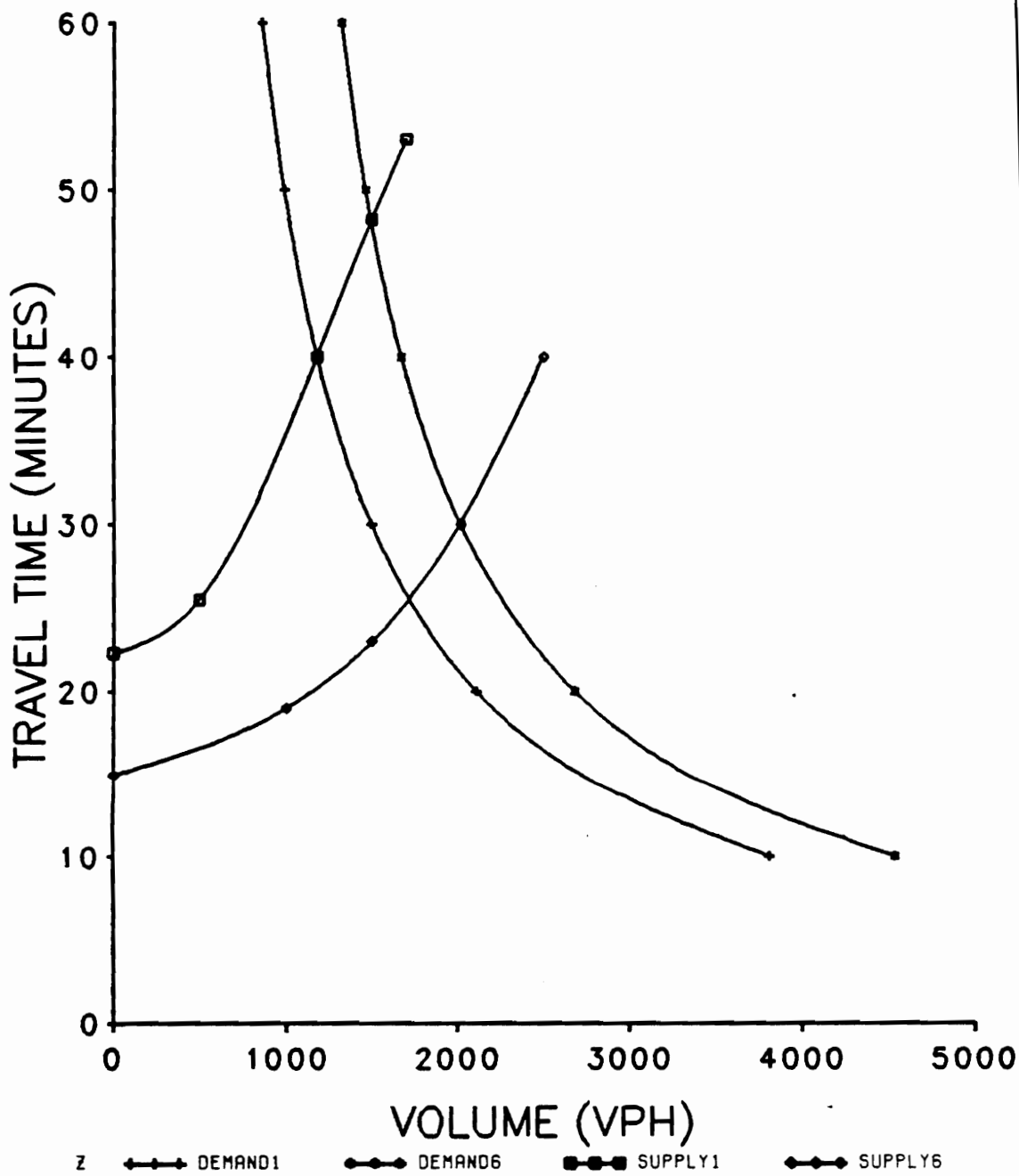


Figure 23. Equilibrium Analysis for Alternative 6

5.14 Alternative 7

Fig.24 shows the user benefits analysis for Alternative 7 where

$$\text{Cost } C = 166,000,000$$

$$\begin{aligned}\text{Revenue } R &= \frac{(P_1 - P_7)(Q_1 + Q_7)}{2} \\ &= \frac{(40 \times 0.2 - 27.27 \times 0.2)(1,182 \times 8,760 + 2,313 \times 8,760)}{2} \\ &= 38,974,423\end{aligned}$$

$$\text{Expenses } E = 3,200,000$$

$$\begin{aligned}\text{BC} &= \frac{R - E}{Cr} (1 - e^{-r}) \\ &= \frac{38,974,423 - 3,200,000}{166,000,000 \times 0.1} (1 - e^{-0.1 \times 15}) \\ &= 1.98\end{aligned}$$

**USER BENEFITS ANALYSIS
BLACKSBURG TO ROANOKE
EQUILIBRIUM ANALYSIS FOR ALT 7**

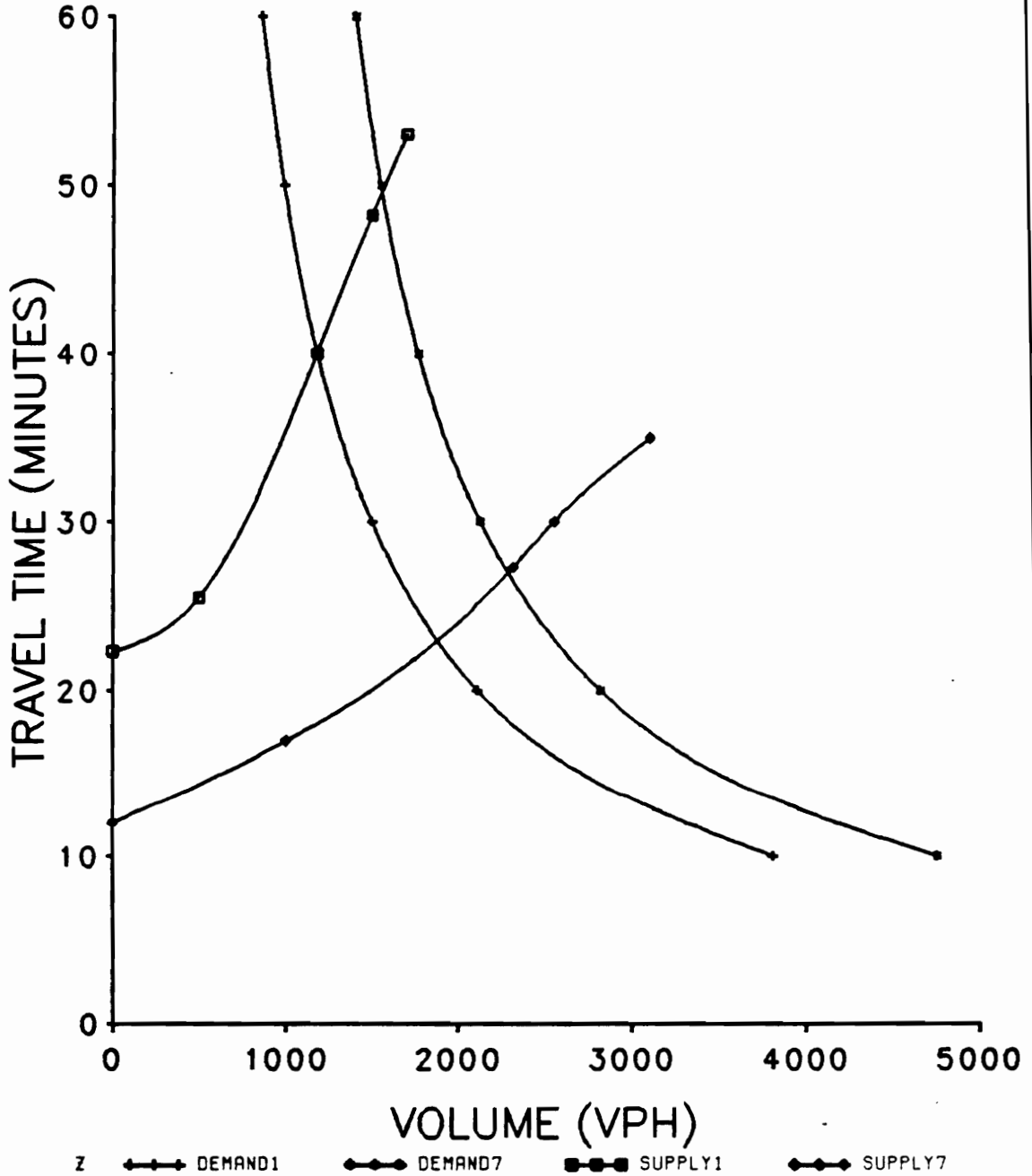


Figure 24. Equilibrium Analysis for Alternative 7

5.15 Alternative 10

Fig.25 shows the user benefits analysis for Alternative 10 where

$$\text{Cost } C = 192,900,000$$

$$\begin{aligned}\text{Revenue } R &= \frac{(P_1 - P_{10})(Q_1 + Q_{10})}{2} \\ &= \frac{(40 \times 0.2 - 26.27 \times 0.2)(1,182 \times 8,760 + 2,355 \times 8,760)}{2} \\ &= 42,541,197\end{aligned}$$

$$\text{Expenses } E = 3,400,000$$

$$\begin{aligned}\text{BC} &= \frac{R - E}{Cr} (1 - e^{-r}) \\ &= \frac{42,541,197 - 3,400,000}{192,900,000 \times 0.1} (1 - e^{-0.1 \times 25}) \\ &= 1.86\end{aligned}$$

USER BENEFITS ANALYSIS
 BLACKSBURG TO ROANOKE
 EQUILIBRIUM ANALYSIS FOR ALT 10

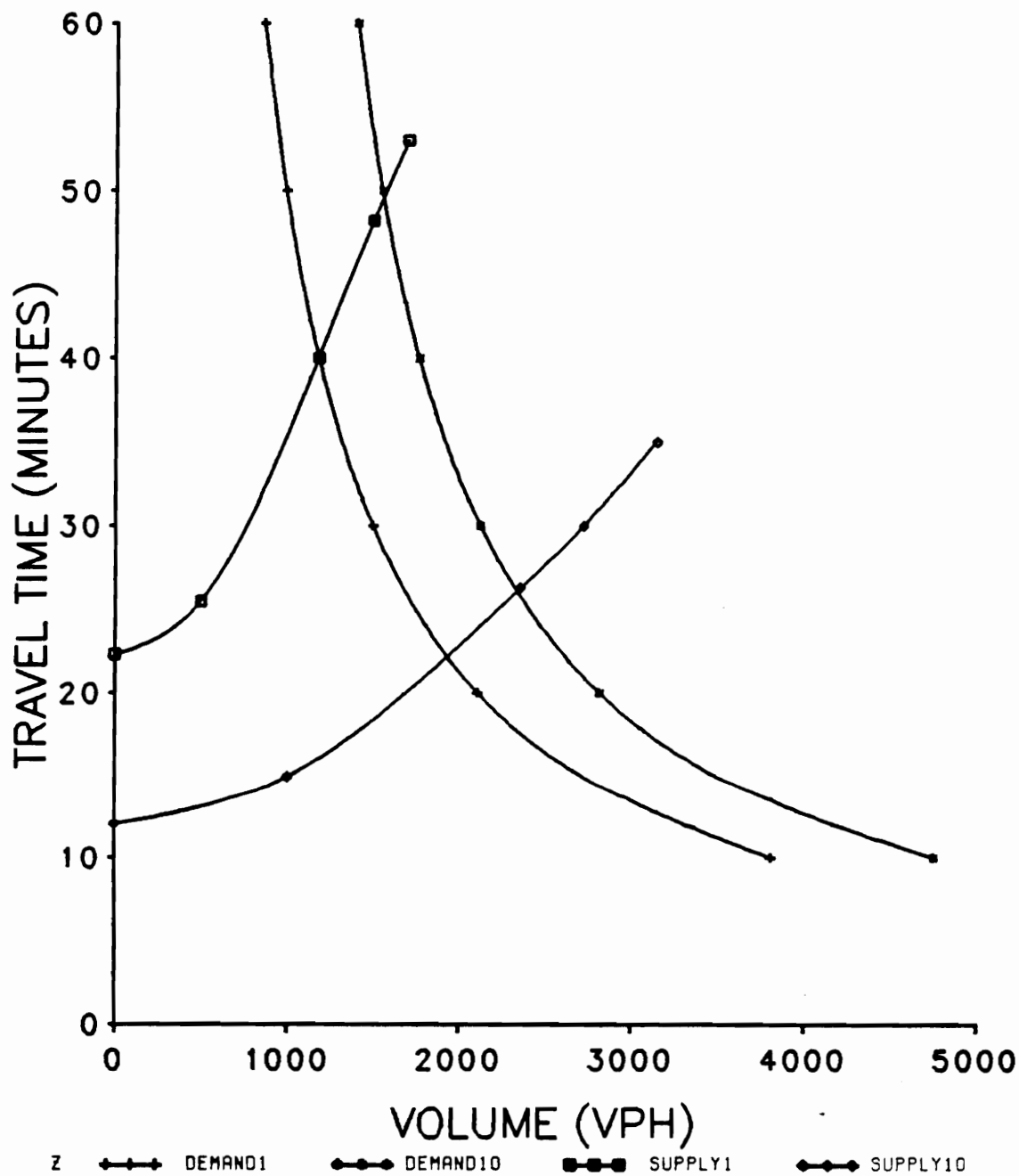


Figure 25. Equilibrium Analysis for Alternative 10

5.16 Sensitivity Analysis

The purpose of sensitivity analysis is to study the effects of changes in parameter values, for example, if the cost of construction is 10% above the current estimate, what will be the affect on the Benefit Cost Ratio. This is illustrated below for alternative 6.

$$\text{Cost } C = 161,810,000$$

$$\begin{aligned} \text{Revenue } R &= \frac{(P_1 - P_0)(Q_1 + Q_0)}{2} \\ &= \frac{(40 \times 0.2 - 29.88 \times 0.2)(1,182 \times 8,760 + 2,015 \times 8,760)}{2} \\ &= 28,341,789 \end{aligned}$$

$$\text{Expenses } E = 2,701,070$$

$$\begin{aligned} \text{BC} &= \frac{R - E}{Cr} (1 - e^{-r}) \\ &= \frac{28,341,789 - 2,701,770}{161,810,000 \times 0.1} (1 - e^{-0.1 \times 25}) \\ &= 1.45 \end{aligned}$$

Table 5.1 shows the Benefit Cost Ratio for alternative 6 for different values of construction cost. Table 5.2 shows the Rate of Return, ROR, for each alternative applying Eq.5.18. From these we can conclude the following:

1. Sensitivity analysis can be executed easily in the proposed model

2. If the construction cost is higher than estimated the Benefit Cost Ratio is lower and consequently the attractiveness of this alternative decreases
3. When the Benefit Cost Ratio less than 1.0 the project becomes unfeasible economically
4. Alternatives 2, 12, and 5 are not feasible economic because the Benefit Cost Ratio is less than 1.0
5. Alternative 7 is the best because it gives the higher Rate of Return
6. Because of many variables are involved in the process of estimation, the construction cost estimates may be different from the actual cost, for example, change in price of real estate, would increase/ decrease construction cost for all alternatives thus resulting in different B/C ratios. However, the best alternative is likely to remain the same provided that these construction cost changes are not drastic. Other problems in the construction such as; cavity in the soil, old valley, weak soil can be analyzed in a similar fashion

TABLE 5.1

BENEFIT COST RATIO FOR ALTERNATIVE 6

Construction cost	B/C
147,100,000	1.6
161,810,000	1.45
180,000,000	1.3
190,000,000	1.24
200,000,000	1.17
220,000,000	1.06
250,000,000	0.94
294,200,000	0.799

TABLE 5.2
RATE OF RETURN (ROR)

Alternative	ROR
2	6.5 %
3A	10 %
5	8.7 %
12	6.7 %
6	17 %
7	20 %
10	19 %

6.0 Results

6.1 Introduction

The results are divided into user benefits and non-user benefits. The focus is on non-user benefits, which traditionally have been handled subjectively because of the obvious difficulty in modeling transportation-induced development.

6.2 User Benefits Evaluation

User-benefits means road user consequences which lead to travel time reduction. Table 6.1 presents summary of B/C results.

Travel time from Blacksburg to Roanoke (T31) is plotted over time for each alternatives in Figure 26 to Figure 33, while Table 6.2 presents travel time from Blacksburg to Roanoke for the horizon year. The (*) sign in travel time means volume exceeds capacity.

TABLE 6.1
SUMMARY OF THE B/C RESULT

Alternative	B/C	Rank
2	0.7	7
3A	1.0	4
5	0.9	5
12	0.75	6
6	1.6	3
7	1.98	1 (the best)
10	1.86	2

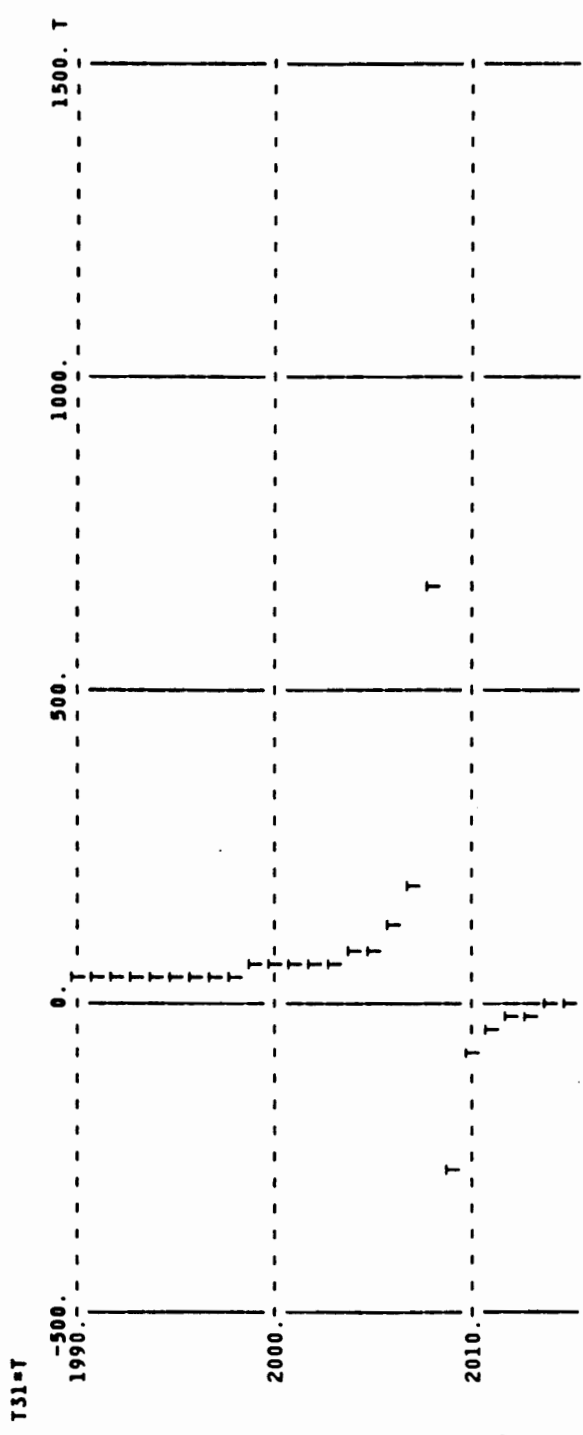


Figure 26. Alternative 1 Travel Time From Blacksburg to Roanoke

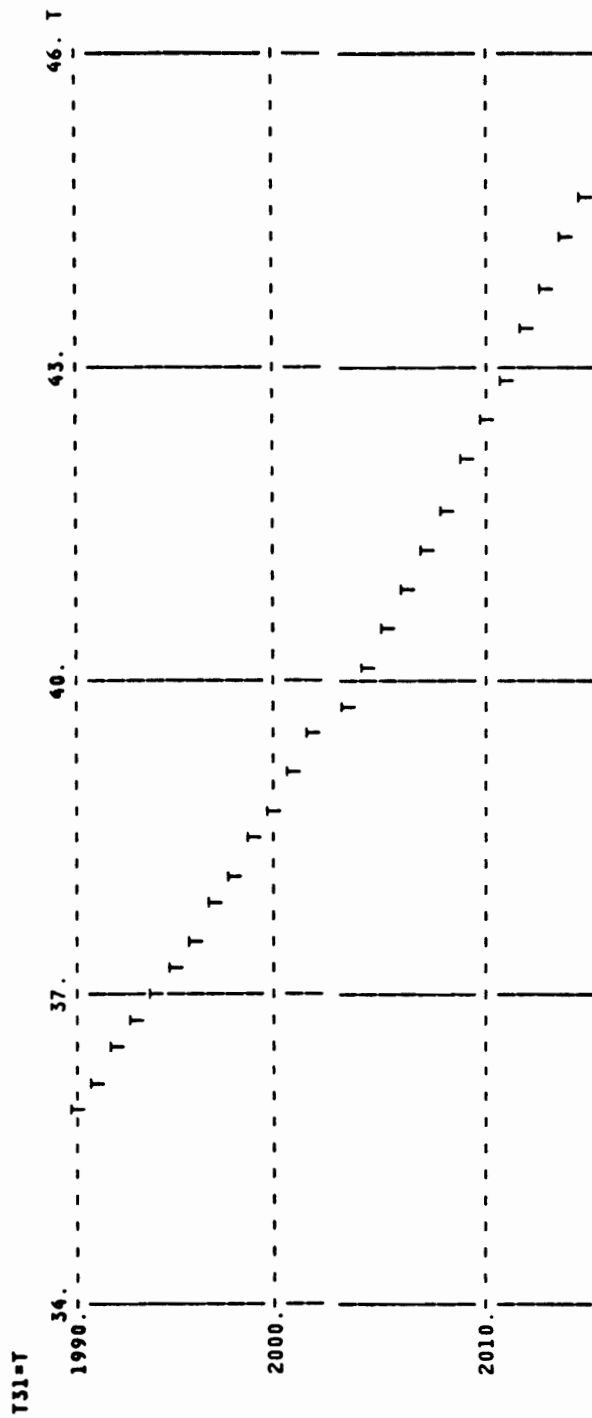


Figure 27. Alternative 2 Travel Time From Blacksburg to Roanoke

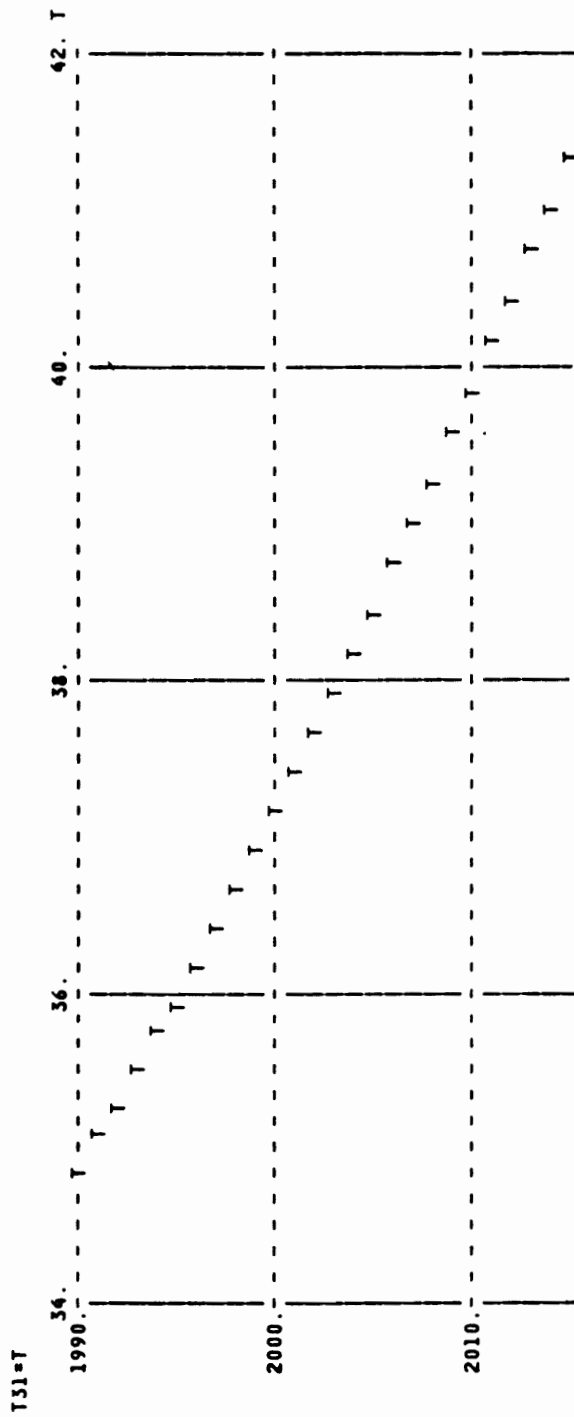


Figure 28. Alternative 3A Travel Time From Blacksburg to Roanoke

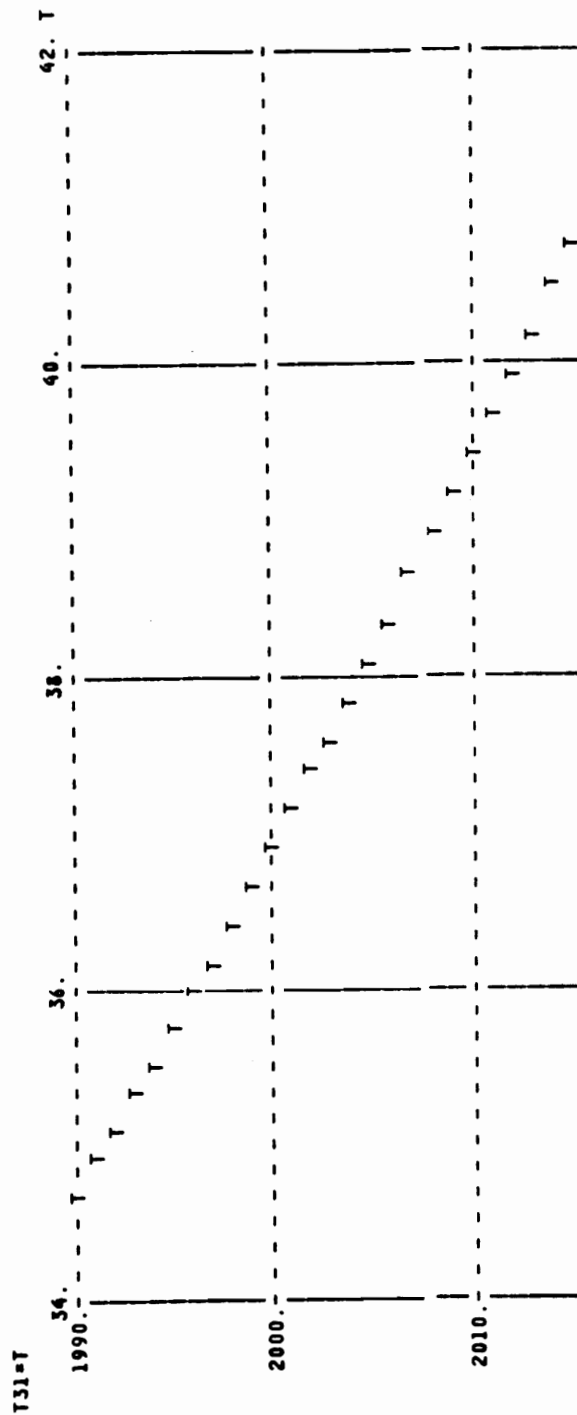


Figure 29. Alternative 5 Travel Time From Blacksburg to Roanoke

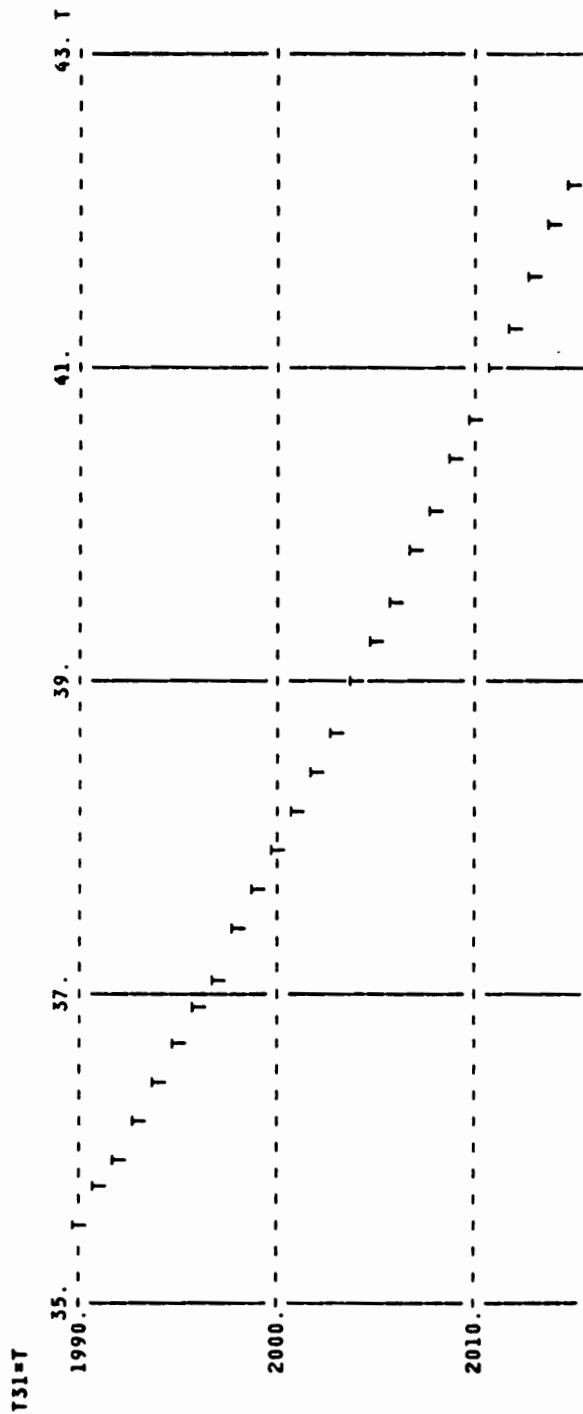


Figure 30. Alternative 12 Travel Time From Blacksburg to Roanoke

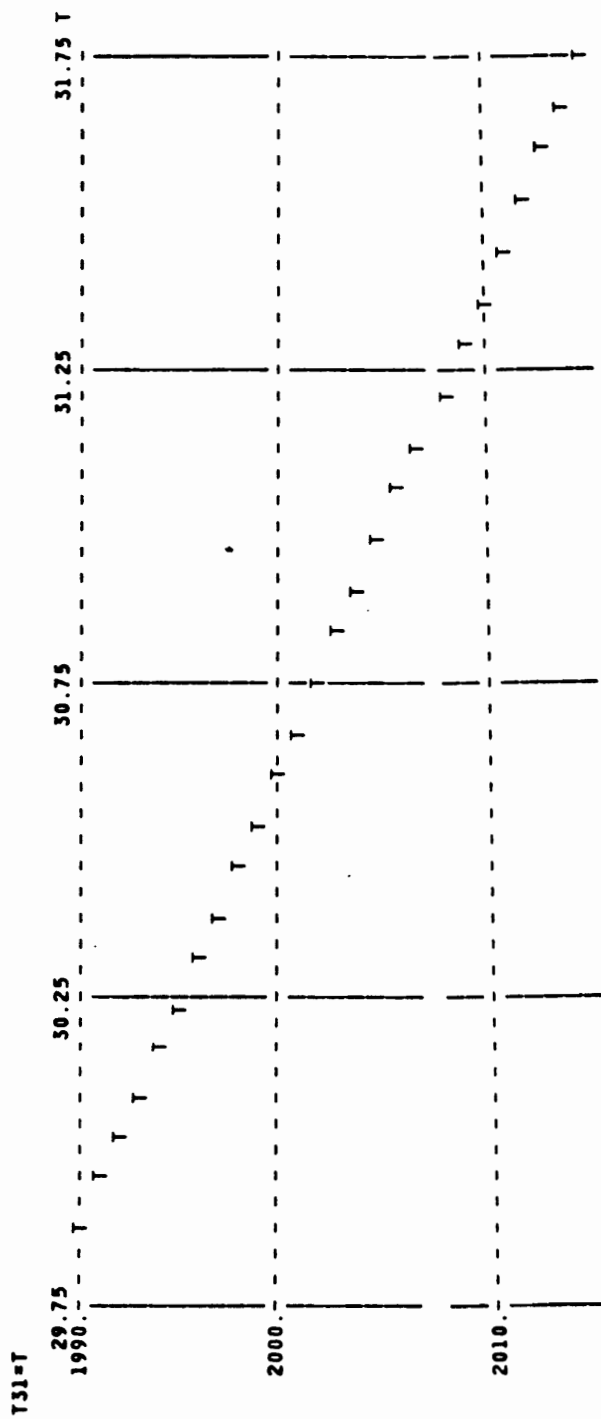


Figure 31. Alternative 6 Travel Time From Blacksburg to Roanoke

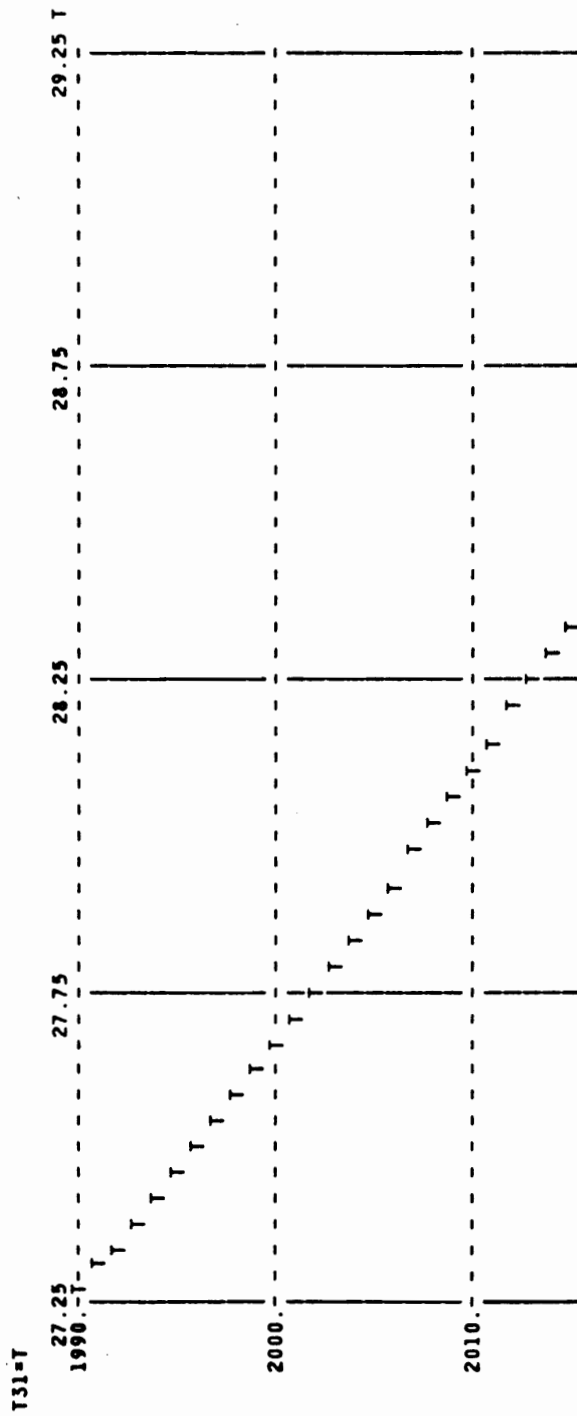


Figure 32. Alternative 7 Travel Time From Blacksburg to Roanoke

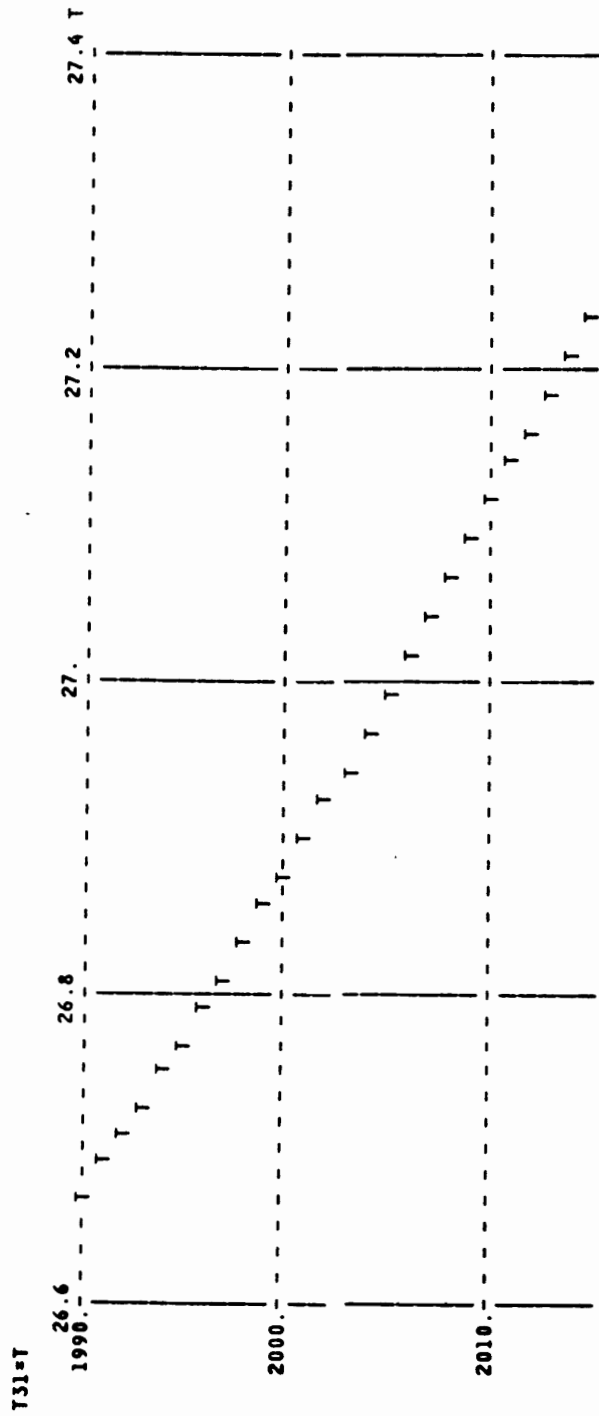


Figure 33. Alternative 10 Travel Time From Blacksburg to Roanoke

TABLE 6.2

PEAK HOUR WEEK DAY
TRAVEL TIME BETWEEN BLACKSBURG AND ROANOKE
FOR THE HORIZON YEAR

Alternative	Travel Time
1	78.0 *
2	44.67
3A	41.31
5	40.73
12	42.19
6	31.75
7	28.34
10	27.24

(*) Means volume exceed capacity

6.2.1 User Benefit Results

From Tables 6.1, 6.2 and Figure 26 to Figure 33 we can see how the improvement of transportation facility will decrease the travel time, so we can rank the alternatives according to the benefit-cost ratio as

- 1 - Alt 7 (the best)
- 2 - Alt 10
- 3 - Alt 6
- 4 - Alt 3A
- 5 - Alt 5
- 6 - Alt 12
- 7 - Alt 2

while according to the travel time between Blacksburg and Roanoke

- 1 - Alt 10 (the best)
- 2 - Alt 7
- 3 - Alt 6
- 4 - Alt 5
- 5 - Alt 3A
- 6 - Alt 12
- 7 - Alt 2

6.3 Non-user Benefit Evaluation

6.3.1 Measures of Effectiveness

The measures of effectiveness of the non-user benefits are:

- 1-The population of Blacksburg, Christiansburg and Roanoke (City and County) (P) in persons
- 2-Per Capita income in Blacksburg, Christiansburg and Roanoke (PCI) in \$ per person
- 3-Funded research (FR) in \$ per year and total graduate student (TGS) in persons in Virginia Tech.

The horizon year is 2015; the results are presented both in graphical form and computational output. Table 6.3 shows the indication for comparison alternatives. 1, 2, 3 means Blacksburg, Christiansburg, Roanoke, respectively.

Sections 6.3.2 to 6.3.9 illustrate the baseline parameters used under each one of seven alternatives tested. These sections are written in terms of the Dynamo equations defined in the model. The reader must note that every alternative is described independently to affect the transportation sector equations thus providing a simple switching mechanism between alternatives.

TABLE 6.3

DEVELOPMENT INDICATIONS FOR COMPARISON THE ALTERNATIVES

Indication	Variable
Travel time between Roanoke and Blacksburg at equilibrium	T31E
Travel time between Blacksburg and Roanoke at equilibrium	T13E
Travel time between Blacksburg and Christiansburg at eq.	T12E
Number of homes from Christiansburg and Blacksburg	N21
Number of homes from Blacksburg and Christiansburg	N12
Number of homes from Blacksburg and Roanoke	N13
Number of homes from Roanoke and Blacksburg	N31
Level of service factor in link 21	LSF21
Level of service factor in link 12	LSF12
Level of service factor in link 31	LSF31
Level of service factor in link 13	LSF13
Trip generation factor from Christiansburg to Blacksburg	TGF21
Trip generation factor from Blacksburg to Christiansburg	TGF12
Trip generation factor from Blacksburg to Roanoke	TGF13
Trip generation factor from Roanoke to Blacksburg	TGF31
Distance between Christiansburg and Blacksburg	X21
Distance between Blacksburg and Christiansburg	X12
Distance between Blacksburg and Roanoke	X13
Distance between Roanoke and Blacksburg	X31
Through traffic from Roanoke to Blacksburg .	Q31T
Through traffic from Blacksburg to Roanoke	Q13T

6.3.2 Alternative 1

C ALT1=1
C ALT2=0
C ALT3A=0
C ALT12=0
C ALT5=0
C ALT6=0
C ALT7=0
C ALT10=0
NOTE ALTX-ALTERNATIVE
C T31E=40
NOTE T31E-TRAVEL TIME BETWEEN AREA 3 AND AREA 1 AT EQUILIBRIUM (MIN)
C T13E=40
NOTE T13E-TRAVEL TIME BETWEEN AREA 1 AND AREA 3 AT EQUILIBRIUM (MIN)
C T12E=16
NOTE T12E-TRAVEL TIME BETWEEN AREA 1 AND AREA 2 AT EQUILIBRIUM (MIN)
C LSF21=0.95
NOTE LSF21-LEVEL OF SERVICE FACTOR ON LINK 21 (DIM)
C LSF31=0.8
NOTE LSF31-LEVEL OF SERVICE FACTOR ON LINK 31 (DIM)
C LSF12=0.95
NOTE LSF12-LEVEL OF SERVICE FACTOR ON LINK 12 (DIM)
C LSF13=0.8
NOTE LSF13-LEVEL OF SERVICE FACTOR ON LINK 13 (DIM)
C N21=2
NOTE N21-NO. OF LANES PER DIRECTION ON LINK 21
C N31=1E-50
NOTE N31-NO. OF LANES PER DIRECTION ON LINK 31
C N12=2
NOTE N12-NO. OF LANES PER DIRECTION ON LINK 12
C N13=1E-50
NOTE N13-NO. OF LANES PER DIRECTION ON LINK 13
C Q31T=1E-50
NOTE Q31T-THRU TRAFFIC ON LINK 31 (VEH/HR)
C Q13T=1E-50
NOTE Q13T-THRU TRAFFIC ON LINK 13 (VEH/HR)
C X21=3.2
NOTE X21-DIST BETWEEN NODES 2 AND 1 (MILES)
C X31=32
NOTE X31-DIST BETWEEN NODES 3 AND 1 (MILES)
C X12=3.2
NOTE X12-DIST BETWEEN NODES 1 AND 2 (MILES)
C X13=32
NOTE X13-DIST BETWEEN NODES 1 AND 3 (MILES)
C TGF31=0.08
C TGF21=2
C TGF13=0.45
C TGF12=0.9
NOTE TGF-TRIP GENERATION FACTOR (DIM)

6.3.3 Alternative 2

C ALT1=0
C ALT2=1
C ALT3A=0
C ALT12=0
C ALT5=0
C ALT6=0
C ALT7=0
C ALT10=0
NOTE ALTX-ALTERNATIVE
C T31E=35.92
NOTE T31E-TRAVEL TIME BETWEEN AREA 3 AND AREA 1 AT EQUILIBRIUM (MIN)
C T13E=35.92
NOTE T13E-TRAVEL TIME BETWEEN AREA 1 AND AREA 3 AT EQUILIBRIUM (MIN)
C T12E=10.99
NOTE T12E-TRAVEL TIME BETWEEN AREA 1 AND AREA 2 AT EQUILIBRIUM (MIN)
C LSF21=0.85
NOTE LSF21-LEVEL OF SERVICE FACTOR ON LINK 21 (DIM)
C LSF31=0.8
NOTE LSF31-LEVEL OF SERVICE FACTOR ON LINK 31 (DIM)
C LSF12=0.85
NOTE LSF12-LEVEL OF SERVICE FACTOR ON LINK 12 (DIM)
C LSF13=0.8
NOTE LSF13-LEVEL OF SERVICE FACTOR ON LINK 13 (DIM)
C N21=4
NOTE N21-NO. OF LANES PER DIRECTION ON LINK 21
C N31=1E-50
NOTE N31-NO. OF LANES PER DIRECTION ON LINK 31
C N12=4
NOTE N12-NO. OF LANES PER DIRECTION ON LINK 12
C N13=1E-50
NOTE N13-NO. OF LANES PER DIRECTION ON LINK 13
C Q31T=1E-50
NOTE Q31T-THRU TRAFFIC ON LINK 31 (VEH/HR)
C Q13T=1E-50
NOTE Q13T-THRU TRAFFIC ON LINK 13 (VEH/HR)
C X21=3.2
NOTE X21-DIST BETWEEN NODES 2 AND 1 (MILES)
C X31=32
NOTE X31-DIST BETWEEN NODES 3 AND 1 (MILES)
C X12=3.2
NOTE X12-DIST BETWEEN NODES 1 AND 2 (MILES)
C X13=32
NOTE X13-DIST BETWEEN NODES 1 AND 3 (MILES)
C TGF31=0.08
C TGF21=2.01
C TGF13=0.46
C TGF12=0.9
NOTE TGF-TRIP GENERATION FACTOR (DIM)

6.3.4 Alternative 3A

C ALT1=0
C ALT2=0
C ALT3A=1
C ALT12=0
C ALT5=0
C ALT6=0
C ALT7=0
C ALT10=0
NOTE ALTX-ALTERNATIVE
C T31E=34.83
NOTE T31E-TRAVEL TIME BETWEEN AREA 3 AND AREA 1 AT EQUILIBRIUM (MIN)
C T13E=34.83
NOTE T13E-TRAVEL TIME BETWEEN AREA 1 AND AREA 3 AT EQUILIBRIUM (MIN)
C T12E=9.86
NOTE T12E-TRAVEL TIME BETWEEN AREA 1 AND AREA 2 AT EQUILIBRIUM (MIN)
C LSF21=0.45
NOTE LSF21-LEVEL OF SERVICE FACTOR ON LINK 21 (DIM)
C LSF31=0.8
NOTE LSF31-LEVEL OF SERVICE FACTOR ON LINK 31 (DIM)
C LSF12=0.45
NOTE LSF12-LEVEL OF SERVICE FACTOR ON LINK 12 (DIM)
C LSF13=0.8
NOTE LSF13-LEVEL OF SERVICE FACTOR ON LINK 13 (DIM)
C N21=5
NOTE N21-NO. OF LANES PER DIRECTION ON LINK 21
C N31=1E-50
NOTE N31-NO. OF LANES PER DIRECTION ON LINK 31
C N12=5
NOTE N12-NO. OF LANES PER DIRECTION ON LINK 12
C N13=1E-50
NOTE N13-NO. OF LANES PER DIRECTION ON LINK 13
C Q31T=1E-50
NOTE Q31T-THRU TRAFFIC ON LINK 31 (VEH/HR)
C Q13T=1E-50
NOTE Q13T-THRU TRAFFIC ON LINK 13 (VEH/HR)
C X21=3.0
NOTE X21-DIST BETWEEN NODES 2 AND 1 (MILES)
C X31=31.8
NOTE X31-DIST BETWEEN NODES 3 AND 1 (MILES)
C X12=3.0
NOTE X12-DIST BETWEEN NODES 1 AND 2 (MILES)
C X13=31.8
NOTE X13-DIST BETWEEN NODES 1 AND 3 (MILES)
C TGF31=0.08
C TGF21=2.015
C TGF13=0.465
C TGF12=0.915
NOTE TGF-TRIP GENERATION FACTOR (DIM)

6.3.5 Alternative 5

C ALT1=0
C ALT2=0
C ALT3A=0
C ALT12=0
C ALT5=1
C ALT6=0
C ALT7=0
C ALT10=0
NOTE ALTX-ALTERNATIVE
C T31E=34.68
NOTE T31E-TRAVEL TIME BETWEEN AREA 3 AND AREA 1 AT EQUILIBRIUM (MIN)
C T13E=34.68
NOTE T13E-TRAVEL TIME BETWEEN AREA 1 AND AREA 3 AT EQUILIBRIUM (MIN)
C T12E=9.76
NOTE T12E-TRAVEL TIME BETWEEN AREA 1 AND AREA 2 AT EQUILIBRIUM (MIN)
C LSF21=0.4
NOTE LSF21-LEVEL OF SERVICE FACTOR ON LINK 21 (DIM)
C LSF31=0.8
NOTE LSF31-LEVEL OF SERVICE FACTOR ON LINK 31 (DIM)
C LSF12=0.4
NOTE LSF12-LEVEL OF SERVICE FACTOR ON LINK 12 (DIM)
C LSF13=0.8
NOTE LSF13-LEVEL OF SERVICE FACTOR ON LINK 13 (DIM)
C N21=6
NOTE N21-NO. OF LANES PER DIRECTION ON LINK 21
C N31=1E-50
NOTE N31-NO. OF LANES PER DIRECTION ON LINK 31
C N12=6
NOTE N12-NO. OF LANES PER DIRECTION ON LINK 12
C N13=1E-50
NOTE N13-NO. OF LANES PER DIRECTION ON LINK 13
C Q31T=1E-50
NOTE Q31T-THRU TRAFFIC ON LINK 31 (VEH/HR)
C Q13T=1E-50
NOTE Q13T-THRU TRAFFIC ON LINK 13 (VEH/HR)
C X21=3.0
NOTE X21-DIST BETWEEN NODES 2 AND 1 (MILES)
C X31=31.8
NOTE X31-DIST BETWEEN NODES 3 AND 1 (MILES)
C X12=3.0
NOTE X12-DIST BETWEEN NODES 1 AND 2 (MILES)
C X13=31.8
NOTE X13-DIST BETWEEN NODES 1 AND 3 (MILES)
C TGF31=0.08
C TGF21=2.015
C TGF13=0.465
C TGF12=0.915
NOTE TGF-TRIP GENERATION FACTOR (DIM)

6.3.6 Alternative 12

C ALT1=0
C ALT2=0
C ALT3A=0
C ALT12=1
C ALT5=0
C ALT6=0
C ALT7=0
C ALT10=0
NOTE ALTX-ALTERNATIVE
C T31E=35.49
NOTE T31E-TRAVEL TIME BETWEEN AREA 3 AND AREA 1 AT EQUILIBRIUM (MIN)
C T13E=35.49
NOTE T13E-TRAVEL TIME BETWEEN AREA 1 AND AREA 3 AT EQUILIBRIUM (MIN)
C T12E=10.6
NOTE T12E-TRAVEL TIME BETWEEN AREA 1 AND AREA 2 AT EQUILIBRIUM (MIN)
C LSF21=0.6
NOTE LSF21-LEVEL OF SERVICE FACTOR ON LINK 21 (DIM)
C LSF31=0.8
NOTE LSF31-LEVEL OF SERVICE FACTOR ON LINK 31 (DIM)
C LSF12=0.6
NOTE LSF12-LEVEL OF SERVICE FACTOR ON LINK 12 (DIM)
C LSF13=0.8
NOTE LSF13-LEVEL OF SERVICE FACTOR ON LINK 13 (DIM)
C N21=5
NOTE N21-NO. OF LANES PER DIRECTION ON LINK 21
C N31=1E-50
NOTE N31-NO. OF LANES PER DIRECTION ON LINK 31
C N12=5
NOTE N12-NO. OF LANES PER DIRECTION ON LINK 12
C N13=1E-50
NOTE N13-NO. OF LANES PER DIRECTION ON LINK 13
C Q31T=1E-50
NOTE Q31T-THRU TRAFFIC ON LINK 31 (VEH/HR)
C Q13T=1E-50
NOTE Q13T-THRU TRAFFIC ON LINK 13 (VEH/HR)
C X21=3.4
NOTE X21-DIST BETWEEN NODES 2 AND 1 (MILES)
C X31=32.2
NOTE X31-DIST BETWEEN NODES 3 AND 1 (MILES)
C X12=3.4
NOTE X12-DIST BETWEEN NODES 1 AND 2 (MILES)
C X13=32.2
NOTE X13-DIST BETWEEN NODES 1 AND 3 (MILES)
C TGF31=0.08
C TGF12=0.915
C TGF13=0.465
C TGF21=2.015
NOTE TGF-TRIP GENERATION FACTOR (DIM)

6.3.7 Alternative 6

C ALT1=0
C ALT2=0
C ALT3A=0
C ALT12=0
C ALT5=0
C ALT6=1
C ALT7=0
C ALT10=0
NOTE ALTX-ALTERNATIVE
C T31E=29.88
NOTE T31E-TRAVEL TIME BETWEEN AREA 3 AND AREA 1 AT EQUILIBRIUM (MIN)
C T13E=29.88
NOTE T13E-TRAVEL TIME BETWEEN AREA 1 AND AREA 3 AT EQUILIBRIUM (MIN)
C T12E=3.601
NOTE T12E-TRAVEL TIME BETWEEN AREA 1 AND AREA 2 AT EQUILIBRIUM (MIN)
C LSF21=0.4
NOTE LSF21-LEVEL OF SERVICE FACTOR ON LINK 21 (DIM)
C LSF12=0.4
NOTE LSF31-LEVEL OF SERVICE FACTOR ON LINK 31 (DIM)
C LSF31=0.4
NOTE LSF12-LEVEL OF SERVICE FACTOR ON LINK 12 (DIM)
C LSF13=0.4
NOTE LSF13-LEVEL OF SERVICE FACTOR ON LINK 13 (DIM)
C N21=4
NOTE N21-NO. OF LANES PER DIRECTION ON LINK 21
C N31=2
NOTE N31-NO. OF LANES PER DIRECTION ON LINK 31
C N12=4
NOTE N12-NO. OF LANES PER DIRECTION ON LINK 12
C N13=2
NOTE N13-NO. OF LANES PER DIRECTION ON LINK 13
C Q31T=100
NOTE Q31T-THRU TRAFFIC ON LINK 31 (VEH/HR)
C Q13T=200
NOTE Q13T-THRU TRAFFIC ON LINK 13 (VEH/HR)
C X21=3.2
NOTE X21-DIST BETWEEN NODES 2 AND 1 (MILES)
C X31=27
NOTE X31-DIST BETWEEN NODES 3 AND 1 (MILES)
C X12=3.2
NOTE X12-DIST BETWEEN NODES 1 AND 2 (MILES)
C X13=27
NOTE X13-DIST BETWEEN NODES 1 AND 3 (MILES)
C TGF12=0.925
C TGF13=0.487
C TGF21=2.015
C TGF31=0.082
NOTE TGF-TRIP GENERATION FACTOR (DIM)

6.3.8 Alternative 7

C ALT1=0
C ALT2=0
C ALT3A=0
C ALT12=0
C ALT5=0
C ALT6=0
C ALT7=1
C ALT10=0
NOTE ALTX-ALTERNATIVE
C T31E=27.27
NOTE T31E-TRAVEL TIME BETWEEN AREA 3 AND AREA 1 AT EQUILIBRIUM (MIN)
C T13E=27.27
NOTE T13E-TRAVEL TIME BETWEEN AREA 1 AND AREA 3 AT EQUILIBRIUM (MIN)
C T12E=3.592
NOTE T12E-TRAVEL TIME BETWEEN AREA 1 AND AREA 2 AT EQUILIBRIUM (MIN)
C LSF21=0.35
NOTE LSF21-LEVEL OF SERVICE FACTOR ON LINK 21 (DIM)
C LSF31=0.2
NOTE LSF31-LEVEL OF SERVICE FACTOR ON LINK 31 (DIM)
C LSF12=0.35
NOTE LSF12-LEVEL OF SERVICE FACTOR ON LINK 12 (DIM)
C LSF13=0.2
NOTE LSF13-LEVEL OF SERVICE FACTOR ON LINK 13 (DIM)
C N21=4
NOTE N21-NO. OF LANES PER DIRECTION ON LINK 21
C N31=2
NOTE N31-NO. OF LANES PER DIRECTION ON LINK 31
C N12=4
NOTE N12-NO. OF LANES PER DIRECTION ON LINK 12
C N13=2
NOTE N13-NO. OF LANES PER DIRECTION ON LINK 13
C Q31T=120
NOTE Q31T-THRU TRAFFIC ON LINK 31 (VEH/HR)
C Q13T=200
NOTE Q13T-THRU TRAFFIC ON LINK 13 (VEH/HR)
C X21=3.2
NOTE X21-DIST BETWEEN NODES 2 AND 1 (MILES)
C X31=25.8
NOTE X31-DIST BETWEEN NODES 3 AND 1 (MILES)
C X12=3.2
NOTE X12-DIST BETWEEN NODES 1 AND 2 (MILES)
C X13=25.8
NOTE X13-DIST BETWEEN NODES 1 AND 3 (MILES)
C TGF12=0.935
C TGF13=0.497
C TGF21=2.057
C TGF31=0.0845
NOTE TGF-TRIP GENERATION FACTOR (DIM)

6.3.9 Alternative 10

C ALT1=0
C ALT2=0
C ALT3A=0
C ALT12=0
C ALT5=0
C ALT6=0
C ALT7=0
C ALT10=10
NOTE ALTX-ALTERNATIVE
C T31E=26.67
NOTE T31E-TRAVEL TIME BETWEEN AREA 3 AND AREA 1 AT EQUILIBRIUM (MIN)
C T13E=26.67
NOTE T13E-TRAVEL TIME BETWEEN AREA 1 AND AREA 3 AT EQUILIBRIUM (MIN)
C T12E=3.450
NOTE T12E-TRAVEL TIME BETWEEN AREA 1 AND AREA 2 AT EQUILIBRIUM (MIN)
C LSF21=0.25
NOTE LSF21-LEVEL OF SERVICE FACTOR ON LINK 21 (DIM)
C LSF31=0.1
NOTE LSF31-LEVEL OF SERVICE FACTOR ON LINK 31 (DIM)
C LSF12=0.25
NOTE LSF12-LEVEL OF SERVICE FACTOR ON LINK 12 (DIM)
C LSF13=0.1
NOTE LSF13-LEVEL OF SERVICE FACTOR ON LINK 13 (DIM)
C N21=4
NOTE N21-NO. OF LANES PER DIRECTION ON LINK 21
C N31=2
NOTE N31-NO. OF LANES PER DIRECTION ON LINK 31
C N12=4
NOTE N12-NO. OF LANES PER DIRECTION ON LINK 12
C N13=2
NOTE N13-NO. OF LANES PER DIRECTION ON LINK 13
C Q31T=150
NOTE Q31T-THRU TRAFFIC ON LINK 31 (VEH/HR)
C Q13T=200
NOTE Q13T-THRU TRAFFIC ON LINK 13 (VEH/HR)
C X21=3.2
NOTE X21-DIST BETWEEN NODES 2 AND 1 (MILES)
C X31=25.9
NOTE X31-DIST BETWEEN NODES 3 AND 1 (MILES)
C X12=3.2
NOTE X12-DIST BETWEEN NODES 1 AND 2 (MILES)
C X13=25.9
NOTE X13-DIST BETWEEN NODES 1 AND 3 (MILES)
C TGF12=0.935
C TGF13=0.497
C TGF21=2.015
C TGF31=0.0846
NOTE TGF-TRIP GENERATION FACTOR (DIM)

6.3.10 Non-User Benefit Results

Fig. 34 shows the population of Blacksburg for each alternative plotted over time, Fig.35 shows the population of Christiansburg for each alternative plotted over time, Fig.36 shows the population of Roanoke for each alternative plotted over time, Fig.37 shows the per capita income of Blacksburg for each alternative plotted over time, Fig.38 shows the per capita income of Christiansburg for each alternative plotted over time, Fig.39 shows the per capita income of Roanoke for each alternative plotted over time, Fig.40 shows the funded research of Virginia Tech for each alternative plotted over time, Fig.41 shows the total graduate student in Virginia Tech for each alternative plotted over time, while Appendix C shows the computational output for each alternative, and Table 6.4 will present the result for the horizon year. In appendix D, we have decomposed the above figures into more details formats.

NON-USER BENEFIT ANALYSIS POPULATION OF BLACKSBURG

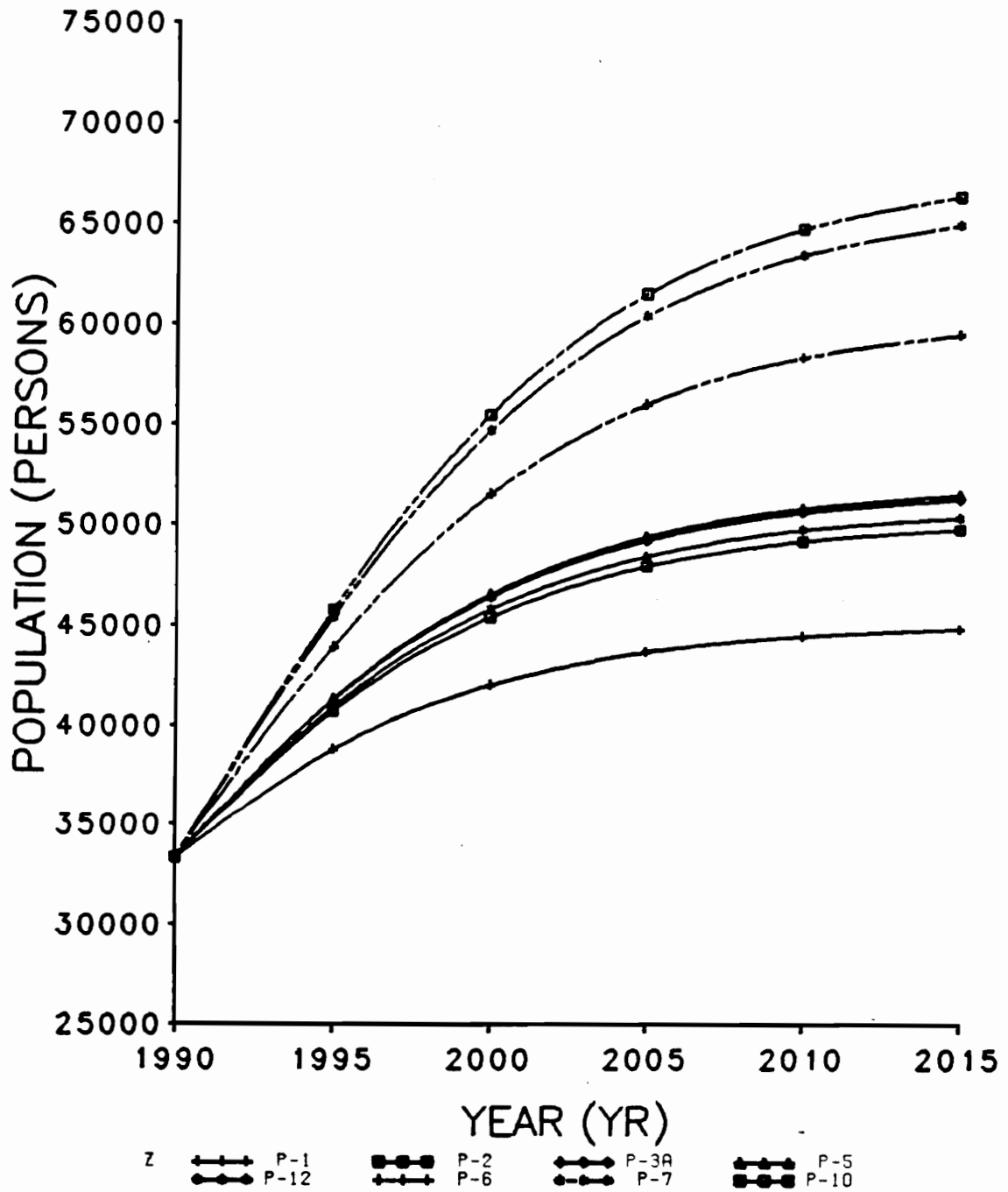


Figure 34. Population of Blacksburg

NON-USER BENEFIT ANALYSIS POPULATION OF CHRISTIANSBURG

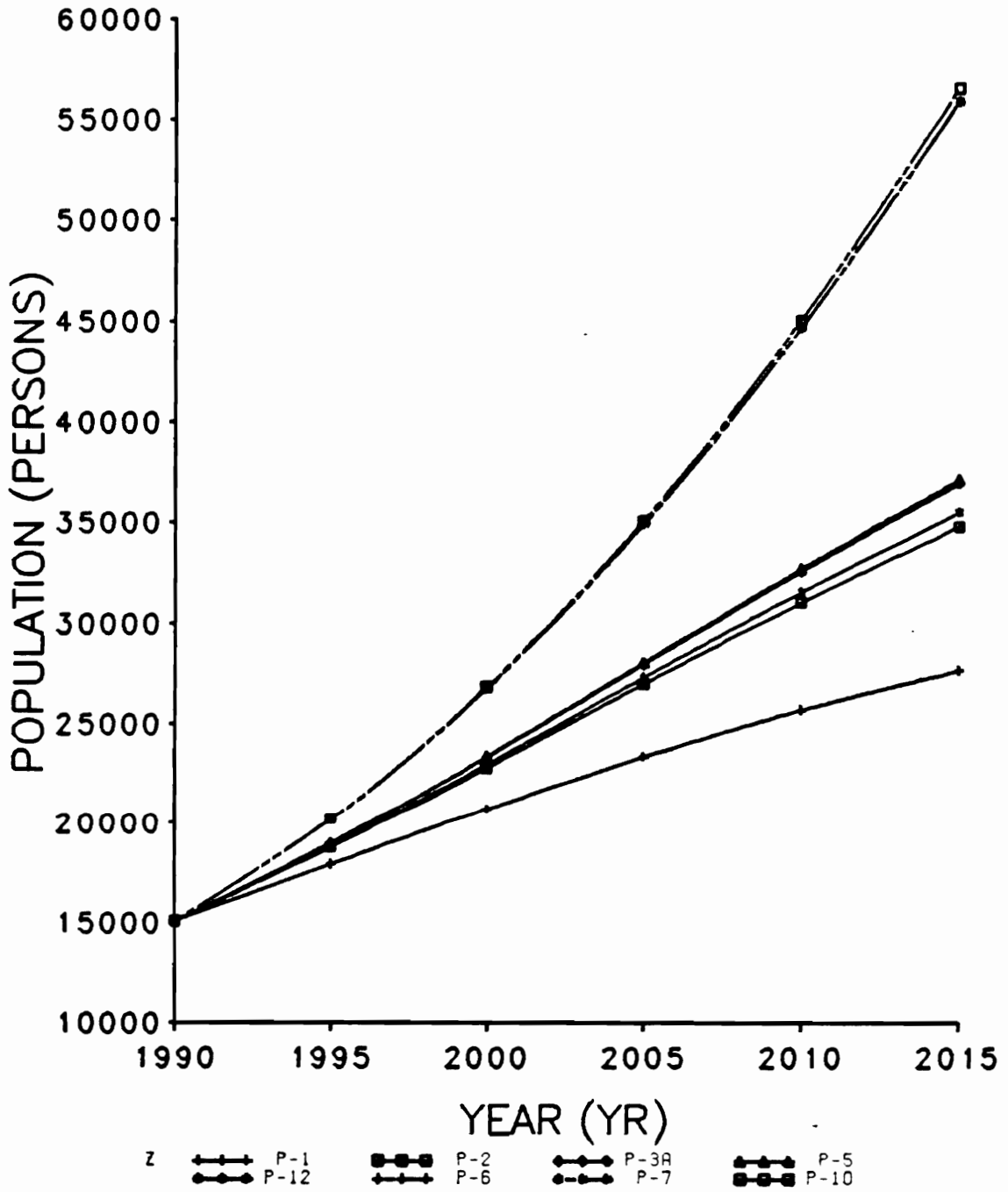


Figure 35. Population of Christiansburg

**NON-USER BENEFIT ANALYSIS
POPULATION OF ROANOKE (CITY AND COUNTY)**

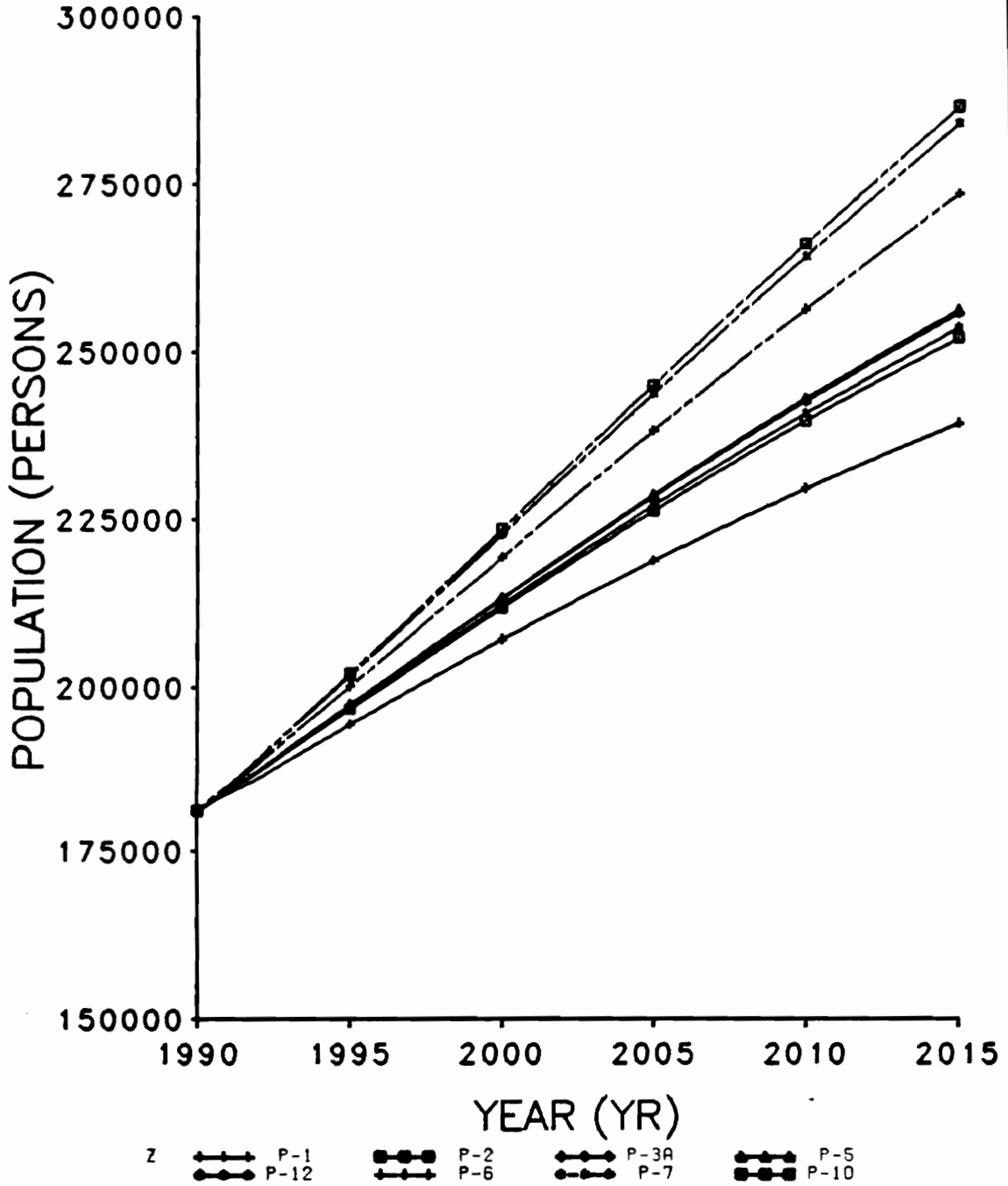


Figure 36. Population of Roanoke

NON-USER BENEFIT ANALYSIS PER CAPITA INCOME IN BLACKSBURG

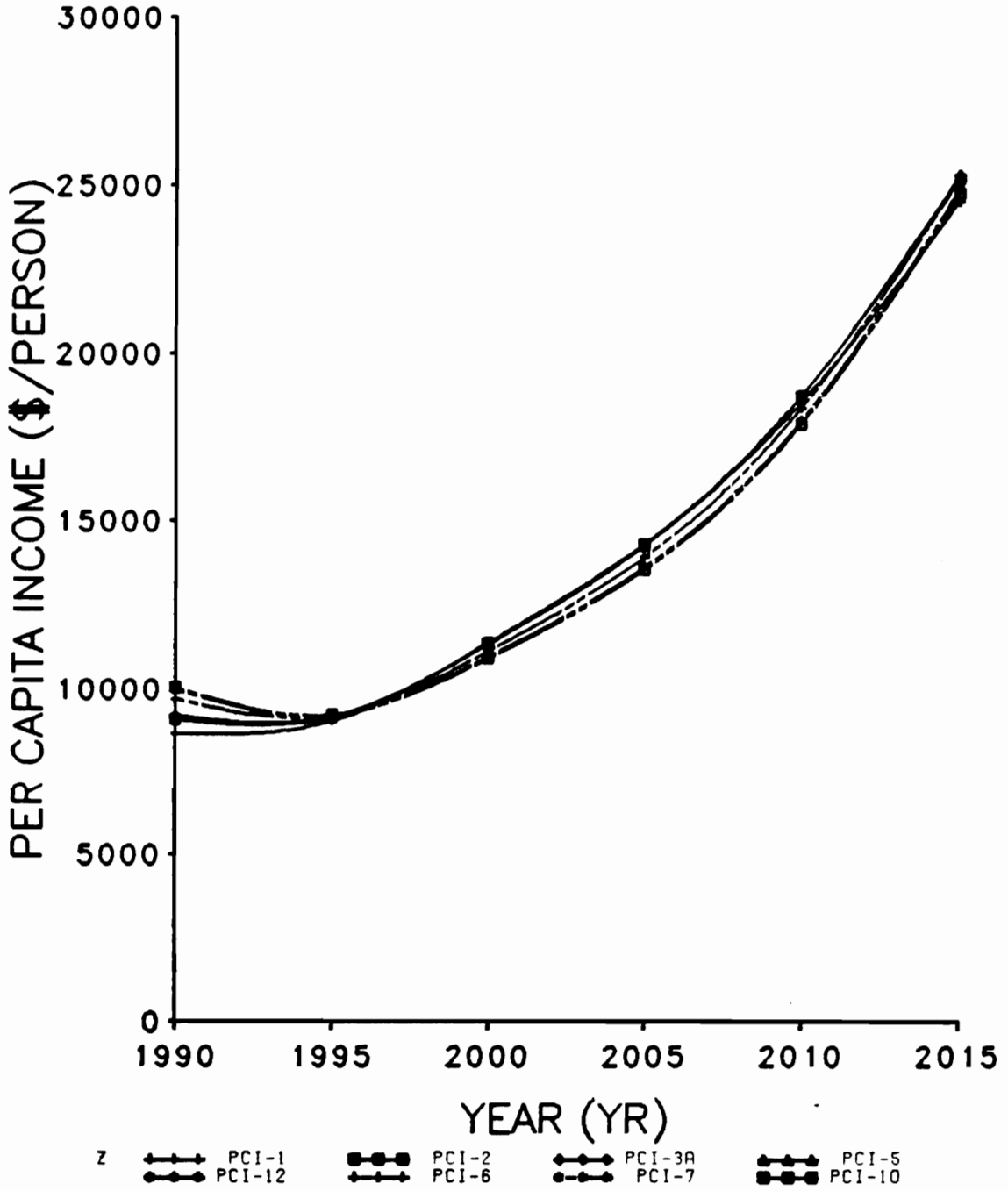


Figure 37. Per capita income in Blacksburg

NON-USER BENEFIT ANALYSIS PER CAPITA INCOME IN CHRISTIANSBURG

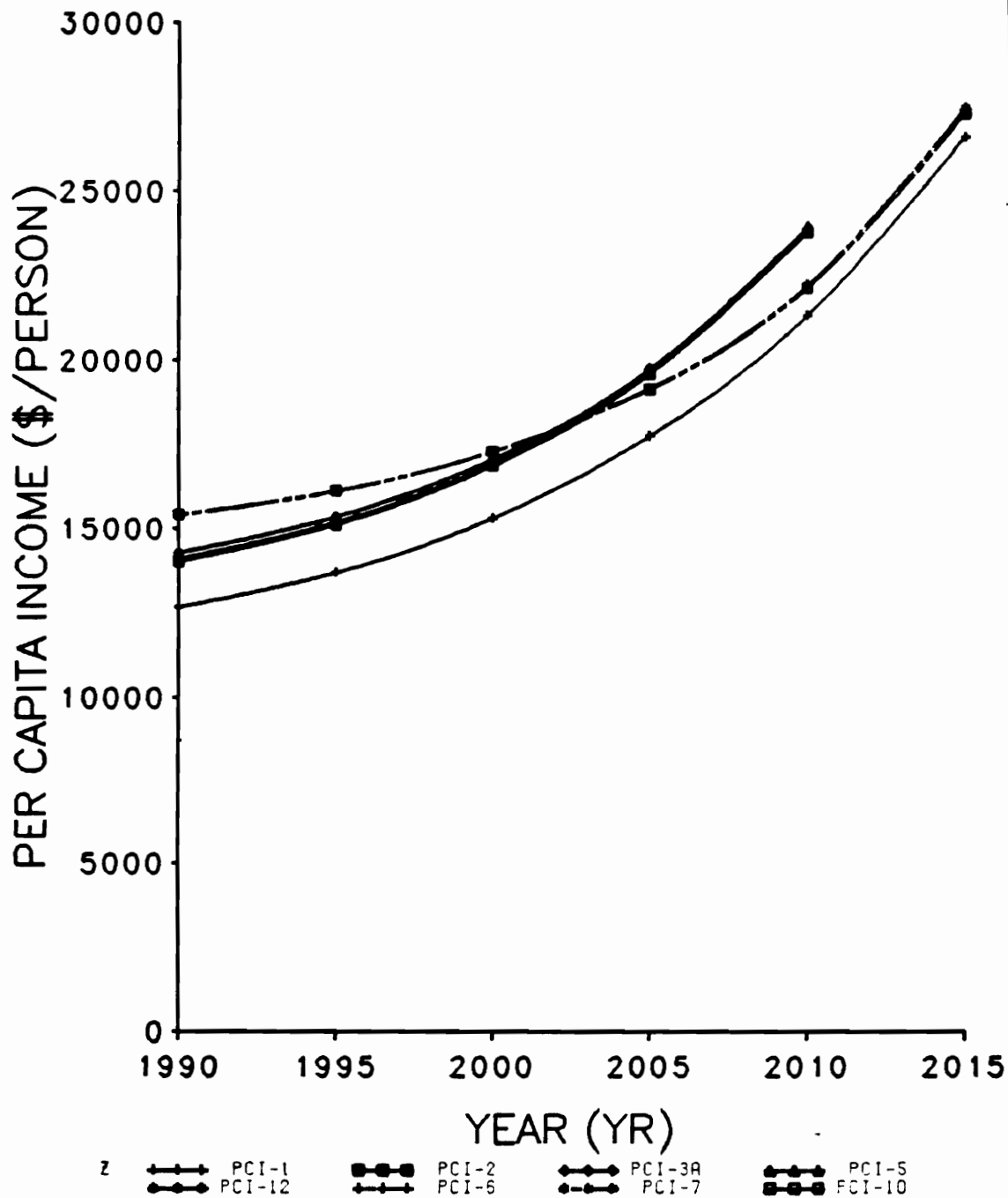


Figure 38. Per capita income in Christiansburg

**NON-USER BENEFIT ANALYSIS
PER CAPITA INCOME IN ROANOKE)
(CITY AND COUNTY)**

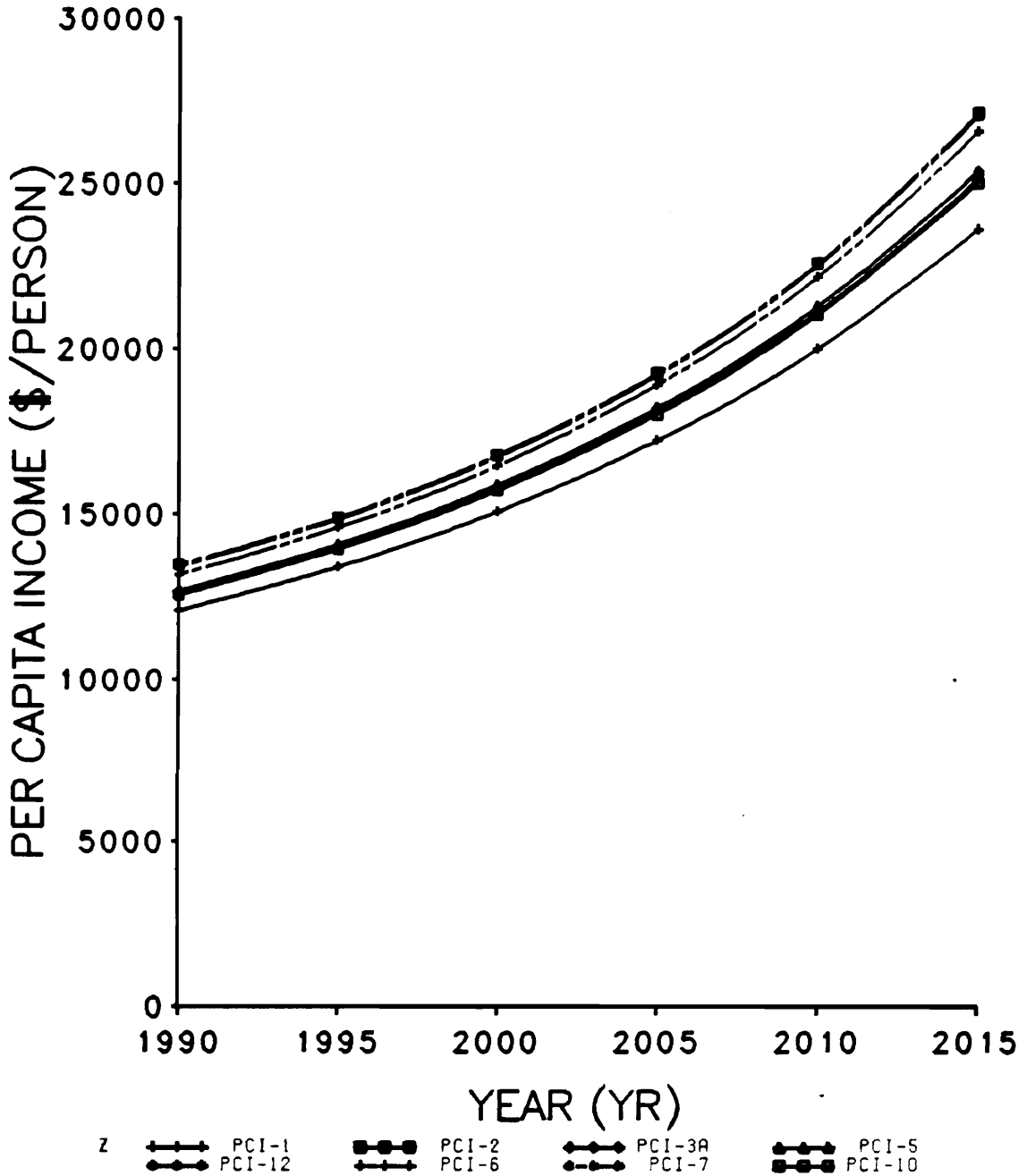


Figure 39. Per capita income in Roanoke

NON-USER BENEFIT ANALYSIS FUNDED RESEARCH AT VIRGINIA TECH

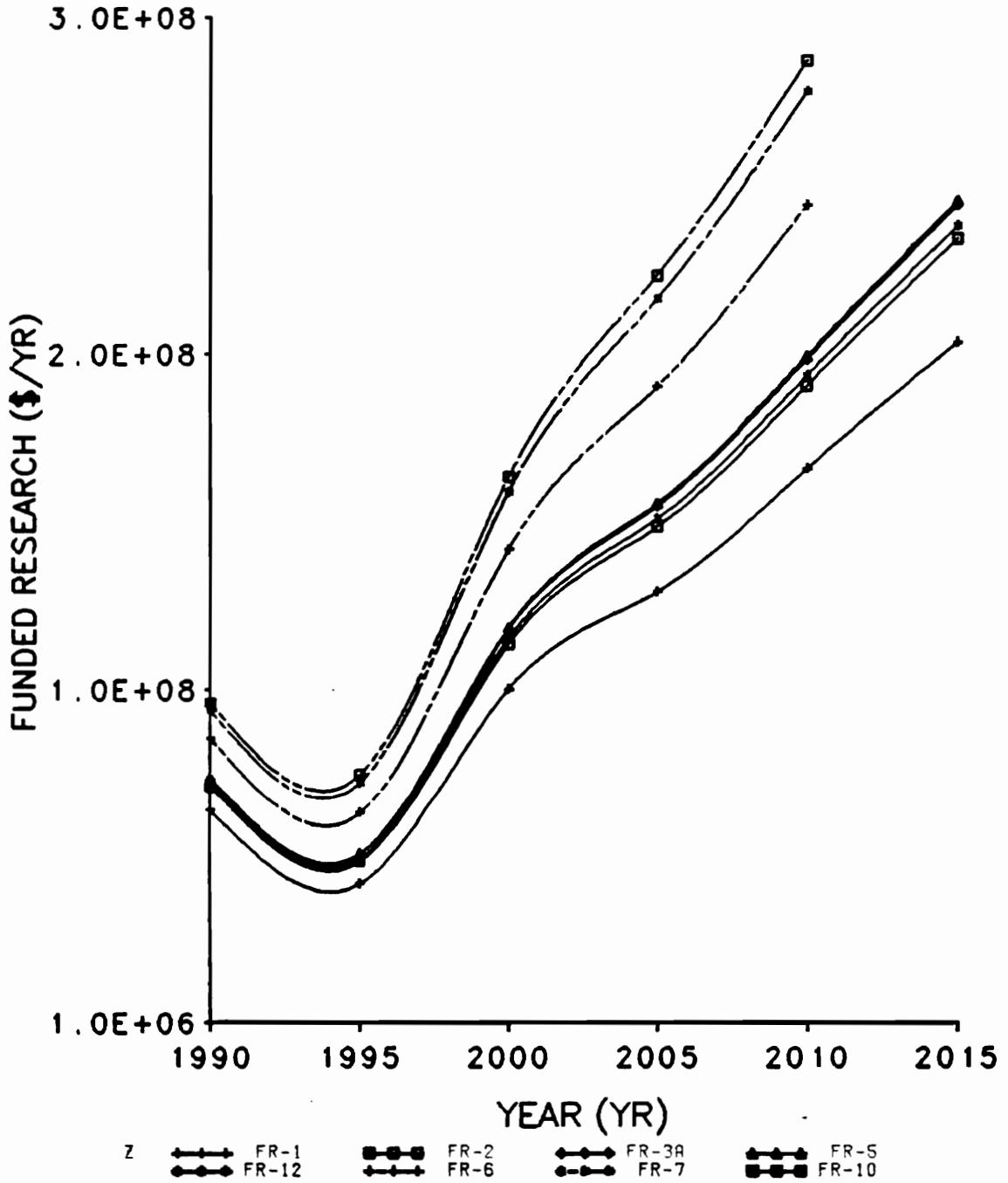


Figure 40. Funded research at Virginia Tech

NON-USER BENEFIT ANALYSIS TOTAL GRADUTE STUDENT AT VIRGINIA TECH

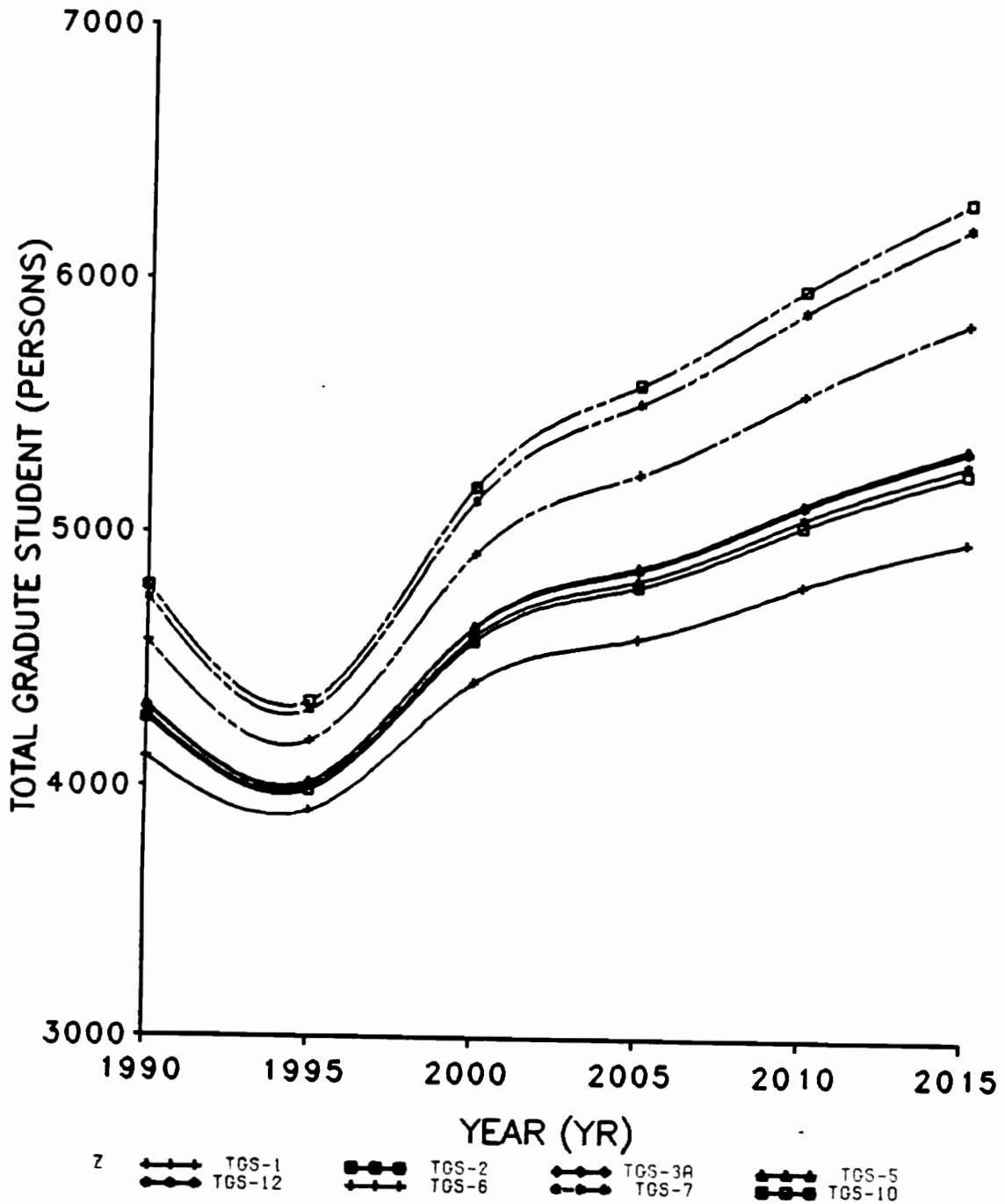


Figure 41. Total graduate student in Virginia Tech

TABLE 6.4

POPULATION, PER CAPITA INCOME, HUNDRED RESEARCH
AT THE HORIZON YEAR

	1 (Do Nothing)	2	3A	5	12	6	7	10
Population of Blacksburg	44,820	49,760	51,260	51,480	50,340	59,450	64,910	66,310
Population of Christiansburg	27,670	34,810	36,960	37,160	35,520	55,870	55,910	56,570
Population of Roanoke (City and County)	239,300	252,000	255,700	256,200	253,500	273,500	284,000	286,500
Per Capita Income of Blacksburg	24,510	25,190	25,290	25,300	25,230	25,230	24,870	24,750
Per Capita Income of Christiansburg	26,590	30,410	30,650	30,660	30,520	27,450	27,440	27,280
Per Capita Income of Roanoke	23,610	25,010	25,340	25,380	25,140	26,570	27,030	27,112
Funded Research at Virginia Tech	204.2M	235 M	244.8M	246.2M	238.8M	302.3M	345 M	356.6M
Total Graduate Students at Virginia Tech	4980	5250	5336	5348	5283	5840	6214	6318
Rank		7	5	4	6	3	2	1 (the best)

6.3.11 Discussion

In order to evaluate the alternatives according to the non-user benefits, we should look at the graphs in Fig. (34) to (41), Appendix C, Appendix D and Table 6.4 From these we can see:

I-The improvement of the transportation facility will induce socio-economic development in each alternative.

II-Population, per capita income of each city, funded research and total number of graduate student at Virginia Tech seem to grow significantly in each case.

III-The alternatives can be divided into three groups based on similarity of results:

1 - Alternative 1, (Do Nothing)

2 - Alternative 2, 3A, 5, 12

3 - Alternative 6, 7, 10

Each group has a very similar results, so we have little difficulty in separating one alternative from another in the same group.

IV-In order to rank them according to our measure of effectiveness which has been discussed in section 6.3.1, we can see:

1 - Alternative 10 (the best)

2 - Alternative 7

3 - Alternative 6

4 - Alternative 5

5 - Alternative 3A

6 - Alternative 12

7 - Alternative 2

7.0 Summary and Conclusions

7.1 Summary

This dissertation concerns a contemporary problem, regional development; a much employed strategy for mitigating the problem, transportation investment; a problem solving philosophy, system dynamics; a transportation/economic development evaluation methodology; a regional context for illustrating the methodology, the Blacksburg-Christiansburg-Roanoke area; and a model of the study area derived from the methodology.

Consider the problem, development. This has become a universal goal. In the United States, it seems to have become a national obsession. Every rural county and city has its own mechanisms and government agencies for promoting economic development. A key element of any strategy is transportation induced development.

The relationship between transportation and economic development has never been as critical as it is today. The efficient movement of people and products is key to a community's competitive position and quality of life. Transportation modes -- highways, rail, air and waterways -- act as a magnet for growth, and intermodal linkages

provide an increased opportunity for regional economic development. The need for improvements in transportation facilities and systems has never been greater; yet it is getting harder to justify soaring expenses in an era of fiscal constraint. Transportation plans have a direct impact on economic development plans. Economic development practitioners have a critical role to play in determining what types of transportation facilities are built and maintained. Making this important link between transportation and economic development is the focus of this dissertation.

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

Transportation benefits accruing to road users, in terms of time savings, cost savings and savings due to accident reduction, are the primary effects of transportation improvements. These transportation user benefits are the main components of benefit-cost analysis, which provide a quantitative assessment of the relative benefits of different alternatives in terms of a common monetary measure.

Economic impacts measure the secondary effects of capital expenditures on the regional economy. They affect income, employment, production, resource consumption, pollution generation and tax revenues.

Impact studies, whether they state it or not, attempt to establish and measure the cause and effect relationships associated with a transportation change and, in doing so, evaluate its socioeconomic consequences. The effects of a transportation change can be categorized in several different ways, but most analysts make a fundamental distinction between changes in the physical environment and changes in the personal well-being of individuals in the community. The most often studied impact in the first

category has been land use changes. Studies of effects in the second category attempt to evaluate transportation in terms that relate it to groups in the community. An important distinction is between impacts on users and impacts on non-users. An example of a user impact is the effect of a new highway on the amount of time that it takes to make certain trips. Non-user impacts include such effects as increased employment opportunities and lower prices on goods for which transportation costs are reduced.

In considering the conclusions which have come from impact studies it is instructive to recall the purposes, ignoring for the moment the promotional (public information) aspects. The studies have sought to establish cause and effect relationships and to evaluate public decisions on transportation in such a way that their measurements would be useful to planning and decision making. Even though an impressive amount of effort has been spent on this type of research, the results have been meager in view of the standards called for by the purposes and objectives stated in the studies. The reason why an unsatisfactory amount of knowledge has come from these studies stem from their completely inadequate theoretical foundations and methodological approaches. These problems have crippled attempts to establish and evaluate transportation impacts.

Better techniques for developing such models are available today than when the Interstate Highway Program was initiated, mandating the need for impact studies in the U.S. Although the field of computer modeling has existed for only a few decades, a number of different methodological schools based on distinct procedures and techniques have already appeared, including linear programming, input-output analysis, econometrics, Monte Carlo simulation and system dynamics. Since a formal model is determined by its choice of theory, data and methodology, the different kinds of modeling can be classified along these dimensions. Models may be distinguished by their information bases (for example, social statistics or behavioral observations), by mathematical procedures employed (differential equation, simultaneous equations, etc.), and by the nature of the model relationships (such as stochastic, deterministic, or non-linear).

The major reason for developing a transportation/development model not just to forecast the future, but to influence the future and to help the decision-maker to decide which of the candidate alternatives is the preferred one. Models need to be built that are explicitly directed toward particular policy or planning issues. This means that variables under the control or sensitive to the policy in question must be involved in the model and that the scale of the modeling effort involved with regard to model construction, data collection, calibration, and application must be commensurate with the nature of the decision being considered.

A body of dynamic behavior and principles of structure is emerging that allows us to organize and understand the development process of a region or a whole nation – a process dominated by feedback in that it features the synthesis of demand and supply functions. For the demand function, we are seeking the transportation improvement required to accommodate a certain socio-economic load, for the supply function we want to know the level of service obtained for a certain transportation improvement. Since higher levels of service attract socio-economic activity, the feedback loop is closed.

Basically transportation impact analysis is an attempt to answer the following question: What would be the economic impact A, the social impact B, the demographic impact C, the land-use impact D, the environmental impact E, and the user-benefit F over geographic scale G for the transportation investment H on mode I at time T? A transportation impact methodology (TIM) with the following desirable qualities in response to this question is proposed [Drew and Al-Dawood, (50)]:

1. It should depict transportation initiatives and impact relationships in terms of variables and relations between the variables.
2. TIM should be applicable to the complete ranges of geographic scale (from interchange to corridor), mode (land, water and air transportation and their interfaces), and initiative (from project to program to policy).

3. TIM should be capable to developing theories so as to verify or refute conclusions regarding transportation and development interactions.
4. We must remember that the design of a system (such as transportation) to serve society requires that we account for the fact that the design itself will influence the inputs that the system must accommodate.
5. A requirement of TIM is that it handle feedback endogenously and explicitly.
6. TIM must be comprehensive taking into consideration transportation investment to increase supply (capacity) and transportation management to smooth demand.
7. In order to forecast development impacts, our TIM must model the development process explicitly.
8. TIM must accommodate the three orientations — user, provider, and society — and their values and goals so as to effectively trade off different policies and combinations of policies.
9. TIM should be capable to generating productivity curves for every policy variable - measure of effectiveness combination.
10. Another requirement of TIM is that it make use of the existing data bases generated in conjunction with the Urban Transportation Planning Process (UTPP) mandated during the period of Interstate Highway Planning.
11. TIM should provide a framework for defining a host of transportation initiatives including (1) communication substitution, (2) transit promotion, (3) increasing vehicle occupancy, (4) staggering work hours, etc.
12. TIM should be a synthesizing device, accommodating the Development Process, the Urban Transportation Initiates and Non-Investment (Management) Initiatives to show how reductions in transportation costs impact users and non-users.
13. Continuing from the previous requirements, TIM should be capable of separating user benefits and non-user benefits so as to eliminate double counting.

Three commonly used methodologies of economic impact analysis -- economic base, econometric, and input-output analysis do not fulfill the above requirements. The economic base approach is highly aggregated, resumming a regional economy consists of two sectors; basic and non-basic. While input-output analysis overcomes this shortcoming, three drawbacks are: (1) the tremendous data requirements, both collection and checking to update the coefficients, (2) insensitivity to marginal economic behaviors, and (3) the lack of a dynamic feedback mechanism. Econometric models are constructed from casual relationships developed using time series data and regression analysis. Static concepts, open-loop structure, and the heavy reliance a mechanical statistical techniques severely compromise their theoretical validity and realism [Huang (68)].

Until recently there has been no way to estimate the long chain of impacts of infrastructure improvements on our socio-economic systems except by contemplation, discussion, argument and guesswork. To point a way out of our present dilemma about transportation/economic development problems an approach that combines the strengths of the human mind and the strengths of today's computers using system dynamics is sketched in this dissertation.

This system dynamics transportation impact methodology is applied to a classic problem facing state highway departments is whether to add lanes to an existing congested highway serving two cities or build a new, more direct highway facility between the two locations. The decision turns on the evaluation of user and non-user benefits for the alternatives. This is the situation we have in the New River Valley with respect to the Blacksburg-Roanoke connection. Since the existing route passes through Christiansburg, it also will be impacted by the alternative chosen.

Using the benefit cost criterion to evaluate highway user benefits for seven route alternatives and developing a system dynamics model to relate highway travel variables to the socio-economic variables for the three urban areas, non-user measures of effectiveness are outputed. Specifically, the steps in finding user benefits for all traffic including induced and diverted as well as through traffic includes the following:

1. Plot the demand function and the supply functions for the seven alternatives.
2. Find the changes in annual user costs by finding the areas under the curves.
3. Calculate the Benefit-Cost Ratios for the alternative using the Benefit Cost expression.

$$BC = \frac{R-E}{cr} (1-e^{-r}) \text{ where}$$

R is obtained from Step (2).

The steps in finding non-user benefits includes the following:

1. Extend the chain of causality from the transportation decision variables such as number of lanes to the measures of effectiveness.
2. Develop the mathematical model expressed in the DYNAMO language corresponding to the causal diagrams developed from mental models of the study area.

The alternatives are compared and ranked. From the view of the user-benefit, according to result Alternative 7 is the best then 10, 6, 3A, 5, 12, 2 respectively. On the other hand, from the non-user benefits, Alternative 10 is the best, then 7, 6, 5, 3A, 12, 2 respectively. But if we have to choose one alternative according to the user and non-user benefits, along with relatively lower cost and short distance, Alternative 6 is the best.

7.2 Discussion

This dissertation is not the first attempt to analyze the Blacksburg-Christiansburg-Roanoke corridor and it won't be the last. In a Master's Thesis in Urban and Regional Planning, Brown [67] studies this problem. He states: "Instead of looking at this issue in terms of just numbers, or in an engineering context, I decided to look at it from two other stand-

points. First, from an analysis of each of the seven proposed alternatives and second, from some of the future consequences which may result, in terms of land uses, economics and geography.” In his Chapter 5, he develops “strengths and weaknesses” in a purely qualitative manner. There is no model, nothing explicit or quantitative is revealed.

In contrast to the approach, the system dynamics model developed in this research explicitly conveys the causal hypothesis linking transportation, land use, economic and demographic variables. The irony is that because they are easily understood, they can and will be challenged by different experts and specialists. These challenges are welcomed. A model is meant to be a dynamic instrumentality that is continually improved upon. Those with differing view points are free to run their own versions of the model. Analysts can agree to disagree on some aspects of the model. This is a strength of this approach, not a weakness. Model building is meant to be a circular process of creating a model structure, testing behavior of the model, comparing that behavior with knowledge about the real world being represented, and reconsidering structure. The process is never over. This doesn't mean that the Model is never ready to be used as a forecasting tool. On the contrary, each step in model development provides a tool for forecasting that is better than the mental images and verbal descriptions from which the model at that stage was derived.

Assuming that we accept the premise that the model becomes better through repeated scrutiny and correction of weaknesses, what criterion should be used to identify weaknesses? In the physical sciences, models are improved by comparing model-based point predictions with quantitative observations. Randers [69], points out that because complex social systems exhibit a significant stochastic element, little help is to be obtained from comparison of detailed model prediction with specific real-world observations.

The question as to how a complex simulation model such as developed in this research should be validated has been a controversial issue for many years. Most system dynamicists claim that model validity is strongly tied to the nature and context of the problem, the purpose of the model, the background of the user and the background of the analysts. Accordingly,

model validation is inherently a social, judgmental, qualitative process: models cannot be proved valid but can be judged to be so [Bulas and Carpenter,(70)].

The author feels that it is important to distinguish between two fundamentally different types of mathematical models: causal (theory-like) models and casual (statistical / correlational) models. The former, since they constitute theories about the system, can be used for both prediction and explanation. Casual models, on the other hand, simply express observed associations among various elements of a real system and should only be used for predictive purposes and then only within a narrow range of values of variables. In creating a causal model, information is used in a substantially different way than in developing a casual model. To the system dynamicist, information exists in three forms: the mental data base, the written data base, and the numerical data base. Conventional, non causal modelers, take a restrictive interpretation of "data" as being numerical. The dictionary meaning is far broader and closer to the system dynamics interpretation: "data are detailed information of any kind."

- the capacity of the model to generate behavior modes corresponding to those observed, expected or credible in the study area,
- the plausibility of the causal mechanisms chosen to represent the transportation, land use, economic and demographic links in the region,
- the reliability of the numerical values of model parameters,
- the compatibility of individual assumptions with established knowledge,
- the internal consistency of the overall structure,
- the completeness with which the model includes the mechanisms thought to generate the problem addressed.

7.3 Conclusions and Recommendations

Following the framework of Section 7.1, the conclusions and recommendations deal with the methodology, the model, the problem and the concept.

Regarding the methodology, the system dynamics based TIM (Transportation Impact Methodology) applied here comes the closest to fulfilling the 13 requirements outlined in Section 7.1. Requirements 1, 4, 5, 7, 12 and 13 are met in developing the 3 city model used to forecast user and non-user benefits. Many of the other requirements were beyond the scope of this research but could have been met in an expanded research project. The ability of the SDTIM (system dynamics TIM) to meet requirements 2, 3, 6, 8, 9, 10, and 11 is discussed in a companion project [Huang], a report derived from this research [Drew and Al-Dawood] and papers upon which this research was built [Drew].

In considering the model, one very positive attribute is the inclusion of the University Sector. It is difficult to see how some of the traditional modeling methodologies such as the economic base, input-output as production function would have handled this industry, Virginia Tech. Yet, not to model it explicitly and endogenously would have been ridiculous.

Ready access to good highways has always been an important element in promoting economic development. The Commonwealth of Virginia recognizes this in their industrial access road program. Virginia Tech is a \$260 million a year corporation with over 10,000 employees spending more than \$56 million a year in research projects alone. Although many people do not view Virginia Tech as a business, it is one of, if not the, largest corporation in Southwest Virginia. As a leader in the education industry, Virginia Tech has the resources to initiate and implement changes which can generate economic well being for the Commonwealth. Roanoke doesn't have a four-year state university.

It's no coincidence that some of the fastest-growing places in Virginia outside the "urban crescent" are college towns - Charlottesville, Harrisonburg, Blacksburg. Major universities -

with their research facilities - serve as magnets for many companies, especially in such high-growth fields as electronics.

Since Virginia isn't planning on building any new universities in Western Virginia (if a new one is build, it'll probably be in Northern Virginia), Roanoke's only alternative is to "adopt" Virginia Tech and push for a more direct road.

Armed with a working model, the many planning agencies interested in the development of Southwest Virginia have an instrumentality to build upon to guide their planning. Sensitivity analyses should be performed to identify weaknesses and to prioritize information collection requirements. Scenario analyses should be performed to evaluate non transportation initiatives as well as the transportation investments. For example, Virginia Tech's policy putting a cap on student enrollments works against the justification for the direct link to Roanoke. If the Automated Highway/Vehicle Control System demonstration project for the University Road Connection becomes a reality, then the model could be used to evaluate its impact on the economic development of the region.

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Appendix A Socio-Economic and Transportation Statistics

Table A.1 to Table A.24 show some relevant socio-economic statistics and Table A.25 to A.40 show some transportation statistics for the Study area.

TABLE A.1
POPULATION IN 1950-1985

	1950	1960	1970	1980	1985
Montgomery County	29,780	32,923	47,157	63,516	65,500
Blacksburg	3,358	7,070	9,384	30,638	31,296
Christiansburg	2,967	3,653	7,857	10,345	11,667

Source: Reference [56]

TABLE A.2
POPULATION IN 1980-1985

	1980	1981	1982	1983	1984	1985
Montgomery County	63,516	64,200	64,700	64,800	64,800	65,500
Roanoke County	76,2945	73,900	73,800	73,500	73,400	73,700
Roanoke City	100,220	100,200	100,400	100,500	100,600	101,200

Source: Reference [54]

TABLE A.3
LAND AREA AND POPULATION DENSITY IN 1980

	LAND AREA		POPULATION DENSITY	
	Square Miles	Square Kilometers	Per Square Mile	Per Square Kilometer
Montgomery County	390	1,009	162.9	62.9
Roanoke County	251	650	290.6	112.2
Roanoke City	43	112	2,330.7	894.8

Source: Reference [54]

TABLE A.4
NUMBER OF RESIDENTIAL BUILDING PERMITS ISSUED IN
MONTGOMERY AND ROANOKE COUNTY 1980-1985

	1980	1981	1982	1983	1984	1985	1987
Montgomery County	437	359	382	470	637	631	884
Roanoke County	786	712	645	294	423	434	437

Source: Reference [55]

TABLE A.5

VALUE OF RESIDENTIAL BUILDING PERMITS ISSUED 1980-1985

	1980	1981	1982	1983	1984	1985
Montgomery Co.	11,348.3	7,396.6	10,213.3	8,405.5	18,371.3	15,204.7
Roanoke County	36,344.5	29,433.2	26,475.1	10,563.2	14,750.0	15,175.2
Roanoke City	7,554.0	4,720.7	3,323.8	3,332.1	1,613.9	10,388.1

Source: Reference [55]

TABLE A.6
MAJOR OCCUPATION GROUPS IN MONTGOMERY COUNTY IN 1986

Occupation	Employment	Avg. Weekly Wage
Construction	1,024	\$299
Manufacturing	7,754	\$378
Transportation, Utilities	180	\$392
Trade	5,307	\$175
Finance, Insurance, Real Estate	812	\$272
Services	2,714	\$230
Government (includes education)	8,228	\$362

Source: Reference [54]

TABLE A.7
POPULATION CHANGE 1980-1986

	Components of change, 1980-1986			
	Net change		Natural increase	
	Number	Percent	Births	Deaths
	Montgomery County	2,900	4.5	4,500
Roanoke County	1,600	2.1	4,800	3,600

Source: Reference [54]

TABLE A.8
PERSONS PER HOUSEHOLDS IN 1985

	Persons Per Household
Montgomery County	2.51
Roanoke County	2.61
Roanoke City	2.46

Source Reference [54]

TABLE A.9
OCCUPATIONAL DISTRIBUTION FOR EMPLOYED WORKERS
1980

	TOTAL EMPLOYED	OCCUPATIONAL GROUP											
		Managerial and Professional Speciality	Technical, Sales, and Administrative Support	Service	Farming, Forestry, and Fishing	Precision Production, Craft, and Repair	Operators, Fabricators, and Laborers	Transportation, Communications, and Other Public Utilities	Finance, Insurance, and Real Estate	Forestry and Fisheries	Mining	Construction	Agriculture
Montgomery County	26,431	7,311	7,348	3,802	557	3,146	4,267	1,029	777	91	1,690	53	536
Roanoke County	35,004	9,889	12,714	3,332	214	3,895	4,960	4,126	2,725	78	1,990	48	277
Roanoke City	43,674	8,608	13,632	7,083	316	5,123	8,914	4,644	2,793	70	2,589	36	226
EMPLOYMENT SECTOR													
Montgomery County	26,431	TOTAL EMPLOYMENT											
Roanoke County	35,004	TOTAL EMPLOYMENT											
Roanoke City	43,674	TOTAL EMPLOYMENT											

Source: Reference [54]

TABLE A.10
LABOR FORCE IN 1986

	<u>Civilian Labor Force</u>	<u>Employed</u>	<u>Unemployed</u>	
			<u>No.</u>	<u>Rate</u>
Montgomery County	32,783	30,675	2108	6.4
Roanoke County	38,792	37,316	1476	3.8
Roanoke City	54,675	51,450	3228	5.9

Source: Reference [53]

TABLE A.11
LABOR FORCE 1985

	<u>Civilian Labor Force</u>	<u>Employed</u>	<u>Unemployed</u>	
			<u>No.</u>	<u>Rate</u>
Montgomery County	31,545	29,605	1940	6.1
Roanoke County	38,436	36,989	1447	3.8
Roanoke City	54,057	50,998	3059	6.1

Source: Reference [53]

TABLE A.12
LABOR FORCE IN 1987

	<u>Civilian Labor Force</u>	<u>Employed</u>	<u>Unemployed</u>	
			<u>No.</u>	<u>Rate</u>
Montgomery County	32,497	30,906	1591	4.9
Roanoke County	42,137	40,950	1187	2.8
Roanoke County	53,442	51,060	2382	4.5

Source: Reference [53]

TABLE A.13
LABOR FORCE 1988

	<u>Civilian Labor Force</u>	<u>Employed</u>	<u>Unemployed</u>	
			<u>No.</u>	<u>Rate</u>
Montgomery County	32,647	30,707	1940	5.9
Roanoke County	42,098	40,716	1382	3.3
Roanoke City	53,991	51,163	2828	5.2

Source: Reference [53]

TABLE A.14
MANUFACTURING IN 1982

	ALL ESTABLISHMENTS		ALL EMPLOYEES		PRODUCTION WORKERS		
	Number *1000	Number with 20 Employees or more	Number *1000	Payroll *10 ⁶	Number *1000	Hours *10 ⁶	Wages *10 ⁶
Montgomery County	41	17	3.5	48.7	2.6	5.2	31.1
Roanoke County	44	15	2.2	35.0	1.6	3.3	22.8
Roanoke City	160	71	10.7	162.5	2.3	13.7	96.4

Source: Reference [54]

TABLE A.15
MANUFACTURERS IN MONTGOMERY AND ROANOKE COUNTY IN 1982

	Establishments	Percent with 100 or more employees	All employees				Production workers			Value added by manufacture (Mil. dol.)	Value of ship-ship-ship (Mil. dol.)	New capital expenditures (Mil. dol.)
			Number (1,000)	Percent change, 1977-1982	Annual payroll (Mil. dol.)	Number (1,000)	Work-hours (Millions)	Total (Mil. dol.)	Average per production worker (Dollars)			
Montgomery County	41	24.4	3.5	9.4	48.7	2.6	5.2	31.1	11,962	98.4	183.6	7.4
Roanoke County	44	9.1	2.2	-31.3	35.0	1.6	3.3	22.8	14,250	86.7	175.3	20.8
	Total		(1,000)	1977-1982	(Mil. dol.)	(1,000)	(Millions)	(Mil. dol.)	(Dollars)	(Mil. dol.)	(Mil. dol.)	(Mil. dol.)

Source: Reference [54]

TABLE A.16

RETAIL TRADE IN 1982 IN MONTGOMERY AND ROANOKE COUNTY

	Number	Total (Mil. dol.)	Percent change, 1977, 1982	Per capita (thousand) (Dol.)
Montgomery Co.	471	260.5	59.6	4,026
Roanoke County	435	238.3	48.2	3,688

Source: Reference [54]

TABLE A.17

WHOLESALE TRADE 1982 IN MONTGOMERY AND ROANOKE COUNTY

	Establish- ments	Sales (Mil. dol.)	Paid employees	Annual payroll (Mil. dol.)
Montgomery Co.	36	49.2	310	2.8
Roanoke County	93	546.0	1,966	26.6
Roanoke City	317	958.3	4,817	8.3

Source: Reference [54]

TABLE A.18
ESTABLISHMENTS BY INDUSTRY

	INDUSTRY DIVISION					
	Transportation and other Utilities	Wholesale Trade	Retail Trade	Finance, Insurance, and Real Estate	Services	Non-classifiable
Montgomery Co.	32	40	369	86	356	84
Roanoke County	30	103	293	97	390	105
Roanoke City	107	334	893	377	1,071	237

Source: Reference [54]

TABLE A.19
PER CAPITA PERSONAL INCOME 1980-1984

	1980	1981	1982	1983	1984
Montgomery County	6,190	6,886	7,390	8,028	8,891
Roanoke County	9,518	10,411	11,056	12,313	13,446
Roanoke City	8,816	9,917	10,650	11,362	12,380
Blacksburg		6,128		6,913	
Christiansburg		7,434		8,360	

Source: Reference [54]

TABLE A.20
RETAIL SALES SUMMARY 1982

	KIND OF BUSINESS					
	Gasoline Service Stations		Apparel and Accessory Stores		Furniture Stores	
	Number	Sales 1000	Number	Sales 1000	Number	Sales 1000
Montgomery County	31	29,214	29	8,770	31	8,552
Roanoke County	27	33,317	43	18,446	28	14,515
Roanoke City	62	49,586	83	34,145	59	31,542

	KIND OF BUSINESS					
	Eating and Drinking Places		Drug and Proprietary Stores		Miscellaneous Retail Stores	
	Number	Sales 1000	Number	Sales 1000	Number	Sales 1000
Montgomery County	72	24,199	13	6,923	63	23,559
Roanoke County	53	20,330	12	9,323	48	8,141
Roanoke City	159	65,705	35	22,667	159	63,096

Source: Reference [54]

TABLE A.21
MONEY INCOME

	Per capita			Percent below poverty level, 1979	
	1985	1979			
	Income	Current dollars	Constant (1985) dollars	Persons	Families
	Montgomery County	9,078	5,658	8,385	19.7
Roanoke County	12,566	8,088	11,986	5.8	4.2
Roanoke City	10,644	7,816	10,101	16.3	12.4

Source: Reference [54]

TABLE A.22
STUDENT AND FACULTY IN 1989 IN VIRGINIA TECH

Freshman	5,673
Sophomores	4,524
Juniors	4,572
Seniors	3,657
Graduate	4,037
Assistant Professor	379
Associate Professor	550
Full Professor	568

Source: Reference [63]

TABLE A.23
DEGREES AWARDED AT VIRGINIA TECH 1883-1988

Year	Bach.	Mast.	Ph.D/Ed.D
1883	2	0	
1884	4	0	
1885	1	0	
1886	3	0	
1887	2	0	
1888	1	0	
1889	4	0	
1890	0	0	
1891	1	0	
1892	5	1	
1893	7	2	
1894	9	3	
1895	18	3	
1896	19	6	
1897	19	5	
1898	17	3	
1899	25	4	
1900	25	11	
1901	35	6	
1902	44	9	
1903	35	17	
1904	57	14	
1905	77	19	
1906	67	13	
1907	70	13	
1908	43	17	
1909	46	14	
1910	48	15	
1911	69	9	
1912	44	15	
1913	49	13	
1914	52	7	
1915	61	13	
1916	77	15	
1917	68	12	
1918	30	3	
1919	36	8	
1920	79	7	
1921	75	8	
1922	106	17	
1923	112	12	
1924	114	11	
1925	141	10	

TABLE __ (Continued)

Year	Bach.	Mast.	Ph.D/Ed.D
1926	133	15	
1927	149	14	
1928	180	14	
1929	178	17	
1930	208	19	
1931	213	28	
1932	227	55	
1933	280	64	
1934	276	41	
1935	280	35	
1936	257	39	
1937	275	62	
1938	311	48	
1939	378	65	0
1940	440	74	0
1941	464	65	0
1942	467	46	1
1943	523	34	3
1944	184	10	0
1945	102	8	1
1946	97	18	1
1947	535	58	0
1948	673	87	1
1949	1042	80	4
1950	1341	97	5
1951	1004	113	5
1952	727	98	5
1953	620	120	7
1954	504	90	5
1955	470	113	7
1956	549	90	13
1957	710	99	10
1958	911	127	16
1959	858	131	12
1960	896	122	18
1961	881	162	20
1962	954	186	25
1963	1032	206	22
1964	1008	194	24
1965	1087	173	52
1966	1064	208	64
1967	1170	247	77
1968	1348	250	86
1969	1766	241	90
1970	2068	234	107

TABLE __ (Continued)

Year	Bach.	Mast.	Ph.D/Ed.D
1971	2117	295	128
1972	2182	385	114
1973	2297	634	102
1974	2660	767	132
1975	2999	870	156
1976	3034	861	186
1977	3211	1027	167
1978	3250	834	178
1979	3373	866	193
1980	3521	898	194
1981	3436	938	211
1982	3639	963	227
1983	3680	914	246
1984	3851	1003	271
1985	3757	812	260
1986	3690	835	274
1987	3581	1002	295
1988	3877	1073	287

Source: Reference [63]

TABLE A.24
ENROLLMENT AT VIRGINIA TECH 1872-1987

1872-73	132	1931-32	1810
1873-74	197	1932-33	1817
1874-75	222	1933-34	1561
1875-76	255	1934-35	1694
1876-77	224	1935-36	1836
1877-78	186	1936-37	2115
1878-79	160	1937-38	2376
1879-80	50	1938-39	2780
1880-81	78	1939-40	3119
1881-82	148	1940-41	3243
1882-83	163	1941-42	3382
1883-84	190	1942-43	3582
1884-85	132	1943-44	1559
1885-86	98	1944 (AWP)	982
1886-87	110	1944-45	738
1887-88	152	1945-46	2331
1888-89	127	1946-47	4971
1889-90	139	1947-48	5458
1890-91	150	1948-49	5689
1891-92	135	1949-50	4857
1892-93	177	1950-51	3948
1893-94	236	1951-52	3259
1894-95	325	1952-53	3215
1895-96	335	1953-54	3322
1896-97	336	1954-55	3747
1897-98	333	1955-56	4420
1898-99	303	1956-57	4786
1899-1900	343	1957-58	5138
1900-01	386	1958-59	5318
1901-02	472	1959-60	5496
1902-03	627	1960-61	5747
1903-04	727	1961-62	5827
1904-05	728	1962-63	6358
1905-06	619	1963-64	6555
1906-07	577	1964-65	7305
1907-08	546	1965-66	7711
1908-09	565	1966-67	9064
1909-10	509	1967-68	10254
1910-11	471	1968	10289
1911-12	463	1969	11028
1912-13	471	1970	12043
1913-14	527	1971	13282
1914-15	490	1972	14471
1915-16	505	1973	16367
1916-17	533	1974	17470

TABLE __ (Continued)

1917-18	519	1975	18477
1918-19	477	1976	18238
1919-20	757	1977	19648
1920-21	798	1978	20261
1921-22	975	1979	20780
1922-23	977	1980	21069
1923-24	1110	1981	21584
1924-25	1191	1982	21510
1925-26	1205	1983	21357
1926-27	1224	1984	21454
1927-28	1300	1985	22044
1928-29	1392	1986	22345
1929-30	1495	1987	22702
1930-31	1659		

Source: Reference [63]

TABLE A.25
VEHICLE REGISTRATIONS 1982-1986

	1982	1983	1984	1985	1986
Montgomery County	37,519	38,437	40,421	42,555	45,092
Roanoke County	63,135	63,279	63,379	64,823	66,645
Roanoke City	69,993	70,779	74,795	77,760	80,009

Source: Reference [54]

TABLE A.26
LICENSED DRIVERS 1982-1986

	1986	1985	1984	1983	1982
Montgomery County	39,586	38,022	37,197	36,804	36,263
Roanoke County	57,090	56,008	55,510	54,891	54,540
Roanoke City	65,566	64,511	64,925	65,156	64,650

Source: Reference [54]

TABLE A.27
TRAFFIC CRASHES, FATALITIES, AND INJURIES 1985

	Crashes	Fatalities	Injuries	Alcohol-Related Crashes
Montgomery County	1453	12	853	251
Roanoke County	1447	12	809	225
Roanoke City	3094	22	1189	417

Source: Reference [56]

TABLE A.28
HIGHWAY MILEAGE IN 1985

	Total	Inter- state	Pri- mary	Secon- dary	Front- age	URBAN SYSTEM	
						Arterial	Collector
Montgomery County	664.27	25.61	65.92	418.49	4.71	21.41	128.13
Roanoke County	622.29	17.68	67.12	493.53	7.00	3.65	33.31
Roanoke City	451.97	5.51				66.35	380.11

Source: Reference [54]

TABLE A.29
VEHICLES PER DAYE AT THE INTERSECTION
OF U.S. 460 AND ROUTE 114

<u>Year</u>	<u>U.S. 460</u>
1968	13,815
1970	17,698
1972	19,600
1974	21,178
1976	25,398
1978	28,888
1980	26,075
1984	27,455
1986	36,523

Source: Reference [61]

TABLE A.30
AVERAGE DAILY TRAFFIC
U.S. ROUTE 460 FROM RT. 114 TO BUS 460 SOUTH OF BLACKSBURG

<u>Year</u>	<u>Total Vehicles</u>
1976	25,565
1977	27,115
1978	29,580
1979	26,310
1980	25,505
1981	25,890
1982	25,660
1983	24,365
1984	27,630
1985	35,975

Source: Reference [61]

TABLE A.31
AVERAGE DAILY TRAFFIC ON ROUTE 460 IN 1982

Route No.	From	To	Vehicles
460 & 221	Rt. 220 Alt Bonsack	Necl Roanoke	15,305
460 & 11	WCL Salem	Rt. 647 West of Salem	7,280
460 & 11	Rt. 647 W of Salem	Rt. 81 E of Christiansburg	5,245
460 & 11	Rt. 81 E of Christiansburg	Business 460	17,860
460 By-pass	Business 460	Rt. 460 N of Christiansburg	9,250
460 By-Pass	Rt. 460 N of Christiansburg	Rt. 114	25,335
460 By-Pass	Rt. 114	Bus 460 S of Blacksburg	25,660
460 By-pass	Bus 460 S of Blacksburg	Prices Fork Road	13,145
460 By-pass	Prices Fork Road	Bus 460 N of Blacksburg	7,085
460 By-pass	Bus 460 N of Blacksburg	Rt. 42 Newport	6,480

Source: Reference [61]

TABLE A.32
AVERAGE DAILY TRAFFIC IN ROUTE 460 IN 1983

Route No.	From	To	Vehicles
460 & 11	Rt. 81 E of Christiansburg	Business 460	18,915
460 By-Pass	Business 460	Rt 460 N of Christiansburg	9,655
460 By-Pass	Rt. 460 N of Christiansburg	Rt. 114	24,580
460 By-Pass	Rt. 114	Bus. 460 South of Blacksburg	24,365
460 By-Pass	Bus. 460 South of Blacksburg	Price Fork RCAC	13,275
460 By-Pass	Price Fork Road	Bus. 460 North of Blacksburg	6,155

Source: Reference [61]

TABLE A.33
AVERAGE DAILY TRAFFIC IN ROUTE 460 IN 1984

Route No.	From	To	Vehicles
460 & 221	Rt. 220 Alt. Bonsack	NECL Roanoke	16,560
460 & 11	WCL Salem	Rt. 647 West of Salem	6,935
460 & 11	Rt. 647 West of Salem	Rt. 81 E of Christiansburg	6,130
460 & 11	Rt. 81 E of Christiansburg	Business 460	20,600
460 By-Pass	Business 460	Rt. 460 of Christiansburg	10,760
460 By-Pass	Rt. 460 N of Christiansburg	Rt. 114	27,280
460 By-Pass	Rt. 114	Bus. 460 South of Blacksburg	27,630
460 By-Pass	Bus. 460 South of Blacksburg	Price Fork Road	14,575
460 By-Pass	Price Fork Road	Bus. 460 North of Blacksburg	7,115

Source: Reference [61]

TABLE A.34
SUMMARY FORM FOR VEHICULAR VOLUME
7-Day Average

COUNTY
Montgomery LOCATION
Eastbound Lane

Between
U.S. 460 Bus. And
Rt. 114

TIME	MON.	TUE.	WED.	THU.	FRI.	SAT.	SUN.	7-DAY AVG.
	Date 2-2-87	2-3-87	2-4-87	2-5-87	2-6-87	2-7-87	2-8-87	
AM 7-8	836	823	896	892	909	369	186	702
8-9	748	798	800	781	858	521	226	676
9-10	684	748	747	751	825	840	534	733
10-11	743	806	802	819	969	932	567	806
11-12	787	870	876	890	1091	1139	663	903
PM 12-1	932	934	898	980	1122	1111	937	988
1-2	940	894	981	1004	1190	1057	1029	1014
2-3	1047	959	1119	1033	1376	1052	1049	1091
3-4	1321	1386	1317	1426	1667	1474	974	1366
4-5	1563	1567	1595	1694	1901	1170	1072	1509
5-6	1570	1594	1636	1693	1898	1031	817	1463
6-7	801	881	911	928	1175	925	688	902
7-8	572	613	645	632	807	698	455	632
8-9	415	488	525	613	662	549	366	517
9-10	377	423	440	1089	503	429	306	510
10-11	265	281	330	378	345	326	247	311
11-12	227	326	384	333	431	293	162	316

(Continued...)

TABLE __ (Continued)
 SUMMARY FORM FOR VEHICULAR VOLUME
 7-Day Average

COUNTY
Montgomery LOCATION
Eastbound Lane

Between
U.S. 460 Bus. And
Rt. 114

TIME	MON.	TUE.	WED.	THU.	FRI.	SAT.	SUN.	7-DAY AVG.
	Date 2-2-87	2-3-87	2-4-87	2-5-87	2-6-87	2-7-87	2-8-87	
AM 12-1	108	147	131	184	199	235	210	174
1-2	88	84	-92	131	95	214	180	163
2-3	45	92	82	71	61	95	91	78
3-4	47	72	66	81	71	68	58	66
4-5	42	45	45	55	54	55	47	49
5-6	143	141	184	161	141	113	53	134
6-7	326	337	362	352	385	163	93	235
TOTAL	14,677	15,306	15,864	16,366	18,749	14,863	11,010	15,392
7-DAY FACTOR	1.05	1.01	0.97	0.94	0.32	1.04	1.40	

Source: Reference [61]

TABLE A.35
SUMMARY FORM FOR VEHICULAR VOLUME
7-Day Average

COUNTY
Montgomery LOCATION
Westbound Lane

Between
U.S. 460 Bus. And
Rt. 114

TIME	MON.	TUE.	WED.	THU.	FRI.	SAT.	SUN.	7-DAY AVG.
	Date 2-2-87	2-3-87	2-4-87	2-5-87	2-6-87	2-7-87	2-8-87	
AM 7-8	1425	1418	1528	1454	1404	319	149	1100
8-9	1117	1144	1214	1168	1186	536	264	947
9-10	797	924	864	863	864	702	463	782
10-11	763	873	842	860	883	846	484	793
11-12	809	875	869	883	962	1753	554	872
PM 12-1	859	962	886	976	969	1407	839	985
1-2	918	922	886	888	982	1040	905	934
2-3	972	990	930	1057	1085	1044	949	1004
3-4	1003	1004	1020	883	1194	1064	939	1015
4-5	1144	1079	1106	1318	1441	1102	968	1165
5-6	1049	1036	1111	1241	1264	1000	932	1090
6-7	762	867	829	1396	1095	931	814	956
7-8	583	596	669	742	908	800	724	717
8-9	409	443	497	432	762	666	606	545
9-10	432	458	506	463	709	588	470	518
10-11	347	421	399	385	564	457	387	423
11-12	174	240	228	218	402	343	227	262

(Continued....)

TABLE __ (Continued)

SUMMARY FORM FOR VEHICULAR VOLUME
7-Day Average

COUNTY
Montgomery LOCATION
Westbound Lane

Between
U.S. 460 Bus. And
Rt. 114

TIME	MON.	TUE.	WED.	THU.	FRI.	SAT.	SUN.	7-DAY AVG.
	Date 2-2-87	2-3-87	2-4-87	2-5-87	2-6-87	2-7-87	2-8-87	
AM 12-1	124	122	106	144	187	329	241	179
1-2	65	85	84	83	101	165	165	107
2-3	45	81	82	90	108	113	121	91
3-4	43	77	79	99	63	98	54	73
4-5	72	77	93	89	105	95	52	83
5-6	172	197	190	196	217	104	56	162
6-7	599	660	681	610	626	223	78	497
TOTAL	14,683	15,551	15,699	16,538	18,081	15,125	11,441	15,300
7-DAY FACTOR	1.04	0.98	0.97	0.93	0.85	1.01	1.34	

Source: Reference [61]

TABLE A.36
SUMMARY FORM FOR VEHICULAR VOLUME
7-Day Average

COUNTY
Montgomery LOCATION
Eastbound Lane

Between
U.S. 460 Bus. And
Rt. 114

TIME	MON.	TUE.	WED.	THU.	FRI.	SAT.	SUN.	7-DAY AVG.
	Date 2-9-87	2-10-87	2-11-87	2-12-87	2-13-87	2-14-87	2-15-87	
AM 7-8	654	968	913	930	938	307	127	691
8-9	710	758	792	797	780	521	203	652
9-10	627	747	737	805	893	801	465	725
10-11	681	719	823	836	1001	1009	516	798
11-12	764	881	858	985	1030	1092	572	884
PM 12-1	905	954	915	967	1260	1144	905	1008
1-2	912	913	910	983	1294	1125	894	1004
2-3	1027	967	1068	1084	1373	1057	995	1082
3-4	1246	1359	1291	1385	1732	1063	964	1291
4-5	1449	1549	1630	1721	2020	1010	975	1479
5-6	1606	1602	1628	1762	1855	929	944	1475
6-7	887	946	974	952	1213	906	801	954
7-8	510	639	637	681	858	796	577	671
8-9	414	480	496	568	710	645	492	544
9-10	360	469	475	544	586	419	386	463
10-11	263	346	304	388	416	315	275	330
11-12	274	319	295	301	502	298	202	313

(Continued...)

TABLE __ (Continued)

SUMMARY FORM FOR VEHICULAR VOLUME
7-Day Average

COUNTY
Montgomery LOCATION
Eastbound Lane

Between
U.S. 460 Bus. And
Rt. 114

TIME	MON.	TUE.	WED.	THU.	FRI.	SAT.	SUN.	7-DAY AVG.
	Date 2-9-87	2-10-87	2-11-87	2-12-87	2-13-87	2-14-87	2-15-87	
AM 12-1	131	145	166	155	137	273	209	174
1-2	89	88	94	110	100	142	189	116
2-3	55	61	70	96	92	131	83	84
3-4	73	40	67	79	85	74	46	66
4-5	38	56	67	45	67	76	36	55
5-6	125	158	184	161	173	93	41	134
6-7	351	389	377	373	677	169	85	303
TOTAL	14,151	15,553	15,771	16,708	19,492	14,395	10,982	15,296
7-DAY FACTOR	1.08	0.98	0.97	0.92	0.79	1.06	1.40	

Source: Reference [61]

TABLE A.37
 SUMMARY FORM FOR VEHICULAR VOLUME
 7-Day Average

COUNTY
Montgomery LOCATION
Westbound Lane
 Between
U.S. 460 Bus. And
Rt. 114

TIME	MON.	TUE.	WED.	THU.	FRI.	SAT.	SUN.	7-DAY AVG.
	Date 2-9-87	2-10-87	2-11-87	2-12-87	2-13-87	2-14-87	2-15-87	
AM								
7-8	1053	1569	1513	1602	1488	314	133	1096
8-9	889	1065	1129	1101	1126	568	246	875
9-10	635	877	890	877	902	715	468	766
10-11	740	830	809	937	856	889	481	792
11-12	784	904	915	893	1000	1069	590	880
PM								
12-1	832	916	868	891	1008	1092	838	921
2-3	990	971	732	978	1188	1033	912	1001
3-4	951	1056	989	1083	1277	1022	881	1037
4-5	1064	1102	1178	1233	1383	1038	1070	1153
5-6	896	1020	1055	1161	1244	1075	1020	1067
6-7	720	814	844	953	1118	972	893	902
7-8	509	601	574	680	969	844	724	700
8-9	386	440	454	449	823	614	696	552
9-10	395	431	509	500	712	558	531	520
10-11	322	396	357	359	554	413	415	402
11-12	187	206	164	203	480	399	254	270

(Continued....)

TABLE __ (Continued)

SUMMARY FORM FOR VEHICULAR VOLUME
7-Day Average

COUNTY
Montgomery LOCATION
Westbound Lane

Between
U.S. 460 Bus. And
Rt. 114

TIME	MON.	TUE.	WED.	THU.	FRI.	SAT.	SUN.	7-DAY AVG.
	Date 2-9-87	2-10-87	2-11-87	2-12-87	2-13-87	2-14-87	2-15-87	
AM 12-1	121	103	145	149	190	335	297	192
1-2	80	85	76	75	104	228	143	113
2-3	51	71	73	83	86	172	129	95
3-4	71	64	76	78	71	76	56	70
4-5	122	124	105	108	100	64	46	96
5-6	161	204	224	232	240	122	46	176
6-7	667	761	788	786	813	196	85	585
TOTAL	13,515	15,542	15,581	16,373	18,756	14,836	11,793	15,202
7-DAY FACTOR	1.12	0.98	0.98	0.93	0.81	1.02	1.29	

Source: Reference [61]

TABLE A.38
 TRAFFIC CLASSIFICATION COUNTS
 EASTBOUND

Route Number 460 Date March 3, 1987 Day Tuesday

TIME PERIOD	PASSENGER CARS	COMMERCIAL VEHICLES							Total Vehicles	
		Pick-Up or Panel	TRUCKS		3-Axle Unit	Combi-nations	BUSES			Taxi
			Other 2-Axle	Dual Rear Tire			Regular C.C.	Other		
	V/R-GINIA	Other State	Single Rear Tire	Dual Rear Tire						
AM 12-1	62	11	4	-	-	25	-	-	-	136
1-2	33	5	2	-	-	12	-	-	-	58
2-3	20	8	4	-	-	19	-	-	-	57
3-4	12	2	2	-	-	11	-	-	-	31
4-5	13	1	1	-	-	10	-	-	-	33
5-6	58	6	2	-	-	10	-	-	-	90
6-7	195	23	8	-	-	13	-	-	-	314
7-8	723	49	22	-	-	13	-	1	-	935
8-9	566	53	39	-	-	12	-	3	-	747
9-10	562	57	44	-	-	29	1	1	-	773
10-11	538	66	36	-	-	32	1	-	-	759
11-12	574	82	29	-	-	25	-	-	-	777

(Continued...)

TABLE __ (Continued)
 TRAFFIC CLASSIFICATION COUNTS
 EASTBOUND

Route Number 460 Date March 3, 1987 Day Tuesday

TIME PERIOD	PASSENGER CARS		COMMERCIAL VEHICLES						Total Vehicles
	VIR-GINIA	Other State	Pick-Up or Panel	TRUCKS		BUSES		Taxi	
				Other 2-Axle	3-Axle Unit	Combinations	Regular C.C.		Other
			Single Rear Tire	Dual Rear Tire					
PM 12-1	728	69	161	37	-	42	-	-	1037
1-2	516	51	175	35	-	29	-	1	807
2-3	647	45	171	37	-	30	-	3	933
3-4	857	55	229	44	-	25	-	4	1214
4-5	1146	84	233	13	-	22	-	1	1499
5-6	1223	83	169	15	-	29	1	-	1520
6-7	685	38	93	5	-	19	1	1	842
7-8	458	27	86	3	-	9	-	-	583
8-9	380	37	87	4	-	14	-	-	522
9-10	256	35	54	2	-	14	-	-	361
10-11	151	37	38	3	-	28	-	-	247
11-12	200	18	61	2	-	16	-	-	297
TOTAL	10,608	932	2,132	393	-	488	4	15	14,572

TABLE A.39
TRAFFIC CLASSIFICATION COUNTS
WESTBOUND

Route Number 460 Date March 3, 1987 Day Tuesday

TIME PERIOD	PASSENGER CARS			COMMERCIAL VEHICLES							Total Vehicles	
	VIRGINIA	Other State	Pick-Up or Panel	TRUCKS		BUSES			Taxi			
				Other 2-Axle	3-Axle Unit	Combinations	Regular C.C.	Other				
				Single Rear Tire	Dual Rear Tire							
AM 12-1	50	11	27	2	-	-	16	-	-	-	1	107
1-2	31	5	6	2	-	-	11	-	-	-	-	55
2-3	22	2	6	3	-	-	14	-	-	-	-	47
3-4	18	3	6	4	-	-	21	-	-	-	-	52
4-5	25	2	15	2	-	-	16	-	-	-	-	60
5-6	92	3	22	6	-	-	30	1	-	-	-	154
6-7	422	11	162	17	-	-	27	-	1	-	-	641
7-8	1171	32	190	42	-	-	25	-	4	-	-	1464
8-9	845	29	55	101	-	-	31	-	3	-	-	1107
9-10	715	30	76	45	-	-	31	1	1	-	-	899
10-11	624	23	118	46	-	-	40	-	3	-	-	854
11-12	597	37	129	32	-	-	28	4	2	-	-	829

(Continued....)

TABLE __ (Continued)
 TRAFFIC CLASSIFICATION COUNTS
 WESTBOUND

Route Number 460 Date March 3, 1987 Day Tuesday

TIME PERIOD	VIRGINIA	Other State	COMMERCIAL VEHICLES							Total Vehicles
			PASSENGER CARS		TRUCKS			BUSES		
			Pick-Up or Panel	Other 2-Axle	3-Axle Unit	Combinations	Regular C.C.	Other	Taxi	
PM 12-1	623	58	117	39	-	20	1	2	-	860
1-2	614	58	110	47	-	39	3	2	-	873
2-3	661	62	123	28	-	22	-	2	-	898
3-4	722	66	224	29	-	23	-	4	-	1068
4-5	771	83	271	13	-	27	-	2	-	1167
5-6	802	62	248	10	-	32	-	3	-	1158
6-7	569	37	175	10	-	37	-	1	-	829
7-8	439	25	82	6	-	18	-	1	-	571
8-9	359	28	32	7	-	22	-	-	-	498
9-10	357	24	75	3	-	19	-	-	-	478
10-11	310	23	81	3	-	22	-	-	-	439
11-12	138	22	42	3	-	23	-	-	-	223
TOTAL	10,978	736	2,485	500	-	595	10	31	1	15,336

Source: Reference [61]

TABLE A.40
TRAFFIC VOLUME AT THE INTERSECTION
OF U.S. 460 AND ROUTE 114

Day: March 25 (Friday), 1988

Time	U.S. 460 Northbound		U.S. 460 Southbound		Route 114 Eastbound		Total
	Straight	Left	Straight	Right	Left	Right	
4:00-4:15	347	88	379	80	75	115	1084
4:15-4:30	313	102	416	65	80	139	1115
4:30-4:45	280	97	426	64	82	177	1126
4:45-5:00	267	91	408	71	79	158	1074
5:00-5:15	300	120	423	77	90	124	1134
5:15-5:30	283	100	368	57	92	85	985
5:30-5:45	310	103	411	57	88	93	1062
5:45-6:00	261	89	325	45	80	103	903
Peak Hour 4:15-5:15	1160	410	1673	277	331	598	4449

PHF = $4449 / (4 \times 1134) = 0.9808$

Source: Reference [61]

A BIAM.K(A) = 1-FBIOI.K(A)
NOTE BIAM-BASIC INDUSTRY ATTRACT MULT (DIM)
A BIP.K(A) = BIO.K(A)*(1-FBIOI.K(A))
NOTE BIP-BASIC INDUSTRY PRODUCT (\$/YR)
A BIO.K(A) = BI.K(A)/BICOR(A)
NOTE BIO-BASIC INDUSTRY OUTPUT (\$/YR)
T BICOR(*) = 1.8/1.8/1.8
NOTE BICOR-BASIC INDUSTRY CAP-OUTPUT RATIO (YR)
A FBIOI.K(A) = (FBOT.K(A) + FBIOE(A) + FBIOW(A) + FBIOM(A))
NOTE FBIOI-FRACT.BASIC INDUSTRY OUTPUT TO INPUT (DIM)
A FBOT.K(1) = FBOTN(1)*EXP(-(1.0-T31E/TN31))
A FBOT.K(2) = FBOTN(2)*EXP(-(1.0-T12E/TN12))
A FBOT.K(3) = FBOTN(3)*EXP(-(1.0-T13E/TN13))
NOTE FBOT-FRACT.BASIC INDUSTRY OUTPUT TO TRANS (DIM)
T FBOTN(*) = 0.2/0.2/0.2
NOTE FBOTN-FRACT.BASIC INDUSTRY OUTPUT TO TRANS NORMAL (DIM)
T FBIOE(*) = 0.08/0.08/0.08
NOTE FBIOE-FRACT.BASIC INDUSTRY OUTPUT TO ELECT (DIM)
T FBIOW(*) = 0.02/0.02/0.02
NOTE FBIOW-FRACT.BASIC INDUSTRY OUTPUT TO WATER (DIM)
T FBIOM(*) = 0.2/0.2/0.2
NOTE FBIOM-FRACT.BASIC INDUSTRY OUTPUT TO MATLS (DIM)
A BIJ.K(A) = BI.K(A)/BICLR(A)
NOTE BIJ-BASIC INDUSTRY JOB (PERSON)
T BICLR(*) = 110000/110000/110000
NOTE BICLR-BASIC INDUSTRY CAP-LABORFORCE (\$/PERSON)
R BII.KL(A) = BIP.K(A)*(1-FBIPI(A))
NOTE BII-BASIC INDUSTRY INVESTMENT (\$/YR)
N FBIPI(A) = FBIPL(A) + FBIPTX(A)
NOTE FBIPI-FRACT.BASIC INDUSTRY PRODUCT INVEST (DIM)
T FBIPTX(*) = 0.2/0.2/0.2
NOTE FBSPTX-FRACT.BASIC INDUSTRY PRODUCT TO TAXES (DIM)
N FBIPL(A) = FBIPTS(A) + FBIPW(A)
NOTE FBIPL-FRACT.BASIC INDUSTRY PRODUCT TO LABOR (DIM)
T FBIPTS(*) = 0.1/0.1/0.1
NOTE FBIPTS-FRACT.BASIC INDUSTRY PRODUCT TO TRANS SUBSIDY (DIM)
T FBIPW(*) = 0.4/0.4/0.5
NOTE FBIPW-FRACT.BASIC INDUSTRY PRODUCT TO WAGES (DIM)
NOTE,
NOTE
NOTE
NOTE
NOTE BUSINESS SERVICES
NOTE,
NOTE,
NOTE
NOTE
NOTE
L BS.K(A) = BS.J(A) + (DT)(NBSAR.JK(A) + BSI.JK(A)-BSD.JK(A))
NOTE BS-BUSINESS SERVICES (\$)
N BS(A) = BSN(A)
T BSN(*) = 1.53E8/0.72E8/1.068E9
NOTE BSN-BUSINESS SERVICESINITIAL (\$)
R BSD.KL(A) = BS.K(A)/LBS(A)
NOTE BSD-BUSINESS SERVICES DEPRECIATION (\$/YR)
T LBS(*) = 50/50/50

NOTE

NOTE

A F.K = ASST.K + ASSOC.K + FULL.K

NOTE F-FACULTY (PERSONS)

L ASST.K = ASST.J + (DT)(ATHR.JK-ATDR.JK-ATAPR.JK)

N ASST = ASSTN

C ASSTN = 379

NOTE ASST-ASST PROFESSORS (PERSONS)

L ASSOC.K = ASSOC.J + (DT)(ACHR.JK-ACDR.JK-ATFPR.JK + ATAPR.JK)

N ASSOC = ASSOEN

C ASSOEN = 550

NOTE ASSOC-ASSOC PROFESSORS (PERSONS)

L FULL.K = FULL.J + (DT)(FHR.JK-FPDR.JK + ATFPR.JK)

N FULL = FULLN

C FULLN = 568

NOTE FULL-FULL PROFESSORS (PERSONS)

A FH.K = SMOOTH((FP.K-F.K)/HD,HD)

NOTE FH-FACULTY HIRING (PERSONS/YR)

C HD = 2

NOTE HD-HIRING DELAY (YRS)

R ATHR.KL = FH.K*ATHF

NOTE ATHR-ASST PROF HIRING RATE (PERSONS/YR)

C ATHF = .5

NOTE ATHF-ASST PROF HIRING FRACTION (DIM)

R ACHR.KL = FH.K*ACHF

NOTE ACHR-ASSOC PROF HIRING RATE (PERSONS/YR)

C ACHF = .33

NOTE ACHF-ASSOC PROF HIRING FRACTION (DIM)

R FHR.KL = FH.K*FHF

NOTE FHR-FULL PROF HIRING RATE (PERSONS/YR)

C FHF = 0.17

NOTE FHF-FULL PROF HIRING FRACTION (DIM)

R ATAPR.KL = ASST.K*ATAPF

NOTE ATAPR-ASST TO ASSOC PROMOTION RATE (PERSONS/YR)

C ATAPF = .1

NOTE ATAPF-ASST TO ASSOC PROMOTION FACTOR (FRACT/YR)

R ATFPR.KL = ASSOC.K*ATFPF

NOTE ATFPR-ASSOC TO FULL PROMOTION RATE (PERSONS/YR)

C ATFPF = .1

NOTE ATFPF-ASSOC TO FULL PROMOTION FACTOR (FRACT/YR)

A FP.K = FOBF*OB.K/TS.K

NOTE FP-FACULTY POSITIONS (PERSONS)

C FOBF = .6

NOTE FOBF-FRACT OPER BUDGET TO FACULTY (DIM)

A TS.K = TSN + RAMP(TSI,1990)

NOTE TS-TEACHING SALARIES (\$/PERSON-YR)

C TSN = 40000

NOTE TSN-TEACHING SALARIES NORMAL (\$/PERSON-YR)

C TSI = 2000

NOTE TSI-TEACHING SALARIES INCREASE (\$/PERSON-YR)

A OB.K = ROB.K + SSPS.K*CLIP(S.K,SSS,TIME.K,SSPCT)

NOTE OB-OPERATING BUDGET (\$/YR)

A SSPS.K = (SSPSN + RAMP(SSPSI,1990))*SSPSM.K

NOTE SSPS-STATE SUPPORT PER STUDENT (\$/PERSON-YR)

C SSPSN = 2500

NOTE SSPSN-STATE SUPPORT PER STUDENT NORMAL (\$/PERSON-YR)

A SSPSM.K = TABHL(SSPSMT,SSS/S.K,0,2,.2)
 T SSPSMT = 1/1/1/1/1/1/1/1/1/1/1
 C SSS = 5200
 C SSPSI = 150
 NOTE SSPSI-STATE SUPPORT PER STUDENT INCREASE (\$/PERSON-YR)
 C SSPCT = 1990
 NOTE SSPCT-STATE SUPPORT POLICY CHANGE TIME (YRS)
 A S.K = FRES.K + SOPH.K + JUN.K + SEN.K
 NOTE S-STUDENTS (PERSONS)
 L FRES.K = FRES.J + (DT)(SA.JK-FTSP.JK)
 N FRES = FRESN
 C FRESN = 5673
 NOTE FRES-FRESHMEN (PERSONS)
 L SOPH.K = SOPH.J + (DT)(FTSP.JK-STJP.JK)
 N SOPH = SOPHN
 C SOPHN = 4524
 NOTE SOPH-SOPHOMORES (PERSONS)
 L JUN.K = JUN.J + (DT)(STJP.JK-JTSP.JK)
 N JUN = JUNN
 C JUNN = 4572
 NOTE JUN-JUNIORS (PERSONS)
 L SEN.K = SEN.J + (DT)(JTSP.JK-SG.JK)
 N SEN = SENN
 C SENN = 3657
 NOTE SEN-SENIORS (PERSONS)
 R SA.KL = CLIP((SP.K-S.K)/ACD,S.K*SAN,TIME.K,APCT)
 NOTE SA-STUDENT ADMISSIONS (PERSONS/YR)
 C ACD = 2
 NOTE ACD-ADMISSION CHANGE DELAY (YRS)
 C SAN = .235
 NOTE SAN-STUDENT ADMISSIONS NORMAL (FRACT/YR)
 C APCT = 1990
 NOTE APCT-ADMISSION POLICY CHANGE TIME (YRS)
 R FTSP.KL = FRES.K*FFP
 NOTE FTSP-FRES TO SOPH PASSING (PERSONS/YR)
 C FFP = .8
 NOTE FFP-FRACT FRES PASSING (1/YR)
 R STJP.KL = SOPH.K*FSP
 NOTE STJP-SOPH TO JUNIOR PASSING (PERSONS/YR)
 C FSP = .85
 NOTE FSP-FRACT SOPH PASSING (1/YR)
 R JTSP.KL = JUN.K*FJP
 NOTE JTSP-JUNIOR TO SENIOR PASSING (PERSONS/YR)
 C FJP = .9
 NOTE FJP-FRACT JUNIORS PASSING (1/YR)
 A SP.K = CLS.K/SPS
 NOTE SP-STUDENT POSITIONS (PERSONS)
 C SPS = 170
 NOTE SPS-SPACE PER STUDENT (SQ FT/PERSON)
 A CLS.K = TOT.K-OS.K
 NOTE CLS-CLASS LAB SPACE (SQ FT)
 A TOT.K = 6500000
 NOTE TOT-TOTAL SPACE (SQ FT)
 A OS.K = (F.K + RFP.K)*SPF + TGS.K*SPG + STFP.K*SPSF
 NOTE OS-OFFICE SPACE (SQ FT)
 C SPG = 250

NOTE SPG-SPACE PER GRAD STUDENT (SQ FT/PERSON)
 C SPF = 500
 NOTE SPF-SPACE PER FACULTY (SQ FT/PERSON)
 C SPSF = 300
 NOTE SPSF-SPACE PER STAFF (SQFT/PERSON)
 R ATDR.KL = ASST.K/EDATP
 NOTE ATDR-ASST PROF DEPARTURE RATE (PERSONS/YR)
 C EDATP = 6
 NOTE EDATP-EMPLOYMENT DURATION ASST PROF (YRS)
 R ACDR.KL = ASSOC.K/EDACP
 NOTE ACDR-ASSOC PROF DEPARTURE RATE (PERSONS/YR)
 C EDACP = 8
 NOTE EDACP-EMPLOYMENT DURATION ASSOC PROF (YRS)
 R FPDR.KL = FULL.K/EDFP
 NOTE FPDR-FULL PROF DEPARTURE RATE (PERSONS/YR)
 C EDFP = 10
 NOTE EDFP-EMPLOYMENT DURATION FULL PROF (YRS)
 R SG.KL = SEN.K*FSG
 NOTE SG-STUDENTS GRADUATING (PERSONS/YR)
 C FSG = .95
 NOTE FSG-FRACT SENIORS GRADUATING (1/YR)
 A ROB.K = RO.K*FROB
 NOTE ROB-RESEARCH OVERHD TO BUDGET (\$/YR)
 C FROB = .6
 NOTE FROB-FRACT RES OVERHD TO BUDGET (DIM)
 A RO.K = FR.K*FRO
 NOTE RO-RESEARCH OVERHEAD (\$/YR)
 C FRO = .5
 NOTE FRO-FRACT RESEARCH TO OVERHEAD (DIM)
 A FR.K = F.K*PPF*FPF.K*VPP.K*(TN31/T31E)
 NOTE FR-FUNDED RESEARCH (\$/YR)
 A FPF.K = 0.6
 NOTE FPF-FRACT PROPOSALS FUNDED (DIM)
 C PPF = 3
 NOTE PPF-PROPOSALS PER FACULTY (PROPOSALS/PERSON)
 A VPP.K = VPPN + RAMP(VPPI,1990)
 NOTE VPP-VALUE PER PROPOSAL (\$/PROPOSAL)
 C VPPN = 24000
 NOTE VPPN-VALUE PER PROPOSAL NORMAL (\$/PROPOSAL)
 C VPPI = 4000
 NOTE VPPI-VALUE PER PROPOSAL INCREASE (\$/PROPOSAL)
 A RFP.K = (FFRFS*FR.K)/TS.K
 NOTE RFP-RESEARCH FACULTY POSITIONS (PERSONS)
 C FFRFS = .15
 NOTE FFRFS-FRACT FUNDED RESEARCH FACULTY SALARIES (DIM)
 A GRA.K = (FFRSS*FR.K)/SS.K
 NOTE GRA-GRADUATE RESEARCH ASSISTANTS (PERSONS)
 C FFRSS = .25
 NOTE FFRSS-FRACT FUNDED RESEARCH STUDENT SALARIES (DIM)
 A SS.K = SSN + RAMP(SSI,1990)
 NOTE SS-STUDENT SALARIES (\$/PERSON-YR)
 C SSN = 12000
 NOTE SSN-STUDENT SALARIES NORMAL (\$/PERSON-YR)
 C SSI = 400
 NOTE SSI-STUDENT SALARIES INCREASE (\$/PERSON-YR)
 A UGS.K = RUGSTS*S.K

NOTE T31-TRAVEL TIME FROM AREA 3 TO AREA 1 (MIN)
A T21.K=(ALT1 + ALT2 + ALT3A + ALT12 + ALT5)*TERM4.K + TERM2.K + TERM3.K + TERM5.K
NOTE T21-TRAVEL TIME FROM AREA 2 TO AREA 1 (MIN)
NOTE
A TERM11.K=(FFT23*(1-((1-LSF23)
X *Q23.K)/(N23*C23)))/(1-Q23.K/(N23*C23))
A TERM22.K=(FFT12*(1-((1-LSF12)*Q12.K)/(N12*C12))
X /(1-Q12.K/(N12*C12))
A TERM33.K=(FFT13*(1-((1-LSF13)*Q13.K)/(N13*C13)))/(1-Q13.K/
X (N13*C13))
A T13.K=(ALT1 + ALT2 + ALT3A + ALT12 + ALT5)*(TERM11.K + TERM22.K) + TERM3.K + (ALT6
X + ALT7 + ALT10)*TERM33.K + TERM5.K + TERM6.K
NOTE T13-TRAVEL TIME FROM AREA 1 TO AREA 3 (MIN)
A T12.K=(ALT1 + ALT2 + ALT3A + ALT12 + ALT5)*TERM33.K + TERM22.K + TERM3.K + TERM5.K
NOTE T12-TRAVEL TIME FROM AREA 1 TO AREA 2 (MIN)
NOTE
C ALT1=1
C ALT2=0
C ALT3A=0
C ALT12=0
C ALT5=0
C ALT6=0
C ALT7=0
C ALT10=0
NOTE ALTX-ALTERNATIVE
N FFT32=60*X32/C1
NOTE FFT32-FREE FLOW TRAVEL TIME ON LINE 32 (MIN)
N FFT21=60*X21/C2
NOTE FFT21-FREE FLOW TRAVEL TIME ON LINE 21 (MIN)
N FFT31=60*X31/C2
NOTE FFT31-FREE FLOW TRAVEL TIME ON LINE 31 (MIN)
N FFT23=60*X23/C1
NOTE FFT23-FREE FLOW TRAVEL TIME ON LINE 23 (MIN)
N FFT12=60*X12/C2
NOTE FFT12-FREE FLOW TRAVEL TIME ON LINE 12 (MIN)
N FFT13=60*X13/C2
NOTE FFT13-FREE FLOW TRAVEL TIME ON LINE 13 (MIN)
C C1=80
C C2=60
NOTE C-FREE SPEED (MPH)
C LSF32=0.4
NOTE LSF32-LEVEL OF SERVICE FACTOR ON LINK 32 (DIM)
C LSF21=0.95
NOTE LSF21-LEVEL OF SERVICE FACTOR ON LINK 21 (DIM)
C LSF31=0.8
NOTE LSF31-LEVEL OF SERVICE FACTOR ON LINK 31 (DIM)
C LSF23=0.4
NOTE LSF23-LEVEL OF SERVICE FACTOR ON LINK 23 (DIM)
C LSF12=0.95
NOTE LSF12-LEVEL OF SERVICE FACTOR ON LINK 12 (DIM)
C LSF13=0.8
NOTE LSF13-LEVEL OF SERVICE FACTOR ON LINK 13 (DIM)
C N32=2
NOTE N32-NO. OF LANES PER DIRECTION ON LINK 32
C N21=2
NOTE N21-NO. OF LANES PER DIRECTION ON LINK 21

C N31 = 1E-50
 NOTE N31-NO. OF LANES PER DIRECTION ON LINK 31
 C N23 = 2
 NOTE N23-NO. OF LANES PER DIRECTION ON LINK 23
 C N12 = 2
 NOTE N12-NO. OF LANES PER DIRECTION ON LINK 12
 C N13 = 1E-50
 NOTE N13-NO. OF LANES PER DIRECTION ON LINK 13
 C C32 = 2400
 NOTE C32-LANE CAPACITY ON LINK 32 (VEH/HR)
 C C21 = 1800
 NOTE C21-LANE CAPACITY ON LINK 21 (VEH/HR)
 C C31 = 2000
 NOTE C31-LANE CAPACITY ON LINK 31 (VEH/HR)
 C C23 = 2400
 NOTE C23-LANE CAPACITY ON LINK 23 (VEH/HR)
 C C12 = 1800
 NOTE C12-LANE CAPACITY ON LINK 12 (VEH/HR)
 C C13 = 2000
 NOTE C13-LANE CAPACITY ON LINK 13 (VEH/HR)
 A Q32.K = (FDTPH/ACO)*V31.K + Q31T + (FDTPH/ACO)*V32.K + Q32T
 NOTE Q32-VOLUME ON LINK 32(VEH/HR)
 A Q21.K = (ALT1 + ALT2 + ALT3A + ALT5 + ALT12)*((FDTPH/ACO)*V31.K + Q31T)
 X + (FDTPH/ACO)*V21.K + Q21T
 NOTE Q21-VOLUME ON LINK 21(VEH/HR)
 A Q31.K = (FDTPH/ACO)*V31.K + Q31T
 NOTE Q31-VOLUME ON LINK 31(VEH/HR)
 A Q23.K = (FDTPH/ACO)*V13.K + Q13T + (FDTPH/ACO)*V23.K + Q23T
 NOTE Q23-VOLUME ON LINK 23(VEH/HR)
 A Q12.K = (ALT1 + ALT2 + ALT3A + ALT5 + ALT12)*((FDTPH/ACO)*V13.K + Q13T)
 X + (FDTPH/ACO)*V12.K + Q12T
 NOTE Q12-VOLUME ON LINK 12(VEH/HR)
 A Q13.K = (FDTPH/ACO)*V13.K + Q13T
 NOTE Q13-VOLUME ON LINK 13(VEH/HR)
 C Q32T = 2000
 NOTE Q32T-THRU TRAFFIC ON LINK 32 (VEH/HR)
 C Q21T = 200
 NOTE Q21T-THRU TRAFFIC ON LINK 21 (VEH/HR)
 C Q31T = 1E-50
 NOTE Q31T-THRU TRAFFIC ON LINK 31 (VEH/HR)
 C Q23T = 2000
 NOTE Q23T-THRU TRAFFIC ON LINK 23 (VEH/HR)
 C Q12T = 200
 NOTE Q12T-THRU TRAFFIC ON LINK 12 (VEH/HR)
 C Q13T = 1E-50
 NOTE Q13T-THRU TRAFFIC ON LINK 13 (VEH/HR)
 C FDTPH = 0.10
 NOTE FDTPH-FRACT DAILY TRAFFIC IN PEAR HOUR (DIM)
 C ACO = 2
 NOTE ACO-AVER. CAR OCCUPANCY (PERSONS/HR)
 A V21.K = P.K(2)*TGF21
 NOTE V21-DEMAND FROM AREA 2 TO AREA 1 (PERSONS/DAY)
 A V31.K = P.K(3)*TGF31
 NOTE V31-DEMAND FROM AREA 3 TO AREA 1 (PERSONS/DAY)
 A V32.K = P.K(3)*TGF32
 NOTE V32-DEMAND FROM AREA 3 TO AREA 2 (PERSONS/DAY)

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A V12.K = P.K(1)*TGF12
NOTE V12-DEMAND FROM AREA 1 TO AREA 2 (PERSONS/DAY)
A V13.K = P.K(1)*TGF13
NOTE V13-DEMAND FROM AREA 1 TO AREA 3 (PERSONS/DAY)
A V23.K = P.K(2)*TGF23
NOTE V23-DEMAND FROM AREA 2 TO AREA 3 (PERSONS/DAY)
C TGF31 = 0.08
C TGF32 = 0.025
C TGF21 = 2
C TGF13 = 0.45
C TGF23 = 0.3
C TGF12 = 0.9
NOTE TGF-TRIP GENERATION FACTOR (DIM)
C T1 = 0
C T2 = 0
C T3 = 0
NOTE TK-COLLECTION,DISTRIBUTION,TRANSFER TIME AT NODE K (MIN)
C X32 = 25.5
NOTE X32-DIST BETWEEN NODES 3 AND 2 (MILES)
C X21 = 3.2
NOTE X21-DIST BETWEEN NODES 2 AND 1 (MILES)
C X31 = 32
NOTE X31-DIST BETWEEN NODES 3 AND 1 (MILES)
C X23 = 25.5
NOTE X23-DIST BETWEEN NODES 2 AND 3 (MILES)
C X12 = 3.2
NOTE X12-DIST BETWEEN NODES 1 AND 2 (MILES)
C X13 = 32
NOTE X13-DIST BETWEEN NODES 1 AND 3 (MILES)
A P1.K = P.K(1)
A P2.K = P.K(2)
A P3.K = P.K(3)
A PCI1.K = PCI.K(1)
A PCI2.K = PCI.K(2)
A PCI3.K = PCI.K(3)
NOTE .....
SPEC DT = .5/LENGTH = 2015/PLTPER = 1/PRTPER = 1
PRINT 2)P1,PCI1,FR,T21/4)P2,PCI2,TGS,T31/6)P3,PCI3,*,*
PLOT P(1) = B,P(2) = C,P(3) = R
PLOT PCI(1),PCI(2),PCI(3)
PLOT FR = $
PLOT TGS = G
PLOT T21 = T
PLOT T31 = T
RUN ALT1 DO NOTHING
C ALT1 = 0
C ALT2 = 1
C ALT3A = 0
C ALT12 = 0
C ALT5 = 0
C ALT6 = 0
C ALT7 = 0
C ALT10 = 0
C T31E = 35.92
C T13E = 35.92
C T12E = 10.99

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C N21=4
C N12=4
C LSF21=0.85
C LSF12=0.85
C TGF21=2.01
C TGF13=0.46
C TGF12=0.9
RUN ALT2
C ALT1=0
C ALT2=0
C ALT3A=1
C ALT12=0
C ALT5=0
C ALT6=0
C ALT7=0
C ALT10=0
C T31E=34.83
C T13E=34.83
C T12E=9.86
C X21=3.0
C X31=31.8
C X12=3.0
C X13=31.8
C N21=5
C N12=5
C LSF21=0.45
C LSF12=0.45
C TGF21=2.015
C TGF13=0.465
C TGF12=0.915
RUN ALT3A
C ALT1=0
C ALT2=0
C ALT3A=0
C ALT12=0
C ALT5=1
C ALT6=0
C ALT7=0
C ALT10=0
C T31E=34.68
C T13E=34.68
C T12E=9.76
C X21=3.0
C X31=31.8
C X12=3.0
C X13=31.8
C N21=6
C N12=6
C LSF21=0.4
C LSF12=0.4
C TGF21=2.015
C TGF13=0.465
C TGF12=0.915
RUN ALT5
C ALT1=0
C ALT2=0

C ALT3A=0
C ALT12=1
C ALT5=0
C ALT6=0
C ALT7=0
C ALT10=0
C T31E=35.49
C T13E=35.49
C T12E=10.6
C X21=3.4
C X31=32.2
C X12=3.4
C X13=32.2
C N21=5
C N12=5
C LSF21=0.6
C LSF12=0.6
C TGF21=2.015
C TGF13=0.465
C TGF12=0.915
RUN ALT12
C ALT1=0
C ALT2=0
C ALT3A=0
C ALT12=0
C ALT5=0
C ALT6=1
C ALT7=0
C ALT10=0
C T31E=29.88
C T13E=29.88
C T12E=3.601
C X31=27
C X13=27
C N21=4
C N12=4
C N31=2
C N13=2
C LSF21=0.4
C LSF12=0.4
C LSF31=0.4
C LSF13=0.4
C Q31T=100
C Q13T=200
C TGF31=0.082
C TGF21=2.015
C TGF13=0.487
C TGF12=0.925
RUN ALT6
C ALT1=0
C ALT2=0
C ALT3A=0
C ALT12=0
C ALT5=0
C ALT6=0
C ALT7=1

C ALT10=0
C T31E=27.27
C T13E=27.27
C T12E=3.592
C X31=25.8
C X13=25.8
C N21=4
C N12=4
C N31=2
C N13=2
C LSF21=0.35
C LSF12=0.35
C LSF31=0.2
C LSF13=0.2
C Q31T=120
C Q13T=200
C TGF31=0.0845
C TGF21=2.057
C TGF13=0.497
C TGF12=0.935
RUN ALT7
C ALT1=0
C ALT2=0
C ALT3A=0
C ALT12=0
C ALT5=0
C ALT6=0
C ALT7=0
C ALT10=1
C T31E=26.67
C T13E=26.67
C T12E=3.450
C X31=25.9
C X13=25.9
C N21=4
C N12=4
C N31=2
C N13=2
C LSF21=0.25
C LSF12=0.25
C LSF31=0.1
C LSF13=0.1
C Q31T=150
C Q13T=200
C TGF31=0.0846
C TGF21=2.015
C TGF13=0.497
C TGF12=0.935
RUN ALT10
QUIT

Appendix C Computational Output

C1 Alternative 1 (do nothing)

C1.1 Population of Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	P1/ 33.32T	P2/ 15.05T	P3/ 181.1T

TIME/ 1991.	P1/ 34.62T	P2/ 15.62T	P3/ 183.8T

TIME/ 1992.	P1/ 35.83T	P2/ 16.19T	P3/ 186.5T

TIME/ 1993.	P1/ 36.93T	P2/ 16.76T	P3/ 189.2T

TIME/ 1994.	P1/ 37.92T	P2/ 17.34T	P3/ 191.9T

TIME/ 1995.	P1/ 38.82T	P2/ 17.91T	P3/ 194.5T

TIME/ 1996.	P1/ 39.63T	P2/ 18.48T	P3/ 197.1T

TIME/ 1997.	P1/ 40.34T	P2/ 19.05T	P3/ 199.7T

TIME/ 1998.	P1/ 40.97T	P2/ 19.62T	P3/ 202.2T

TIME/ 1999.	P1/ 41.53T	P2/ 20.18T	P3/ 204.7T

TIME/ 2000.	P1/ 42.02T	P2/ 20.73T	P3/ 207.2T

TIME/ 2001.	P1/ 42.44T	P2/ 21.28T	P3/ 209.6T
TIME/ 2002.	P1/ 42.82T	P2/ 21.82T	P3/ 212.0T
TIME/ 2003.	P1/ 43.14T	P2/ 22.35T	P3/ 214.3T
TIME/ 2004.	P1/ 43.42T	P2/ 22.86T	P3/ 216.6T
TIME/ 2005.	P1/ 43.66T	P2/ 23.37T	P3/ 218.9T
TIME/ 2006.	P1/ 43.87T	P2/ 23.86T	P3/ 221.1T
TIME/ 2007.	P1/ 44.05T	P2/ 24.34T	P3/ 223.3T
TIME/ 2008.	P1/ 44.20T	P2/ 24.81T	P3/ 225.5T
TIME/ 2009.	P1/ 44.34T	P2/ 25.26T	P3/ 227.6T
TIME/ 2010.	P1/ 44.45T	P2/ 25.70T	P3/ 229.6T
TIME/ 2011.	P1/ 44.55T	P2/ 26.13T	P3/ 231.7T
TIME/ 2012.	P1/ 44.63T	P2/ 26.54T	P3/ 233.6T
TIME/ 2013.	P1/ 44.70T	P2/ 26.93T	P3/ 235.6T
TIME/ 2014.	P1/ 44.77T	P2/ 27.31T	P3/ 237.5T
TIME/ 2015.	P1/ 44.82T	P2/ 27.67T	P3/ 239.3T

C1.2 Per capita income in Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	PCI1/ 8.68T	PCI2/ 12.67T	PCI3/ 12.10T
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TIME/ 1991.	PCI1/ 8.57T	PCI2/ 12.84T	PCI3/ 12.34T
TIME/ 1992.	PCI1/ 8.52T	PCI2/ 13.02T	PCI3/ 12.59T
TIME/ 1993.	PCI1/ 8.57T	PCI2/ 13.22T	PCI3/ 12.85T
TIME/ 1994.	PCI1/ 8.76T	PCI2/ 13.45T	PCI3/ 13.13T
TIME/ 1995.	PCI1/ 9.06T	PCI2/ 13.70T	PCI3/ 13.42T
TIME/ 1996.	PCI1/ 9.45T	PCI2/ 13.97T	PCI3/ 13.72T
TIME/ 1997.	PCI1/ 9.91T	PCI2/ 14.27T	PCI3/ 14.04T
TIME/ 1998.	PCI1/ 10.39T	PCI2/ 14.59T	PCI3/ 14.37T
TIME/ 1999.	PCI1/ 10.89T	PCI2/ 14.94T	PCI3/ 14.72T
TIME/ 2000.	PCI1/ 11.39T	PCI2/ 15.32T	PCI3/ 15.09T
TIME/ 2001.	PCI1/ 11.91T	PCI2/ 15.74T	PCI3/ 15.48T
TIME/ 2002.	PCI1/ 12.45T	PCI2/ 16.19T	PCI3/ 15.89T
TIME/ 2003.	PCI1/ 13.02T	PCI2/ 16.67T	PCI3/ 16.31T
TIME/ 2004.	PCI1/ 13.64T	PCI2/ 17.19T	PCI3/ 16.76T
TIME/ 2005.	PCI1/ 14.31T	PCI2/ 17.76T	PCI3/ 17.24T
TIME/ 2006.	PCI1/ 15.04T	PCI2/ 18.37T	PCI3/ 17.74T
TIME/ 2007.	PCI1/ 15.82T	PCI2/ 19.03T	PCI3/ 18.26T
TIME/ 2008.	PCI1/ 16.66T	PCI2/ 19.74T	PCI3/ 18.81T
TIME/	PCI1/	PCI2/	PCI3/

2009.	17.57T	20.51T	19.39T
TIME/ 2010.	PCI1/ 18.54T	PCI2/ 21.33T	PCI3/ 20.00T
TIME/ 2011.	PCI1/ 19.57T	PCI2/ 22.23T	PCI3/ 20.65T
TIME/ 2012.	PCI1/ 20.68T	PCI2/ 23.19T	PCI3/ 21.33T
TIME/ 2013.	PCI1/ 21.87T	PCI2/ 24.24T	PCI3/ 22.05T
TIME/ 2014.	PCI1/ 23.14T	PCI2/ 25.37T	PCI3/ 22.81T
TIME/ 2015.	PCI1/ 24.51T	PCI2/ 26.59T	PCI3/ 23.61T

C1.3 Funded research and total graduate student at Virginia Tech

TIME/ 1990.	FR/ 64.7M	TGS/ 4111.
TIME/ 1991.	FR/ 53.8M	TGS/ 3891.
TIME/ 1992.	FR/ 42.7M	TGS/ 3743.
TIME/ 1993.	FR/ 36.1M	TGS/ 3711.
TIME/ 1994.	FR/ 36.1M	TGS/ 3780.
TIME/ 1995.	FR/ 42.6M	TGS/ 3901.
TIME/ 1996.	FR/ 53.8M	TGS/ 4034.
TIME/ 1997.	FR/ 67.2M	TGS/ 4158.
TIME/ 1998.	FR/ 80.4M	TGS/ 4263.
TIME/ 1999.	FR/ 92.0M	TGS/ 4348.

TIME/ 2000.	FR/ 101.2M	TGS/ 4412.

TIME/ 2001.	FR/ 108.3M	TGS/ 4458.

TIME/ 2002.	FR/ 114.1M	TGS/ 4493.

TIME/ 2003.	FR/ 119.2M	TGS/ 4524.

TIME/ 2004.	FR/ 124.5M	TGS/ 4555.

TIME/ 2005.	FR/ 130.2M	TGS/ 4591.

TIME/ 2006.	FR/ 136.6M	TGS/ 4630.

TIME/ 2007.	FR/ 143.7M	TGS/ 4673.

TIME/ 2008.	FR/ 151.2M	TGS/ 4718.

TIME/ 2009.	FR/ 158.9M	TGS/ 4762.

TIME/ 2010.	FR/ 166.7M	TGS/ 4804.

TIME/ 2011.	FR/ 174.5M	TGS/ 4844.

TIME/ 2012.	FR/ 182.1M	TGS/ 4881.

TIME/ 2013.	FR/ 189.6M	TGS/ 4917.

TIME/ 2014.	FR/ 197.0M	TGS/ 4950.

TIME/ 2015.	FR/ 204.3M	TGS/ 4982.

C2 Alternative 2

C2.1 Population of Blacksburg, Christiansburg

and Roanoke (city and county)

TIME/ 1990.	P1/ 33.32T	P2/ 15.05T	P3/ 181.1T
TIME/ 1991.	P1/ 35.01T	P2/ 15.76T	P3/ 184.3T
TIME/ 1992.	P1/ 36.60T	P2/ 16.49T	P3/ 187.4T
TIME/ 1993.	P1/ 38.09T	P2/ 17.24T	P3/ 190.6T
TIME/ 1994.	P1/ 39.47T	P2/ 18.00T	P3/ 193.7T
TIME/ 1995.	P1/ 40.73T	P2/ 18.77T	P3/ 196.8T
TIME/ 1996.	P1/ 41.88T	P2/ 19.56T	P3/ 199.9T
TIME/ 1997.	P1/ 42.91T	P2/ 20.36T	P3/ 202.9T
TIME/ 1998.	P1/ 43.84T	P2/ 21.18T	P3/ 205.9T
TIME/ 1999.	P1/ 44.67T	P2/ 22.00T	P3/ 209.0T
TIME/ 2000.	P1/ 45.40T	P2/ 22.82T	P3/ 211.9T
TIME/ 2001.	P1/ 46.05T	P2/ 23.66T	P3/ 214.9T
TIME/ 2002.	P1/ 46.62T	P2/ 24.49T	P3/ 217.8T
TIME/ 2003.	P1/ 47.12T	P2/ 25.33T	P3/ 220.7T
TIME/ 2004.	P1/ 47.55T	P2/ 26.16T	P3/ 223.5T
TIME/	P1/	P2/	P3/

2005.	47.93T	27.00T	226.3T
TIME/ 2006.	P1/ 48.25T	P2/ 27.83T	P3/ 229.1T
TIME/ 2007.	P1/ 48.53T	P2/ 28.65T	P3/ 231.8T
TIME/ 2008.	P1/ 48.78T	P2/ 29.46T	P3/ 234.5T
TIME/ 2009.	P1/ 48.99T	P2/ 30.27T	P3/ 237.1T
TIME/ 2010.	P1/ 49.17T	P2/ 31.06T	P3/ 239.7T
TIME/ 2011.	P1/ 49.33T	P2/ 31.84T	P3/ 242.3T
TIME/ 2012.	P1/ 49.46T	P2/ 32.61T	P3/ 244.8T
TIME/ 2013.	P1/ 49.57T	P2/ 33.36T	P3/ 247.2T
TIME/ 2014.	P1/ 49.67T	P2/ 34.10T	P3/ 249.7T
TIME/ 2015.	P1/ 49.76T	P2/ 34.81T	P3/ 252.0T

C2.2 Per capita income in Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	PCI1/ 8.68T	PCI2/ 12.67T	PCI3/ 12.10T
TIME/ 1991.	PCI1/ 8.57T	PCI2/ 12.84T	PCI3/ 12.34T
TIME/ 1992.	PCI1/ 8.52T	PCI2/ 13.02T	PCI3/ 12.59T
TIME/ 1993.	PCI1/ 8.57T	PCI2/ 13.22T	PCI3/ 12.85T
TIME/ 1994.	PCI1/ 8.76T	PCI2/ 13.45T	PCI3/ 13.13T
TIME/	PCI1/	PCI2/	PCI3/

1995.	9.06T	13.70T	13.42T

TIME/ 1996.	PCI1/ 9.45T	PCI2/ 13.97T	PCI3/ 13.72T

TIME/ 1997.	PCI1/ 9.91T	PCI2/ 14.27T	PCI3/ 14.04T

TIME/ 1998.	PCI1/ 10.39T	PCI2/ 14.59T	PCI3/ 14.37T

TIME/ 1999.	PCI1/ 10.89T	PCI2/ 14.94T	PCI3/ 14.72T

TIME/ 2000.	PCI1/ 11.39T	PCI2/ 15.32T	PCI3/ 15.09T

TIME/ 2001.	PCI1/ 11.91T	PCI2/ 15.74T	PCI3/ 15.48T

TIME/ 2002.	PCI1/ 12.45T	PCI2/ 16.19T	PCI3/ 15.89T

TIME/ 2003.	PCI1/ 13.02T	PCI2/ 16.67T	PCI3/ 16.31T

TIME/ 2004.	PCI1/ 13.64T	PCI2/ 17.19T	PCI3/ 16.76T

TIME/ 2005.	PCI1/ 14.31T	PCI2/ 17.76T	PCI3/ 17.24T

TIME/ 2006.	PCI1/ 15.04T	PCI2/ 18.37T	PCI3/ 17.74T

TIME/ 2007.	PCI1/ 15.82T	PCI2/ 19.03T	PCI3/ 18.26T

TIME/ 2008.	PCI1/ 16.66T	PCI2/ 19.74T	PCI3/ 18.81T

TIME/ 2009.	PCI1/ 17.57T	PCI2/ 20.51T	PCI3/ 19.39T

TIME/ 2010.	PCI1/ 18.54T	PCI2/ 21.33T	PCI3/ 20.00T

TIME/ 2011.	PCI1/ 19.57T	PCI2/ 22.23T	PCI3/ 20.65T

TIME/ 2012.	PCI1/ 20.68T	PCI2/ 23.19T	PCI3/ 21.33T

TIME/ 2013.	PCI1/ 21.87T	PCI2/ 24.24T	PCI3/ 22.05T

TIME/ 2014.	PCI1/ 23.14T	PCI2/ 25.37T	PCI3/ 22.81T
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TIME/ 2015.	PCI1/ 24.51T	PCI2/ 26.59T	PCI3/ 23.61T
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C2.3 Funded research and total graduate student at Virginia Tech

TIME/ 1990.	FR/ 64.7M	TGS/ 4111.
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TIME/ 1991.	FR/ 53.8M	TGS/ 3891.
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TIME/ 1992.	FR/ 42.7M	TGS/ 3743.
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TIME/ 1993.	FR/ 36.1M	TGS/ 3711.
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TIME/ 1994.	FR/ 36.1M	TGS/ 3780.
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TIME/ 1995.	FR/ 42.6M	TGS/ 3901.
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TIME/ 1996.	FR/ 53.8M	TGS/ 4034.
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TIME/ 1997.	FR/ 67.2M	TGS/ 4158.
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TIME/ 1998.	FR/ 80.4M	TGS/ 4263.
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TIME/ 1999.	FR/ 92.0M	TGS/ 4348.
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TIME/ 2000.	FR/ 101.2M	TGS/ 4412.
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TIME/ 2001.	FR/ 108.3M	TGS/ 4458.
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TIME/ 2002.	FR/ 114.1M	TGS/ 4493.
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TIME/ 2003.	FR/ 119.2M	TGS/ 4524.
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TIME/ 2004.	FR/ 124.5M	TGS/ 4555.
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TIME/ 2005.	FR/ 130.2M	TGS/ 4591.
TIME/ 2006.	FR/ 136.6M	TGS/ 4630.
TIME/ 2007.	FR/ 143.7M	TGS/ 4673.
TIME/ 2008.	FR/ 151.2M	TGS/ 4718.
TIME/ 2009.	FR/ 158.9M	TGS/ 4762.
TIME/ 2010.	FR/ 166.7M	TGS/ 4804.
TIME/ 2011.	FR/ 174.5M	TGS/ 4844.
TIME/ 2012.	FR/ 182.1M	TGS/ 4881.
TIME/ 2013.	FR/ 189.6M	TGS/ 4917.
TIME/ 2014.	FR/ 197.0M	TGS/ 4950.
TIME/ 2015.	FR/ 204.3M	TGS/ 4982.

C3 Alternative 3A

C3.1 Population of Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	P1/ 33.32T	P2/ 15.05T	P3/ 181.1T
TIME/ 1991.	P1/ 35.11T	P2/ 15.79T	P3/ 184.4T
TIME/ 1992.	P1/ 36.81T	P2/ 16.56T	P3/ 187.7T
TIME/	P1/	P2/	P3/

1993.	38.41T	17.35T	190.9T

TIME/ 1994.	P1/ 39.90T	P2/ 18.15T	P3/ 194.2T

TIME/ 1995.	P1/ 41.27T	P2/ 18.98T	P3/ 197.4T

TIME/ 1996.	P1/ 42.52T	P2/ 19.82T	P3/ 200.6T

TIME/ 1997.	P1/ 43.65T	P2/ 20.68T	P3/ 203.8T

TIME/ 1998.	P1/ 44.68T	P2/ 21.56T	P3/ 207.0T

TIME/ 1999.	P1/ 45.59T	P2/ 22.45T	P3/ 210.1T

TIME/ 2000.	P1/ 46.40T	P2/ 23.35T	P3/ 213.2T

TIME/ 2001.	P1/ 47.12T	P2/ 24.26T	P3/ 216.3T

TIME/ 2002.	P1/ 47.75T	P2/ 25.18T	P3/ 219.4T

TIME/ 2003.	P1/ 48.30T	P2/ 26.11T	P3/ 222.4T

TIME/ 2004.	P1/ 48.79T	P2/ 27.04T	P3/ 225.4T

TIME/ 2005.	P1/ 49.21T	P2/ 27.97T	P3/ 228.4T

TIME/ 2006.	P1/ 49.57T	P2/ 28.90T	P3/ 231.3T

TIME/ 2007.	P1/ 49.89T	P2/ 29.83T	P3/ 234.2T

TIME/ 2008.	P1/ 50.16T	P2/ 30.76T	P3/ 237.0T

TIME/ 2009.	P1/ 50.40T	P2/ 31.68T	P3/ 239.8T

TIME/ 2010.	P1/ 50.60T	P2/ 32.59T	P3/ 242.6T

TIME/ 2011.	P1/ 50.78T	P2/ 33.49T	P3/ 245.3T

TIME/ 2012.	P1/ 50.93T	P2/ 34.38T	P3/ 247.9T
TIME/ 2013.	P1/ 51.06T	P2/ 35.25T	P3/ 250.6T
TIME/ 2014.	P1/ 51.17T	P2/ 36.11T	P3/ 253.1T
TIME/ 2015.	P1/ 51.26T	P2/ 36.96T	P3/ 255.7T

**C3.2 Per capita income in Blacksburg, Christiansburg
and Roanoke (city and county)**

TIME/ 1990.	PCI1/ 8.68T	PCI2/ 12.67T	PCI3/ 12.10T
TIME/ 1991.	PCI1/ 8.57T	PCI2/ 12.84T	PCI3/ 12.34T
TIME/ 1992.	PCI1/ 8.52T	PCI2/ 13.02T	PCI3/ 12.59T
TIME/ 1993.	PCI1/ 8.57T	PCI2/ 13.22T	PCI3/ 12.85T
TIME/ 1994.	PCI1/ 8.76T	PCI2/ 13.45T	PCI3/ 13.13T
TIME/ 1995.	PCI1/ 9.06T	PCI2/ 13.70T	PCI3/ 13.42T
TIME/ 1996.	PCI1/ 9.45T	PCI2/ 13.97T	PCI3/ 13.72T
TIME/ 1997.	PCI1/ 9.91T	PCI2/ 14.27T	PCI3/ 14.04T
TIME/ 1998.	PCI1/ 10.39T	PCI2/ 14.59T	PCI3/ 14.37T
TIME/ 1999.	PCI1/ 10.89T	PCI2/ 14.94T	PCI3/ 14.72T
TIME/ 2000.	PCI1/ 11.39T	PCI2/ 15.32T	PCI3/ 15.09T
TIME/ 2001.	PCI1/ 11.91T	PCI2/ 15.74T	PCI3/ 15.48T

TIME/ 2002.	PCI1/ 12.45T	PCI2/ 16.19T	PCI3/ 15.89T
TIME/ 2003.	PCI1/ 13.02T	PCI2/ 16.67T	PCI3/ 16.31T
TIME/ 2004.	PCI1/ 13.64T	PCI2/ 17.19T	PCI3/ 16.76T
TIME/ 2005.	PCI1/ 14.31T	PCI2/ 17.76T	PCI3/ 17.24T
TIME/ 2006.	PCI1/ 15.04T	PCI2/ 18.37T	PCI3/ 17.74T
TIME/ 2007.	PCI1/ 15.82T	PCI2/ 19.03T	PCI3/ 18.26T
TIME/ 2008.	PCI1/ 16.66T	PCI2/ 19.74T	PCI3/ 18.81T
TIME/ 2009.	PCI1/ 17.57T	PCI2/ 20.51T	PCI3/ 19.39T
TIME/ 2010.	PCI1/ 18.54T	PCI2/ 21.33T	PCI3/ 20.00T
TIME/ 2011.	PCI1/ 19.57T	PCI2/ 22.23T	PCI3/ 20.65T
TIME/ 2012.	PCI1/ 20.68T	PCI2/ 23.19T	PCI3/ 21.33T
TIME/ 2013.	PCI1/ 21.87T	PCI2/ 24.24T	PCI3/ 22.05T
TIME/ 2014.	PCI1/ 23.14T	PCI2/ 25.37T	PCI3/ 22.81T
TIME/ 2015.	PCI1/ 24.51T	PCI2/ 26.59T	PCI3/ 23.61T

C3.3 Funded research and total graduate student at Virginia Tech

TIME/ 1990.	FR/ 64.7M	TGS/ 4111.
TIME/ 1991.	FR/ 53.8M	TGS/ 3891.
TIME/ 1992.	FR/ 42.7M	TGS/ 3743.

TIME/ 1993.	FR/ 36.1M	TGS/ 3711.
TIME/ 1994.	FR/ 36.1M	TGS/ 3780.
TIME/ 1995.	FR/ 42.6M	TGS/ 3901.
TIME/ 1996.	FR/ 53.8M	TGS/ 4034.
TIME/ 1997.	FR/ 67.2M	TGS/ 4158.
TIME/ 1998.	FR/ 80.4M	TGS/ 4263.
TIME/ 1999.	FR/ 92.0M	TGS/ 4348.
TIME/ 2000.	FR/ 101.2M	TGS/ 4412.
TIME/ 2001.	FR/ 108.3M	TGS/ 4458.
TIME/ 2002.	FR/ 114.1M	TGS/ 4493.
TIME/ 2003.	FR/ 119.2M	TGS/ 4524.
TIME/ 2004.	FR/ 124.5M	TGS/ 4555.
TIME/ 2005.	FR/ 130.2M	TGS/ 4591.
TIME/ 2006.	FR/ 136.6M	TGS/ 4630.
TIME/ 2007.	FR/ 143.7M	TGS/ 4673.
TIME/ 2008.	FR/ 151.2M	TGS/ 4718.
TIME/ 2009.	FR/ 158.9M	TGS/ 4762.
TIME/ 2010.	FR/ 166.7M	TGS/ 4804.
TIME/	FR/	TGS/

2011.	174.5M	4844.
TIME/ 2012.	FR/ 182.1M	TGS/ 4881.
TIME/ 2013.	FR/ 189.6M	TGS/ 4917.
TIME/ 2014.	FR/ 197.0M	TGS/ 4950.
TIME/ 2015.	FR/ 204.3M	TGS/ 4982.

C4 Alternative 5

C4.1 Population of Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	P1/ 33.32T	P2/ 15.05T	P3/ 181.1T
TIME/ 1991.	P1/ 35.13T	P2/ 15.80T	P3/ 184.4T
TIME/ 1992.	P1/ 36.84T	P2/ 16.56T	P3/ 187.7T
TIME/ 1993.	P1/ 38.46T	P2/ 17.36T	P3/ 191.0T
TIME/ 1994.	P1/ 39.96T	P2/ 18.17T	P3/ 194.2T
TIME/ 1995.	P1/ 41.34T	P2/ 19.00T	P3/ 197.5T
TIME/ 1996.	P1/ 42.61T	P2/ 19.85T	P3/ 200.7T
TIME/ 1997.	P1/ 43.76T	P2/ 20.71T	P3/ 203.9T
TIME/ 1998.	P1/ 44.79T	P2/ 21.59T	P3/ 207.1T
TIME/ 1999.	P1/ 45.72T	P2/ 22.49T	P3/ 210.3T

TIME/ 2000.	P1/ 46.54T	P2/ 23.40T	P3/ 213.4T
TIME/ 2001.	P1/ 47.27T	P2/ 24.32T	P3/ 216.5T
TIME/ 2002.	P1/ 47.91T	P2/ 25.25T	P3/ 219.6T
TIME/ 2003.	P1/ 48.47T	P2/ 26.18T	P3/ 222.7T
TIME/ 2004.	P1/ 48.96T	P2/ 27.12T	P3/ 225.7T
TIME/ 2005.	P1/ 49.39T	P2/ 28.06T	P3/ 228.7T
TIME/ 2006.	P1/ 49.76T	P2/ 29.00T	P3/ 231.6T
TIME/ 2007.	P1/ 50.08T	P2/ 29.94T	P3/ 234.5T
TIME/ 2008.	P1/ 50.36T	P2/ 30.88T	P3/ 237.4T
TIME/ 2009.	P1/ 50.60T	P2/ 31.81T	P3/ 240.2T
TIME/ 2010.	P1/ 50.81T	P2/ 32.73T	P3/ 243.0T
TIME/ 2011.	P1/ 50.99T	P2/ 33.64T	P3/ 245.7T
TIME/ 2012.	P1/ 51.14T	P2/ 34.54T	P3/ 248.4T
TIME/ 2013.	P1/ 51.27T	P2/ 35.43T	P3/ 251.0T
TIME/ 2014.	P1/ 51.38T	P2/ 36.30T	P3/ 253.6T
TIME/ 2015.	P1/ 51.48T	P2/ 37.16T	P3/ 256.2T

**C4.2 Per capita income in Blacksburg, Christiansburg
and Roanoke (city and county)**

TIME/ 1990.	PCI1/ 8.68T	PCI2/ 12.67T	PCI3/ 12.10T

TIME/ 1991.	PCI1/ 8.57T	PCI2/ 12.84T	PCI3/ 12.34T

TIME/ 1992.	PCI1/ 8.52T	PCI2/ 13.02T	PCI3/ 12.59T

TIME/ 1993.	PCI1/ 8.57T	PCI2/ 13.22T	PCI3/ 12.85T

TIME/ 1994.	PCI1/ 8.76T	PCI2/ 13.45T	PCI3/ 13.13T

TIME/ 1995.	PCI1/ 9.06T	PCI2/ 13.70T	PCI3/ 13.42T

TIME/ 1996.	PCI1/ 9.45T	PCI2/ 13.97T	PCI3/ 13.72T

TIME/ 1997.	PCI1/ 9.91T	PCI2/ 14.27T	PCI3/ 14.04T

TIME/ 1998.	PCI1/ 10.39T	PCI2/ 14.59T	PCI3/ 14.37T

TIME/ 1999.	PCI1/ 10.89T	PCI2/ 14.94T	PCI3/ 14.72T

TIME/ 2000.	PCI1/ 11.39T	PCI2/ 15.32T	PCI3/ 15.09T

TIME/ 2001.	PCI1/ 11.91T	PCI2/ 15.74T	PCI3/ 15.48T

TIME/ 2002.	PCI1/ 12.45T	PCI2/ 16.19T	PCI3/ 15.89T

TIME/ 2003.	PCI1/ 13.02T	PCI2/ 16.67T	PCI3/ 16.31T

TIME/ 2004.	PCI1/ 13.64T	PCI2/ 17.19T	PCI3/ 16.76T

TIME/ 2005.	PCI1/ 14.31T	PCI2/ 17.76T	PCI3/ 17.24T

TIME/ 2006.	PCI1/ 15.04T	PCI2/ 18.37T	PCI3/ 17.74T

TIME/ 2007.	PCI1/ 15.82T	PCI2/ 19.03T	PCI3/ 18.26T
TIME/ 2008.	PCI1/ 16.66T	PCI2/ 19.74T	PCI3/ 18.81T
TIME/ 2009.	PCI1/ 17.57T	PCI2/ 20.51T	PCI3/ 19.39T
TIME/ 2010.	PCI1/ 18.54T	PCI2/ 21.33T	PCI3/ 20.00T
TIME/ 2011.	PCI1/ 19.57T	PCI2/ 22.23T	PCI3/ 20.65T
TIME/ 2012.	PCI1/ 20.68T	PCI2/ 23.19T	PCI3/ 21.33T
TIME/ 2013.	PCI1/ 21.87T	PCI2/ 24.24T	PCI3/ 22.05T
TIME/ 2014.	PCI1/ 23.14T	PCI2/ 25.37T	PCI3/ 22.81T
TIME/ 2015.	PCI1/ 24.51T	PCI2/ 26.59T	PCI3/ 23.61T

C4.3 Funded research and total graduate student at Virginia Tech

TIME/ 1990.	FR/ 64.7M	TGS/ 4111.
TIME/ 1991.	FR/ 53.8M	TGS/ 3891.
TIME/ 1992.	FR/ 42.7M	TGS/ 3743.
TIME/ 1993.	FR/ 36.1M	TGS/ 3711.
TIME/ 1994.	FR/ 36.1M	TGS/ 3780.
TIME/ 1995.	FR/ 42.6M	TGS/ 3901.
TIME/ 1996.	FR/ 53.8M	TGS/ 4034.
TIME/	FR/	TGS/

1997.	67.2M	4158.

TIME/ 1998.	FR/ 80.4M	TGS/ 4263.

TIME/ 1999.	FR/ 92.0M	TGS/ 4348.

TIME/ 2000.	FR/ 101.2M	TGS/ 4412.

TIME/ 2001.	FR/ 108.3M	TGS/ 4458.

TIME/ 2002.	FR/ 114.1M	TGS/ 4493.

TIME/ 2003.	FR/ 119.2M	TGS/ 4524.

TIME/ 2004.	FR/ 124.5M	TGS/ 4555.

TIME/ 2005.	FR/ 130.2M	TGS/ 4591.

TIME/ 2006.	FR/ 136.6M	TGS/ 4630.

TIME/ 2007.	FR/ 143.7M	TGS/ 4673.

TIME/ 2008.	FR/ 151.2M	TGS/ 4718.

TIME/ 2009.	FR/ 158.9M	TGS/ 4762.

TIME/ 2010.	FR/ 166.7M	TGS/ 4804.

TIME/ 2011.	FR/ 174.5M	TGS/ 4844.

TIME/ 2012.	FR/ 182.1M	TGS/ 4881.

TIME/ 2013.	FR/ 189.6M	TGS/ 4917.

TIME/ 2014.	FR/ 197.0M	TGS/ 4950.

TIME/ 2015.	FR/ 204.3M	TGS/ 4982.

C5 Alternative 12

C5.1 Population of Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	P1/ 33.32T	P2/ 15.05T	P3/ 181.1T

TIME/ 1991.	P1/ 35.05T	P2/ 15.77T	P3/ 184.3T

TIME/ 1992.	P1/ 36.69T	P2/ 16.51T	P3/ 187.5T

TIME/ 1993.	P1/ 38.22T	P2/ 17.27T	P3/ 190.7T

TIME/ 1994.	P1/ 39.64T	P2/ 18.05T	P3/ 193.9T

TIME/ 1995.	P1/ 40.94T	P2/ 18.84T	P3/ 197.0T

TIME/ 1996.	P1/ 42.13T	P2/ 19.65T	P3/ 200.2T

TIME/ 1997.	P1/ 43.20T	P2/ 20.47T	P3/ 203.3T

TIME/ 1998.	P1/ 44.17T	P2/ 21.31T	P3/ 206.4T

TIME/ 1999.	P1/ 45.03T	P2/ 22.15T	P3/ 209.4T

TIME/ 2000.	P1/ 45.79T	P2/ 23.00T	P3/ 212.4T

TIME/ 2001.	P1/ 46.47T	P2/ 23.86T	P3/ 215.4T

TIME/ 2002.	P1/ 47.06T	P2/ 24.73T	P3/ 218.4T

TIME/ 2003.	P1/ 47.58T	P2/ 25.59T	P3/ 221.3T

TIME/ 2004.	P1/ 48.03T	P2/ 26.46T	P3/ 224.2T

TIME/ 2005.	P1/ 48.42T	P2/ 27.33T	P3/ 227.1T
TIME/ 2006.	P1/ 48.77T	P2/ 28.19T	P3/ 229.9T
TIME/ 2007.	P1/ 49.06T	P2/ 29.05T	P3/ 232.7T
TIME/ 2008.	P1/ 49.32T	P2/ 29.90T	P3/ 235.5T
TIME/ 2009.	P1/ 49.54T	P2/ 30.74T	P3/ 238.2T
TIME/ 2010.	P1/ 49.73T	P2/ 31.57T	P3/ 240.8T
TIME/ 2011.	P1/ 49.89T	P2/ 32.39T	P3/ 243.4T
TIME/ 2012.	P1/ 50.03T	P2/ 33.20T	P3/ 246.0T
TIME/ 2013.	P1/ 50.15T	P2/ 33.99T	P3/ 248.5T
TIME/ 2014.	P1/ 50.25T	P2/ 34.77T	P3/ 251.0T
TIME/ 2015.	P1/ 50.34T	P2/ 35.52T	P3/ 253.5T

C5.2 Per capita income in Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	PCI1/ 8.68T	PCI2/ 12.67T	PCI3/ 12.10T
TIME/ 1991.	PCI1/ 8.57T	PCI2/ 12.84T	PCI3/ 12.34T
TIME/ 1992.	PCI1/ 8.52T	PCI2/ 13.02T	PCI3/ 12.59T
TIME/ 1993.	PCI1/ 8.57T	PCI2/ 13.22T	PCI3/ 12.85T
TIME/ 1994.	PCI1/ 8.76T	PCI2/ 13.45T	PCI3/ 13.13T

TIME/ 1995.	PCI1/ 9.06T	PCI2/ 13.70T	PCI3/ 13.42T
TIME/ 1996.	PCI1/ 9.45T	PCI2/ 13.97T	PCI3/ 13.72T
TIME/ 1997.	PCI1/ 9.91T	PCI2/ 14.27T	PCI3/ 14.04T
TIME/ 1998.	PCI1/ 10.39T	PCI2/ 14.59T	PCI3/ 14.37T
TIME/ 1999.	PCI1/ 10.89T	PCI2/ 14.94T	PCI3/ 14.72T
TIME/ 2000.	PCI1/ 11.39T	PCI2/ 15.32T	PCI3/ 15.09T
TIME/ 2001.	PCI1/ 11.91T	PCI2/ 15.74T	PCI3/ 15.48T
TIME/ 2002.	PCI1/ 12.45T	PCI2/ 16.19T	PCI3/ 15.89T
TIME/ 2003.	PCI1/ 13.02T	PCI2/ 16.67T	PCI3/ 16.31T
TIME/ 2004.	PCI1/ 13.64T	PCI2/ 17.19T	PCI3/ 16.76T
TIME/ 2005.	PCI1/ 14.31T	PCI2/ 17.76T	PCI3/ 17.24T
TIME/ 2006.	PCI1/ 15.04T	PCI2/ 18.37T	PCI3/ 17.74T
TIME/ 2007.	PCI1/ 15.82T	PCI2/ 19.03T	PCI3/ 18.26T
TIME/ 2008.	PCI1/ 16.66T	PCI2/ 19.74T	PCI3/ 18.81T
TIME/ 2009.	PCI1/ 17.57T	PCI2/ 20.51T	PCI3/ 19.39T
TIME/ 2010.	PCI1/ 18.54T	PCI2/ 21.33T	PCI3/ 20.00T
TIME/ 2011.	PCI1/ 19.57T	PCI2/ 22.23T	PCI3/ 20.65T
TIME/ 2012.	PCI1/ 20.68T	PCI2/ 23.19T	PCI3/ 21.33T
TIME/	PCI1/	PCI2/	PCI3/

2013.	21.87T	24.24T	22.05T

TIME/ 2014.	PCI1/ 23.14T	PCI2/ 25.37T	PCI3/ 22.81T

TIME/ 2015.	PCI1/ 24.51T	PCI2/ 26.59T	PCI3/ 23.61T

C5.3 Funded research and total graduate student at Virginia Tech

TIME/ 1990.	FR/ 64.7M	TGS/ 4111.

TIME/ 1991.	FR/ 53.8M	TGS/ 3891.

TIME/ 1992.	FR/ 42.7M	TGS/ 3743.

TIME/ 1993.	FR/ 36.1M	TGS/ 3711.

TIME/ 1994.	FR/ 36.1M	TGS/ 3780.

TIME/ 1995.	FR/ 42.6M	TGS/ 3901.

TIME/ 1996.	FR/ 53.8M	TGS/ 4034.

TIME/ 1997.	FR/ 67.2M	TGS/ 4158.

TIME/ 1998.	FR/ 80.4M	TGS/ 4263.

TIME/ 1999.	FR/ 92.0M	TGS/ 4348.

TIME/ 2000.	FR/ 101.2M	TGS/ 4412.

TIME/ 2001.	FR/ 108.3M	TGS/ 4458.

TIME/ 2002.	FR/ 114.1M	TGS/ 4493.

TIME/ 2003.	FR/ 119.2M	TGS/ 4524.

TIME/ 2004.	FR/ 124.5M	TGS/ 4555.
TIME/ 2005.	FR/ 130.2M	TGS/ 4591.
TIME/ 2006.	FR/ 136.6M	TGS/ 4630.
TIME/ 2007.	FR/ 143.7M	TGS/ 4673.
TIME/ 2008.	FR/ 151.2M	TGS/ 4718.
TIME/ 2009.	FR/ 158.9M	TGS/ 4762.
TIME/ 2010.	FR/ 166.7M	TGS/ 4804.
TIME/ 2011.	FR/ 174.5M	TGS/ 4844.
TIME/ 2012.	FR/ 182.1M	TGS/ 4881.
TIME/ 2013.	FR/ 189.6M	TGS/ 4917.
TIME/ 2014.	FR/ 197.0M	TGS/ 4950.
TIME/ 2015.	FR/ 204.3M	TGS/ 4982.

C6 Alternative 6

C6.1 Population of Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	P1/ 33.32T	P2/ 15.05T	P3/ 181.1T
TIME/ 1991.	P1/ 35.59T	P2/ 15.97T	P3/ 184.9T
TIME/ 1992.	P1/ 37.80T	P2/ 16.95T	P3/ 188.7T

TIME/ 1993.	P1/ 39.93T	P2/ 17.98T	P3/ 192.6T
TIME/ 1994.	P1/ 41.97T	P2/ 19.06T	P3/ 196.4T
TIME/ 1995.	P1/ 43.89T	P2/ 20.19T	P3/ 200.2T
TIME/ 1996.	P1/ 45.69T	P2/ 21.38T	P3/ 204.1T
TIME/ 1997.	P1/ 47.35T	P2/ 22.64T	P3/ 207.9T
TIME/ 1998.	P1/ 48.88T	P2/ 23.95T	P3/ 211.8T
TIME/ 1999.	P1/ 50.26T	P2/ 25.32T	P3/ 215.6T
TIME/ 2000.	P1/ 51.52T	P2/ 26.75T	P3/ 219.4T
TIME/ 2001.	P1/ 52.64T	P2/ 28.25T	P3/ 223.2T
TIME/ 2002.	P1/ 53.64T	P2/ 29.82T	P3/ 227.0T
TIME/ 2003.	P1/ 54.53T	P2/ 31.45T	P3/ 230.7T
TIME/ 2004.	P1/ 55.32T	P2/ 33.14T	P3/ 234.5T
TIME/ 2005.	P1/ 56.00T	P2/ 34.90T	P3/ 238.2T
TIME/ 2006.	P1/ 56.61T	P2/ 36.73T	P3/ 241.9T
TIME/ 2007.	P1/ 57.13T	P2/ 38.61T	P3/ 245.6T
TIME/ 2008.	P1/ 57.59T	P2/ 40.57T	P3/ 249.2T
TIME/ 2009.	P1/ 57.98T	P2/ 42.58T	P3/ 252.8T
TIME/ 2010.	P1/ 58.33T	P2/ 44.66T	P3/ 256.3T
TIME/	P1/	P2/	P3/

2011.	58.62T	46.80T	259.9T

TIME/ 2012.	P1/ 58.88T	P2/ 48.99T	P3/ 263.3T

TIME/ 2013.	P1/ 59.10T	P2/ 51.23T	P3/ 266.8T

TIME/ 2014.	P1/ 59.29T	P2/ 53.53T	P3/ 270.2T

TIME/ 2015.	P1/ 59.45T	P2/ 55.87T	P3/ 273.5T

C6.2 Per capita income in Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	PCI1/ 8.68T	PCI2/ 12.67T	PCI3/ 12.10T

TIME/ 1991.	PCI1/ 8.57T	PCI2/ 12.84T	PCI3/ 12.34T

TIME/ 1992.	PCI1/ 8.52T	PCI2/ 13.02T	PCI3/ 12.59T

TIME/ 1993.	PCI1/ 8.57T	PCI2/ 13.22T	PCI3/ 12.85T

TIME/ 1994.	PCI1/ 8.76T	PCI2/ 13.45T	PCI3/ 13.13T

TIME/ 1995.	PCI1/ 9.06T	PCI2/ 13.70T	PCI3/ 13.42T

TIME/ 1996.	PCI1/ 9.45T	PCI2/ 13.97T	PCI3/ 13.72T

TIME/ 1997.	PCI1/ 9.91T	PCI2/ 14.27T	PCI3/ 14.04T

TIME/ 1998.	PCI1/ 10.39T	PCI2/ 14.59T	PCI3/ 14.37T

TIME/ 1999.	PCI1/ 10.89T	PCI2/ 14.94T	PCI3/ 14.72T

TIME/ 2000.	PCI1/ 11.39T	PCI2/ 15.32T	PCI3/ 15.09T

TIME/	PCI1/	PCI2/	PCI3/

2001.	11.91T	15.74T	15.48T
TIME/ 2002.	PCI1/ 12.45T	PCI2/ 16.19T	PCI3/ 15.89T
TIME/ 2003.	PCI1/ 13.02T	PCI2/ 16.67T	PCI3/ 16.31T
TIME/ 2004.	PCI1/ 13.64T	PCI2/ 17.19T	PCI3/ 16.76T
TIME/ 2005.	PCI1/ 14.31T	PCI2/ 17.76T	PCI3/ 17.24T
TIME/ 2006.	PCI1/ 15.04T	PCI2/ 18.37T	PCI3/ 17.74T
TIME/ 2007.	PCI1/ 15.82T	PCI2/ 19.03T	PCI3/ 18.26T
TIME/ 2008.	PCI1/ 16.66T	PCI2/ 19.74T	PCI3/ 18.81T
TIME/ 2009.	PCI1/ 17.57T	PCI2/ 20.51T	PCI3/ 19.39T
TIME/ 2010.	PCI1/ 18.54T	PCI2/ 21.33T	PCI3/ 20.00T
TIME/ 2011.	PCI1/ 19.57T	PCI2/ 22.23T	PCI3/ 20.65T
TIME/ 2012.	PCI1/ 20.68T	PCI2/ 23.19T	PCI3/ 21.33T
TIME/ 2013.	PCI1/ 21.87T	PCI2/ 24.24T	PCI3/ 22.05T
TIME/ 2014.	PCI1/ 23.14T	PCI2/ 25.37T	PCI3/ 22.81T
TIME/ 2015.	PCI1/ 24.51T	PCI2/ 26.59T	PCI3/ 23.61T

C6.3 Funded research and total graduate student at Virginia Tech

TIME/ 1990.	FR/ 64.7M	TGS/ 4111.
TIME/ 1991.	FR/ 53.8M	TGS/ 3891.

TIME/ 1992.	FR/ 42.7M	TGS/ 3743.
TIME/ 1993.	FR/ 36.1M	TGS/ 3711.
TIME/ 1994.	FR/ 36.1M	TGS/ 3780.
TIME/ 1995.	FR/ 42.6M	TGS/ 3901.
TIME/ 1996.	FR/ 53.8M	TGS/ 4034.
TIME/ 1997.	FR/ 67.2M	TGS/ 4158.
TIME/ 1998.	FR/ 80.4M	TGS/ 4263.
TIME/ 1999.	FR/ 92.0M	TGS/ 4348.
TIME/ 2000.	FR/ 101.2M	TGS/ 4412.
TIME/ 2001.	FR/ 108.3M	TGS/ 4458.
TIME/ 2002.	FR/ 114.1M	TGS/ 4493.
TIME/ 2003.	FR/ 119.2M	TGS/ 4524.
TIME/ 2004.	FR/ 124.5M	TGS/ 4555.
TIME/ 2005.	FR/ 130.2M	TGS/ 4591.
TIME/ 2006.	FR/ 136.6M	TGS/ 4630.
TIME/ 2007.	FR/ 143.7M	TGS/ 4673.
TIME/ 2008.	FR/ 151.2M	TGS/ 4718.
TIME/ 2009.	FR/ 158.9M	TGS/ 4762.
TIME/ 2010.	FR/ 166.7M	TGS/ 4804.

TIME/ 2011.	FR/ 174.5M	TGS/ 4844.
TIME/ 2012.	FR/ 182.1M	TGS/ 4881.
TIME/ 2013.	FR/ 189.6M	TGS/ 4917.
TIME/ 2014.	FR/ 197.0M	TGS/ 4950.
TIME/ 2015.	FR/ 204.3M	TGS/ 4982.

C7 Alternative 7

C7.1 Population of Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	P1/ 33.32T	P2/ 15.05T	P3/ 181.1T
TIME/ 1991.	P1/ 35.84T	P2/ 15.97T	P3/ 185.2T
TIME/ 1992.	P1/ 38.33T	P2/ 16.95T	P3/ 189.3T
TIME/ 1993.	P1/ 40.78T	P2/ 17.98T	P3/ 193.4T
TIME/ 1994.	P1/ 43.14T	P2/ 19.06T	P3/ 197.6T
TIME/ 1995.	P1/ 45.40T	P2/ 20.19T	P3/ 201.8T
TIME/ 1996.	P1/ 47.54T	P2/ 21.39T	P3/ 206.0T
TIME/ 1997.	P1/ 49.55T	P2/ 22.64T	P3/ 210.2T
TIME/ 1998.	P1/ 51.41T	P2/ 23.95T	P3/ 214.4T
TIME/	P1/	P2/	P3/

1999.	53.12T	25.32T	218.6T

TIME/ 2000.	P1/ 54.68T	P2/ 26.76T	P3/ 222.8T

TIME/ 2001.	P1/ 56.10T	P2/ 28.26T	P3/ 227.0T

TIME/ 2002.	P1/ 57.37T	P2/ 29.83T	P3/ 231.2T

TIME/ 2003.	P1/ 58.50T	P2/ 31.46T	P3/ 235.4T

TIME/ 2004.	P1/ 59.50T	P2/ 33.15T	P3/ 239.6T

TIME/ 2005.	P1/ 60.39T	P2/ 34.91T	P3/ 243.7T

TIME/ 2006.	P1/ 61.17T	P2/ 36.74T	P3/ 247.9T

TIME/ 2007.	P1/ 61.86T	P2/ 38.63T	P3/ 252.0T

TIME/ 2008.	P1/ 62.45T	P2/ 40.59T	P3/ 256.1T

TIME/ 2009.	P1/ 62.97T	P2/ 42.60T	P3/ 260.2T

TIME/ 2010.	P1/ 63.42T	P2/ 44.68T	P3/ 264.2T

TIME/ 2011.	P1/ 63.81T	P2/ 46.82T	P3/ 268.3T

TIME/ 2012.	P1/ 64.15T	P2/ 49.02T	P3/ 272.3T

TIME/ 2013.	P1/ 64.44T	P2/ 51.27T	P3/ 276.2T

TIME/ 2014.	P1/ 64.69T	P2/ 53.57T	P3/ 280.1T

TIME/ 2015.	P1/ 64.91T	P2/ 55.91T	P3/ 284.0T

**C7.2 Per capita income in Blacksburg, Christiansburg
and Roanoke (city and county)**

TIME/ 1990.	PCI1/ 8.68T	PCI2/ 12.67T	PCI3/ 12.10T
TIME/ 1991.	PCI1/ 8.57T	PCI2/ 12.84T	PCI3/ 12.34T
TIME/ 1992.	PCI1/ 8.52T	PCI2/ 13.02T	PCI3/ 12.59T
TIME/ 1993.	PCI1/ 8.57T	PCI2/ 13.22T	PCI3/ 12.85T
TIME/ 1994.	PCI1/ 8.76T	PCI2/ 13.45T	PCI3/ 13.13T
TIME/ 1995.	PCI1/ 9.06T	PCI2/ 13.70T	PCI3/ 13.42T
TIME/ 1996.	PCI1/ 9.45T	PCI2/ 13.97T	PCI3/ 13.72T
TIME/ 1997.	PCI1/ 9.91T	PCI2/ 14.27T	PCI3/ 14.04T
TIME/ 1998.	PCI1/ 10.39T	PCI2/ 14.59T	PCI3/ 14.37T
TIME/ 1999.	PCI1/ 10.89T	PCI2/ 14.94T	PCI3/ 14.72T
TIME/ 2000.	PCI1/ 11.39T	PCI2/ 15.32T	PCI3/ 15.09T
TIME/ 2001.	PCI1/ 11.91T	PCI2/ 15.74T	PCI3/ 15.48T
TIME/ 2002.	PCI1/ 12.45T	PCI2/ 16.19T	PCI3/ 15.89T
TIME/ 2003.	PCI1/ 13.02T	PCI2/ 16.67T	PCI3/ 16.31T
TIME/ 2004.	PCI1/ 13.64T	PCI2/ 17.19T	PCI3/ 16.76T
TIME/ 2005.	PCI1/ 14.31T	PCI2/ 17.76T	PCI3/ 17.24T
TIME/ 2006.	PCI1/ 15.04T	PCI2/ 18.37T	PCI3/ 17.74T

TIME/ 2007.	PCI1/ 15.82T	PCI2/ 19.03T	PCI3/ 18.26T
TIME/ 2008.	PCI1/ 16.66T	PCI2/ 19.74T	PCI3/ 18.81T
TIME/ 2009.	PCI1/ 17.57T	PCI2/ 20.51T	PCI3/ 19.39T
TIME/ 2010.	PCI1/ 18.54T	PCI2/ 21.33T	PCI3/ 20.00T
TIME/ 2011.	PCI1/ 19.57T	PCI2/ 22.23T	PCI3/ 20.65T
TIME/ 2012.	PCI1/ 20.68T	PCI2/ 23.19T	PCI3/ 21.33T
TIME/ 2013.	PCI1/ 21.87T	PCI2/ 24.24T	PCI3/ 22.05T
TIME/ 2014.	PCI1/ 23.14T	PCI2/ 25.37T	PCI3/ 22.81T
TIME/ 2015.	PCI1/ 24.51T	PCI2/ 26.59T	PCI3/ 23.61T

C7.3 Funded research and total graduate student at Virginia Tech

TIME/ 1990.	FR/ 64.7M	TGS/ 4111.
TIME/ 1991.	FR/ 53.8M	TGS/ 3891.
TIME/ 1992.	FR/ 42.7M	TGS/ 3743.
TIME/ 1993.	FR/ 36.1M	TGS/ 3711.
TIME/ 1994.	FR/ 36.1M	TGS/ 3780.
TIME/ 1995.	FR/ 42.6M	TGS/ 3901.
TIME/ 1996.	FR/ 53.8M	TGS/ 4034.
TIME/	FR/	TGS/

1997.	67.2M	4158.

TIME/ 1998.	FR/ 80.4M	TGS/ 4263.

TIME/ 1999.	FR/ 92.0M	TGS/ 4348.

TIME/ 2000.	FR/ 101.2M	TGS/ 4412.

TIME/ 2001.	FR/ 108.3M	TGS/ 4458.

TIME/ 2002.	FR/ 114.1M	TGS/ 4493.

TIME/ 2003.	FR/ 119.2M	TGS/ 4524.

TIME/ 2004.	FR/ 124.5M	TGS/ 4555.

TIME/ 2005.	FR/ 130.2M	TGS/ 4591.

TIME/ 2006.	FR/ 136.6M	TGS/ 4630.

TIME/ 2007.	FR/ 143.7M	TGS/ 4673.

TIME/ 2008.	FR/ 151.2M	TGS/ 4718.

TIME/ 2009.	FR/ 158.9M	TGS/ 4762.

TIME/ 2010.	FR/ 166.7M	TGS/ 4804.

TIME/ 2011.	FR/ 174.5M	TGS/ 4844.

TIME/ 2012.	FR/ 182.1M	TGS/ 4881.

TIME/ 2013.	FR/ 189.6M	TGS/ 4917.

TIME/ 2014.	FR/ 197.0M	TGS/ 4950.

TIME/ 2015.	FR/ 204.3M	TGS/ 4982.

C.8 Alternative 10

C.8.1 Population of Blacksburg, Christiansburg and Roanoke (city and county)

TIME/ 1990.	P1/ 33.32T	P2/ 15.05T	P3/ 181.1T

TIME/ 1991.	P1/ 35.90T	P2/ 15.98T	P3/ 185.3T

TIME/ 1992.	P1/ 38.46T	P2/ 16.96T	P3/ 189.4T

TIME/ 1993.	P1/ 40.97T	P2/ 17.99T	P3/ 193.7T

TIME/ 1994.	P1/ 43.42T	P2/ 19.08T	P3/ 197.9T

TIME/ 1995.	P1/ 45.76T	P2/ 20.22T	P3/ 202.1T

TIME/ 1996.	P1/ 47.99T	P2/ 21.42T	P3/ 206.4T

TIME/ 1997.	P1/ 50.08T	P2/ 22.69T	P3/ 210.7T

TIME/ 1998.	P1/ 52.03T	P2/ 24.01T	P3/ 215.0T

TIME/ 1999.	P1/ 53.82T	P2/ 25.40T	P3/ 219.3T

TIME/ 2000.	P1/ 55.47T	P2/ 26.85T	P3/ 223.6T

TIME/ 2001.	P1/ 56.95T	P2/ 28.37T	P3/ 227.9T

TIME/ 2002.	P1/ 58.29T	P2/ 29.95T	P3/ 232.2T

TIME/ 2003.	P1/ 59.49T	P2/ 31.60T	P3/ 236.5T

TIME/ 2004.	P1/ 60.56T	P2/ 33.32T	P3/ 240.8T

TIME/ 2005.	P1/ 61.50T	P2/ 35.11T	P3/ 245.0T
TIME/ 2006.	P1/ 62.33T	P2/ 36.96T	P3/ 249.3T
TIME/ 2007.	P1/ 63.06T	P2/ 38.89T	P3/ 253.5T
TIME/ 2008.	P1/ 63.69T	P2/ 40.88T	P3/ 257.8T
TIME/ 2009.	P1/ 64.24T	P2/ 42.94T	P3/ 262.0T
TIME/ 2010.	P1/ 64.72T	P2/ 45.06T	P3/ 266.1T
TIME/ 2011.	P1/ 65.14T	P2/ 47.25T	P3/ 270.3T
TIME/ 2012.	P1/ 65.50T	P2/ 49.49T	P3/ 274.4T
TIME/ 2013.	P1/ 65.81T	P2/ 51.80T	P3/ 278.5T
TIME/ 2014.	P1/ 66.08T	P2/ 54.16T	P3/ 282.5T
TIME/ 2015.	P1/ 66.31T	P2/ 56.57T	P3/ 286.5T

**C8.2 Per capita income in Blacksburg, Christiansburg
and Roanoke (city and county)**

TIME/ 1990.	PCI1/ 8.68T	PCI2/ 12.67T	PCI3/ 12.10T
TIME/ 1991.	PCI1/ 8.57T	PCI2/ 12.84T	PCI3/ 12.34T
TIME/ 1992.	PCI1/ 8.52T	PCI2/ 13.02T	PCI3/ 12.59T
TIME/ 1993.	PCI1/ 8.57T	PCI2/ 13.22T	PCI3/ 12.85T
TIME/ 1994.	PCI1/ 8.76T	PCI2/ 13.45T	PCI3/ 13.13T

TIME/ 1995.	PCI1/ 9.06T	PCI2/ 13.70T	PCI3/ 13.42T
TIME/ 1996.	PCI1/ 9.45T	PCI2/ 13.97T	PCI3/ 13.72T
TIME/ 1997.	PCI1/ 9.91T	PCI2/ 14.27T	PCI3/ 14.04T
TIME/ 1998.	PCI1/ 10.39T	PCI2/ 14.59T	PCI3/ 14.37T
TIME/ 1999.	PCI1/ 10.89T	PCI2/ 14.94T	PCI3/ 14.72T
TIME/ 2000.	PCI1/ 11.39T	PCI2/ 15.32T	PCI3/ 15.09T
TIME/ 2001.	PCI1/ 11.91T	PCI2/ 15.74T	PCI3/ 15.48T
TIME/ 2002.	PCI1/ 12.45T	PCI2/ 16.19T	PCI3/ 15.89T
TIME/ 2003.	PCI1/ 13.02T	PCI2/ 16.67T	PCI3/ 16.31T
TIME/ 2004.	PCI1/ 13.64T	PCI2/ 17.19T	PCI3/ 16.76T
TIME/ 2005.	PCI1/ 14.31T	PCI2/ 17.76T	PCI3/ 17.24T
TIME/ 2006.	PCI1/ 15.04T	PCI2/ 18.37T	PCI3/ 17.74T
TIME/ 2007.	PCI1/ 15.82T	PCI2/ 19.03T	PCI3/ 18.26T
TIME/ 2008.	PCI1/ 16.66T	PCI2/ 19.74T	PCI3/ 18.81T
TIME/ 2009.	PCI1/ 17.57T	PCI2/ 20.51T	PCI3/ 19.39T
TIME/ 2010.	PCI1/ 18.54T	PCI2/ 21.33T	PCI3/ 20.00T
TIME/ 2011.	PCI1/ 19.57T	PCI2/ 22.23T	PCI3/ 20.65T
TIME/ 2012.	PCI1/ 20.68T	PCI2/ 23.19T	PCI3/ 21.33T
TIME/	PCI1/	PCI2/	PCI3/

2013.	21.87T	24.24T	22.05T
TIME/ 2014.	PCI1/ 23.14T	PCI2/ 25.37T	PCI3/ 22.81T
TIME/ 2015.	PCI1/ 24.51T	PCI2/ 26.59T	PCI3/ 23.61T

C8.3 Funded research and total graduate student at Virginia Tech

TIME/ 1990.	FR/ 64.7M	TGS/ 4111.
TIME/ 1991.	FR/ 53.8M	TGS/ 3891.
TIME/ 1992.	FR/ 42.7M	TGS/ 3743.
TIME/ 1993.	FR/ 36.1M	TGS/ 3711.
TIME/ 1994.	FR/ 36.1M	TGS/ 3780.
TIME/ 1995.	FR/ 42.6M	TGS/ 3901.
TIME/ 1996.	FR/ 53.8M	TGS/ 4034.
TIME/ 1997.	FR/ 67.2M	TGS/ 4158.
TIME/ 1998.	FR/ 80.4M	TGS/ 4263.
TIME/ 1999.	FR/ 92.0M	TGS/ 4348.
TIME/ 2000.	FR/ 101.2M	TGS/ 4412.
TIME/ 2001.	FR/ 108.3M	TGS/ 4458.
TIME/ 2002.	FR/ 114.1M	TGS/ 4493.
TIME/ 2003.	FR/ 119.2M	TGS/ 4524.

TIME/ 2004.	FR/ 124.5M	TGS/ 4555.

TIME/ 2005.	FR/ 130.2M	TGS/ 4591.

TIME/ 2006.	FR/ 136.6M	TGS/ 4630.

TIME/ 2007.	FR/ 143.7M	TGS/ 4673.

TIME/ 2008.	FR/ 151.2M	TGS/ 4718.

TIME/ 2009.	FR/ 158.9M	TGS/ 4762.

TIME/ 2010.	FR/ 166.7M	TGS/ 4804.

TIME/ 2011.	FR/ 174.5M	TGS/ 4844.

TIME/ 2012.	FR/ 182.1M	TGS/ 4881.

TIME/ 2013.	FR/ 189.6M	TGS/ 4917.

TIME/ 2014.	FR/ 197.0M	TGS/ 4950.

TIME/ 2015.	FR/ 204.3M	TGS/ 4982.

Appendix D Graphs Output

Fig. 42 to Fig.49 shows the population of Blacksburg for each alternative plotted over time, Fig.50 to Fig.57 shows the population of Christiansburg for each alternative plotted over time, Fig.58 to Fig.65 shows the population of Roanoke for each alternative plotted over time, Fig.66 to Fig.73 shows the per capita income of Blacksburg for each alternative plotted over time, Fig.74 to Fig.81 shows the per capita income of Christiansburg for each alternative plotted over time, Fig.82 to Fig.89 shows the per capita income of Roanoke for each alternative plotted over time, Fig.90 to Fig.97 shows the funded research of Virginia Tech for each alternative plotted over time, Fig.100 to Fig.107 shows the total graduate student at Virginia Tech for each alternative plotted over time.

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 1
POPULATION OF BLACKSBURG

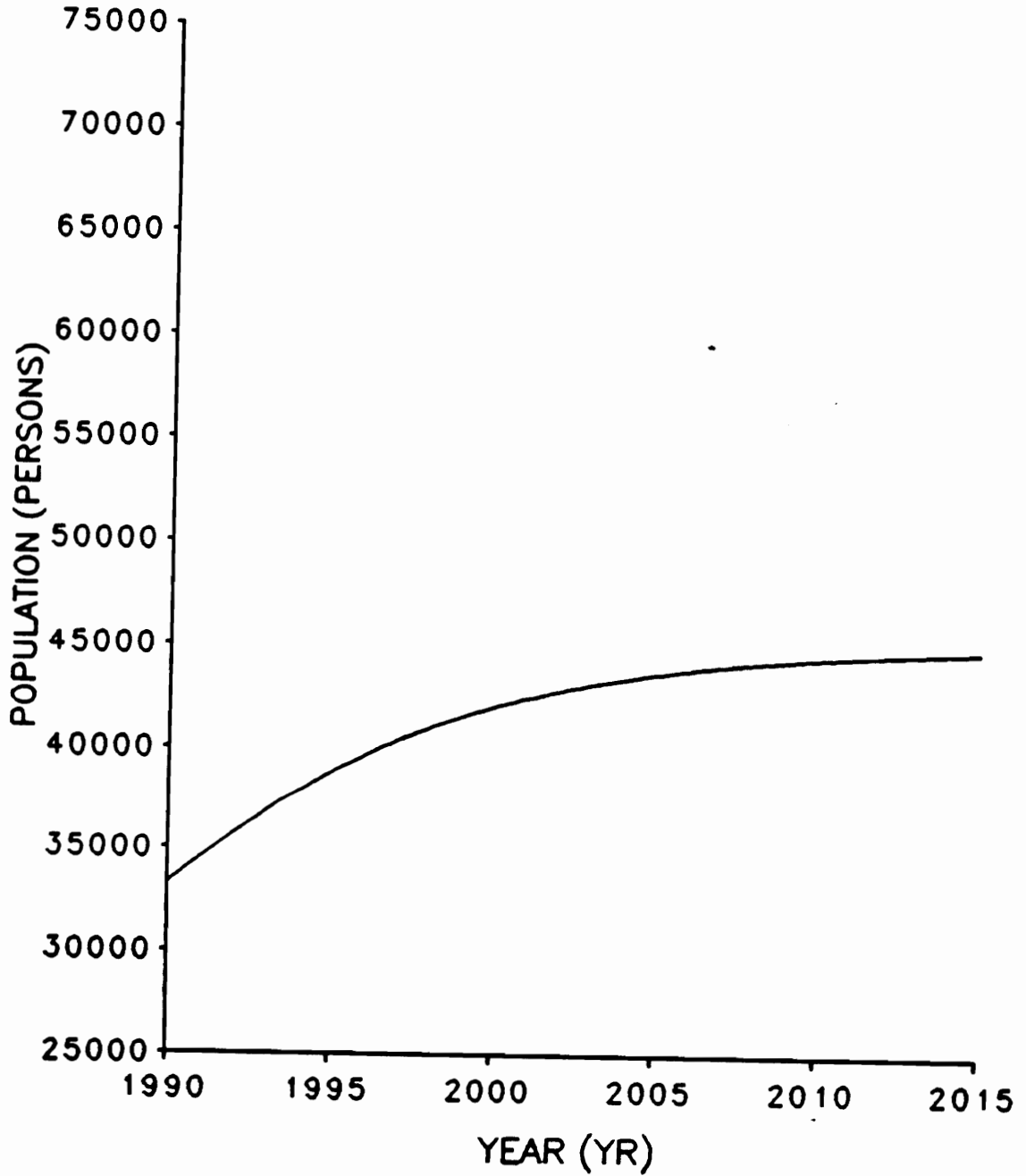


Figure 42. Alternative 1 Population of Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 2
POPULATION OF BLACKSBURG

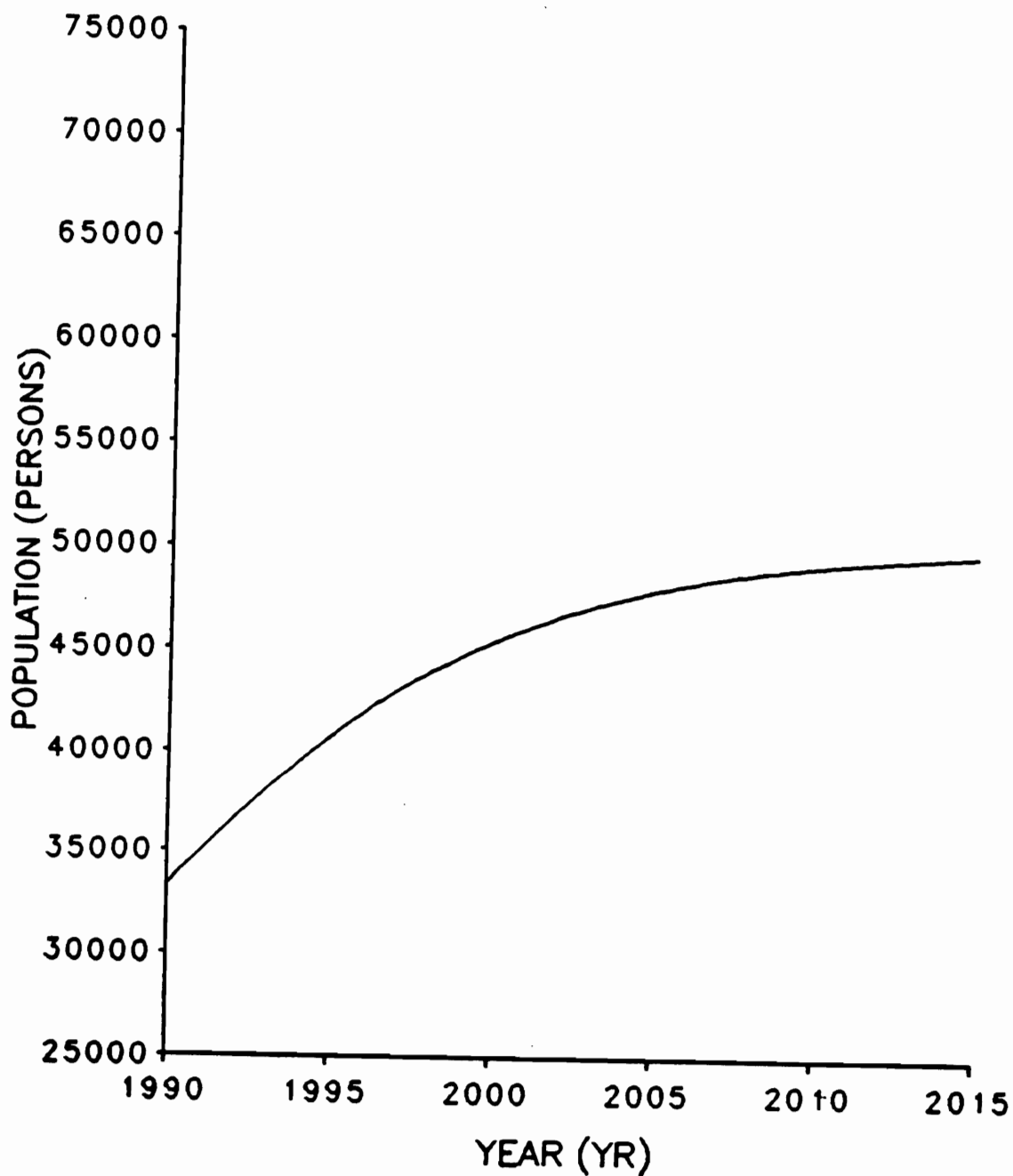


Figure 43. Alternative 2 Population of Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 3A
POPULATION OF BLACKSBURG

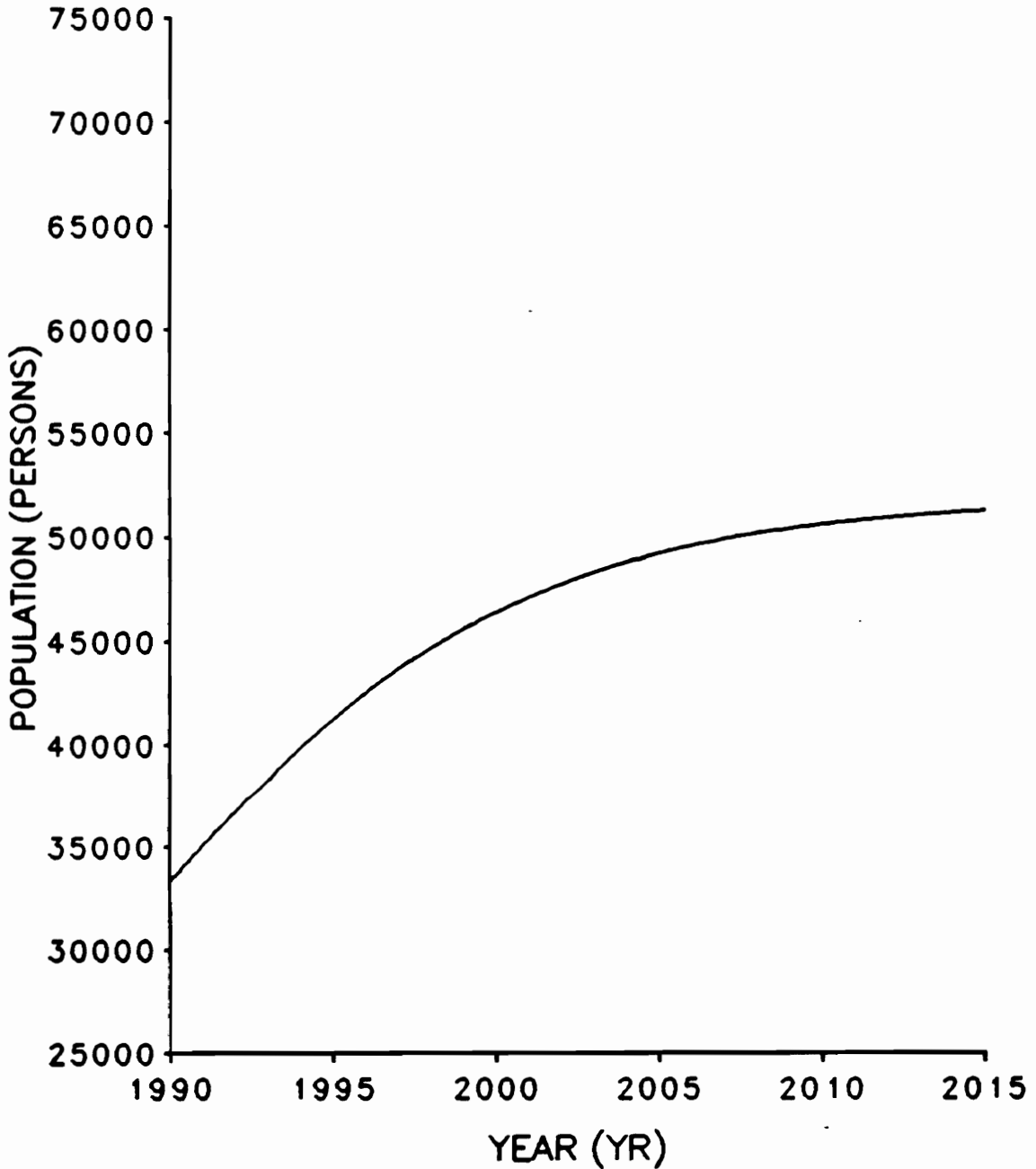


Figure 44. Alternative 3A Population of Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 5
POPULATION OF BLACKSBURG

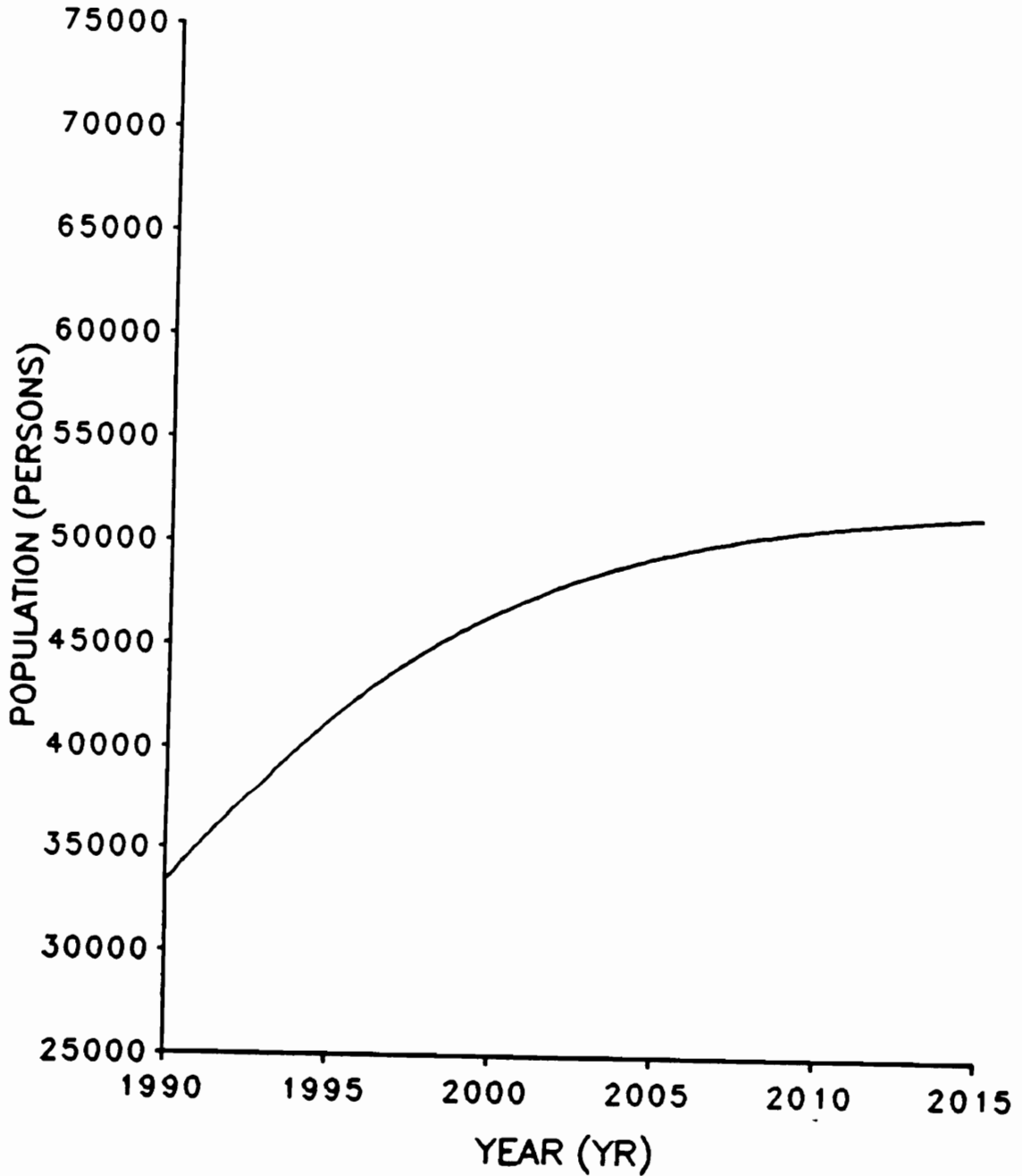


Figure 45. Alternative 5 Population of Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 12
POPULATION OF BLACKSBURG

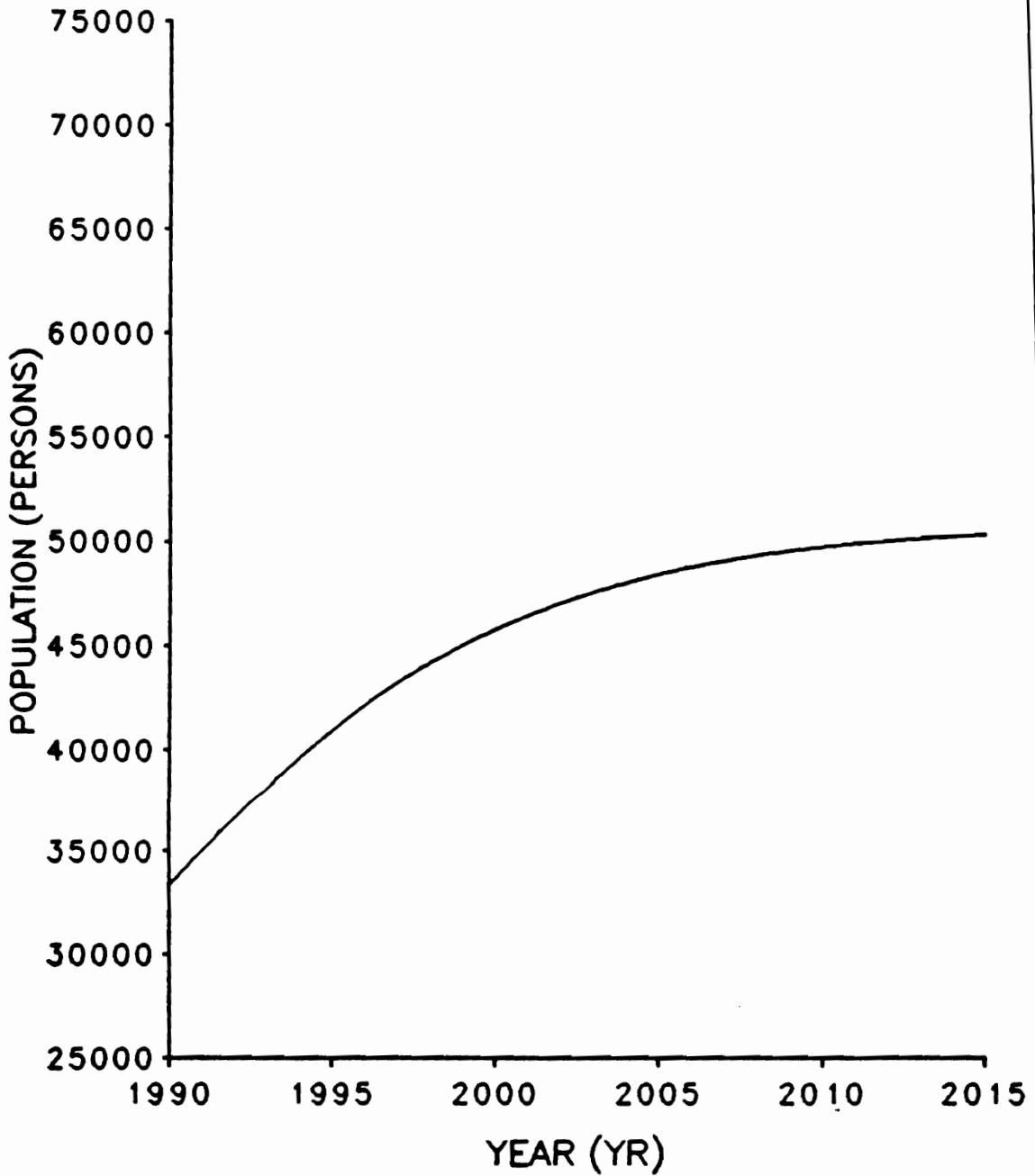


Figure 46. Alternative 12 Population of Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 6
POPULATION OF BLACKSBURG

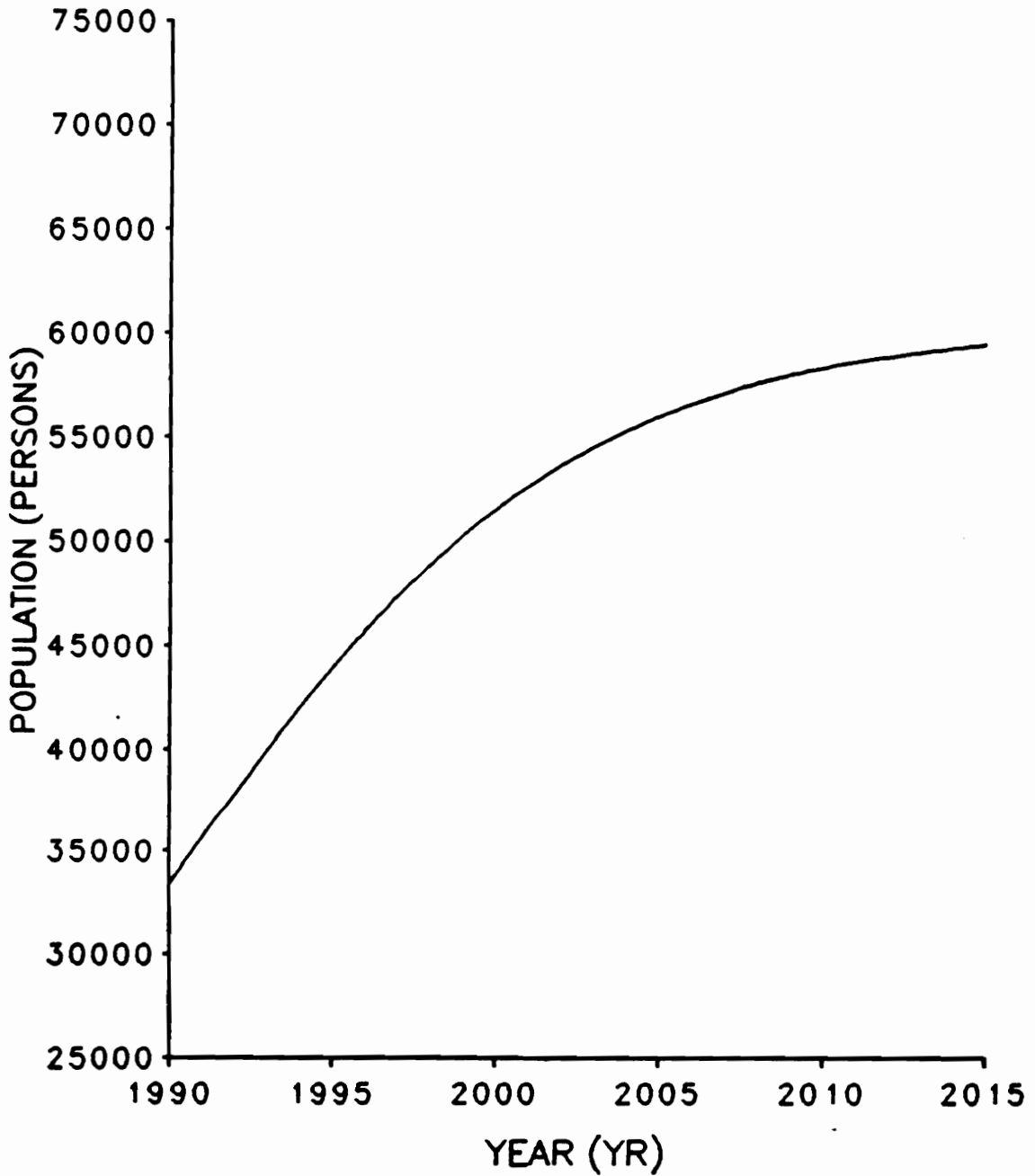


Figure 47. Alternative 6 Population of Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 7
POPULATION OF BLACKSBURG

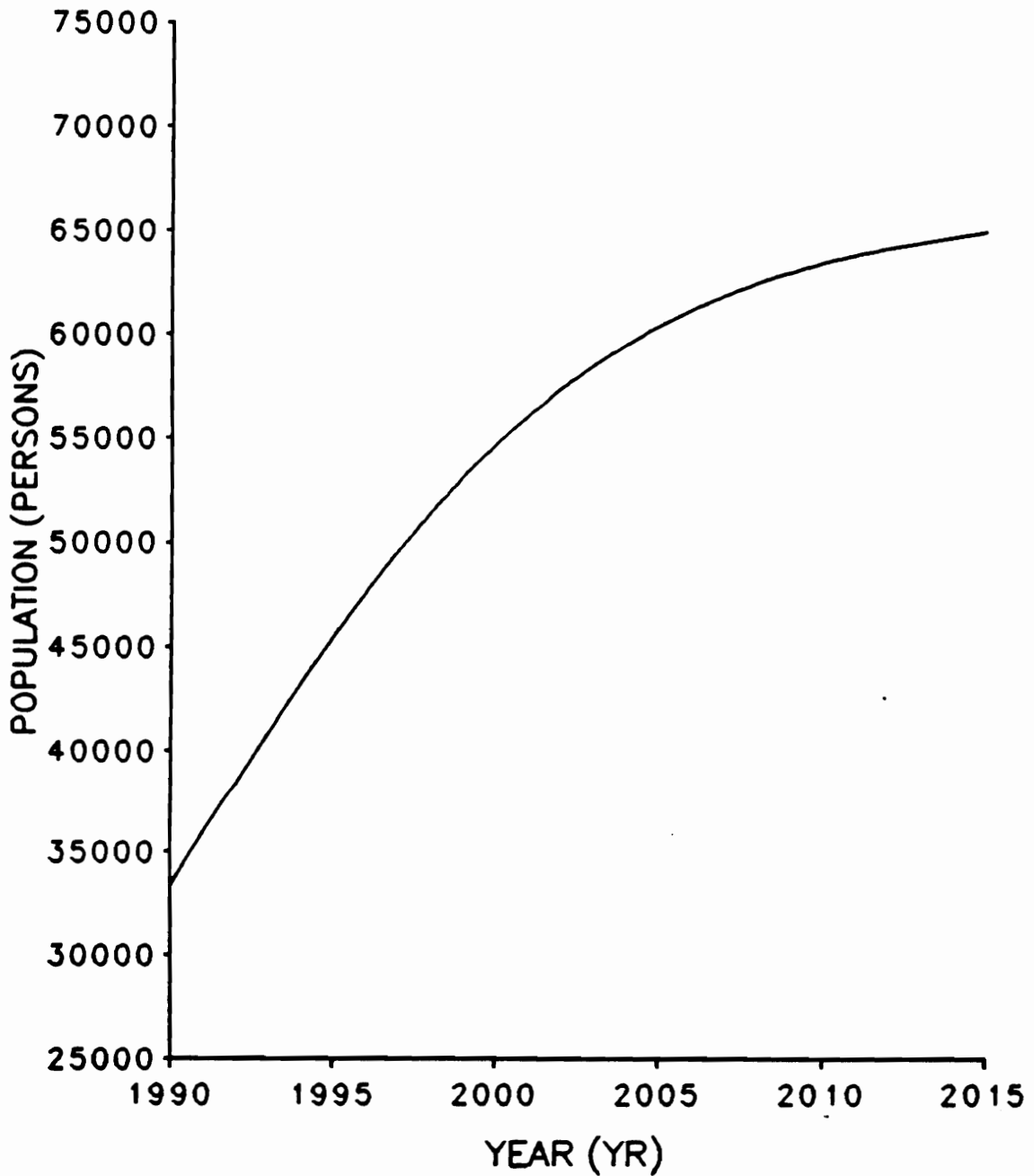


Figure 48. Alternative 7 Population of Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 10
POPULATION OF BLACKSBURG

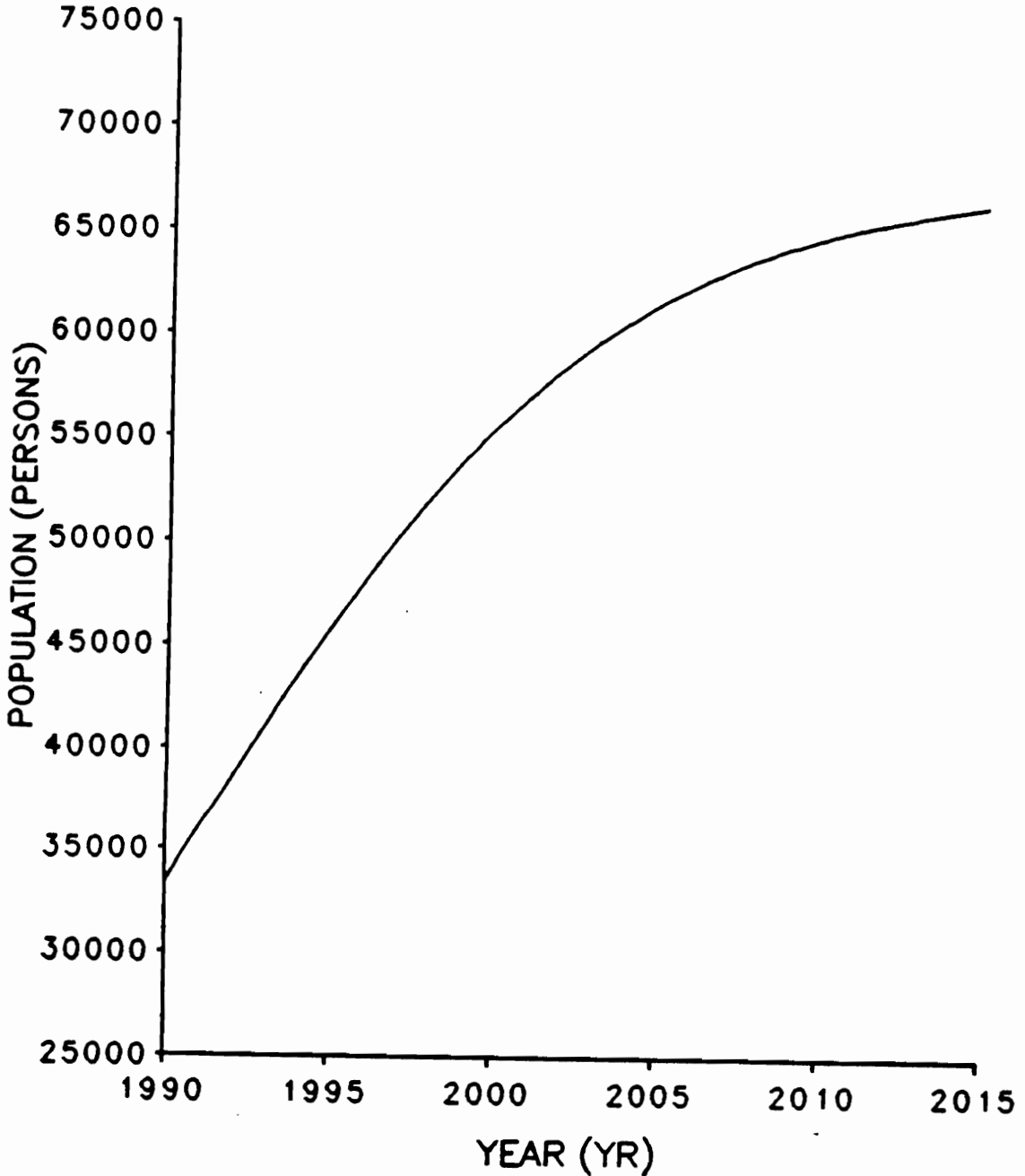


Figure 49. Alternative 10 Population of Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 1
POPULATION OF CHRISTIANSBURG

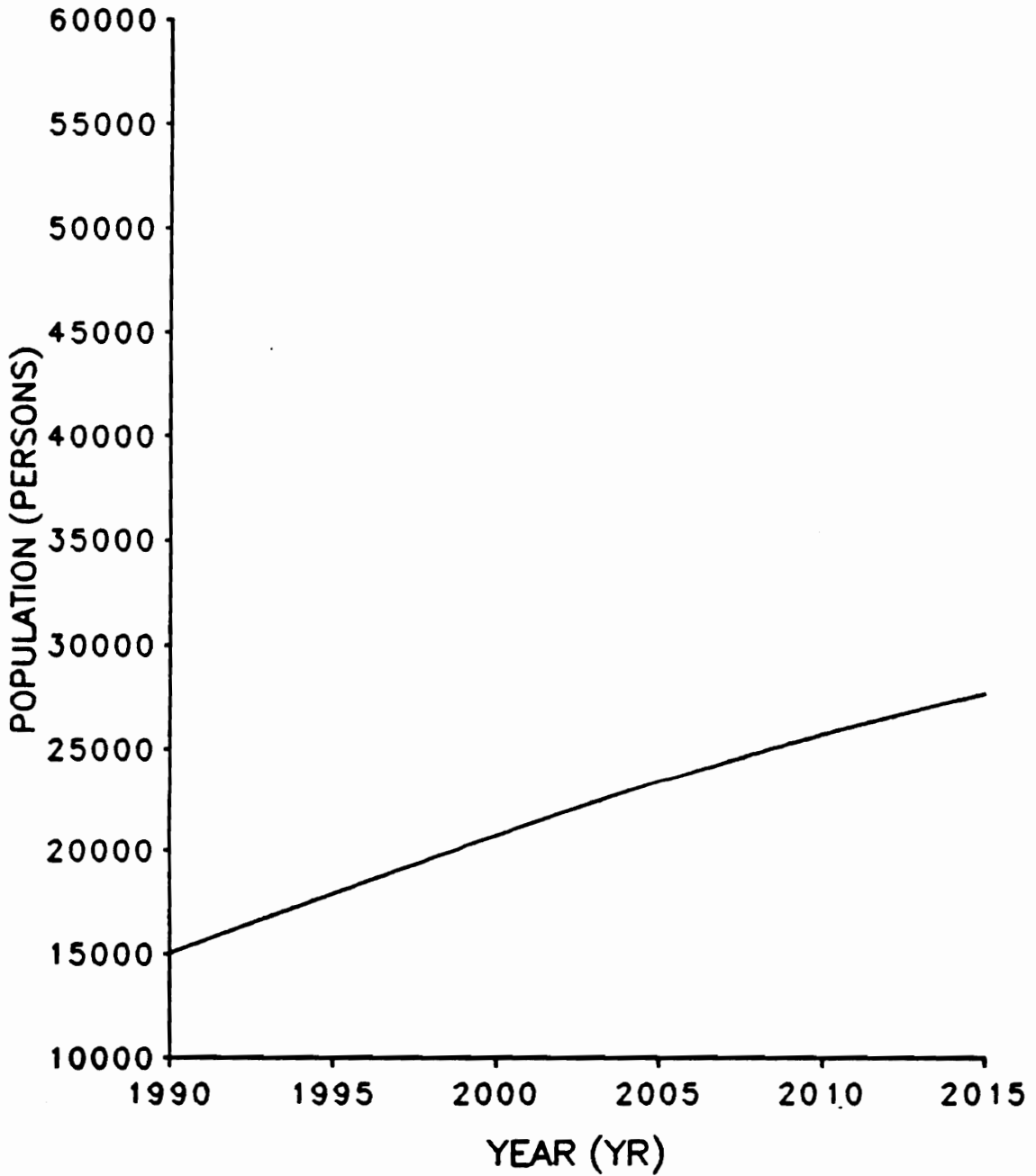


Figure 50. Alternative 1 Population of Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 2
POPULATION OF CHRISTIANSBURG

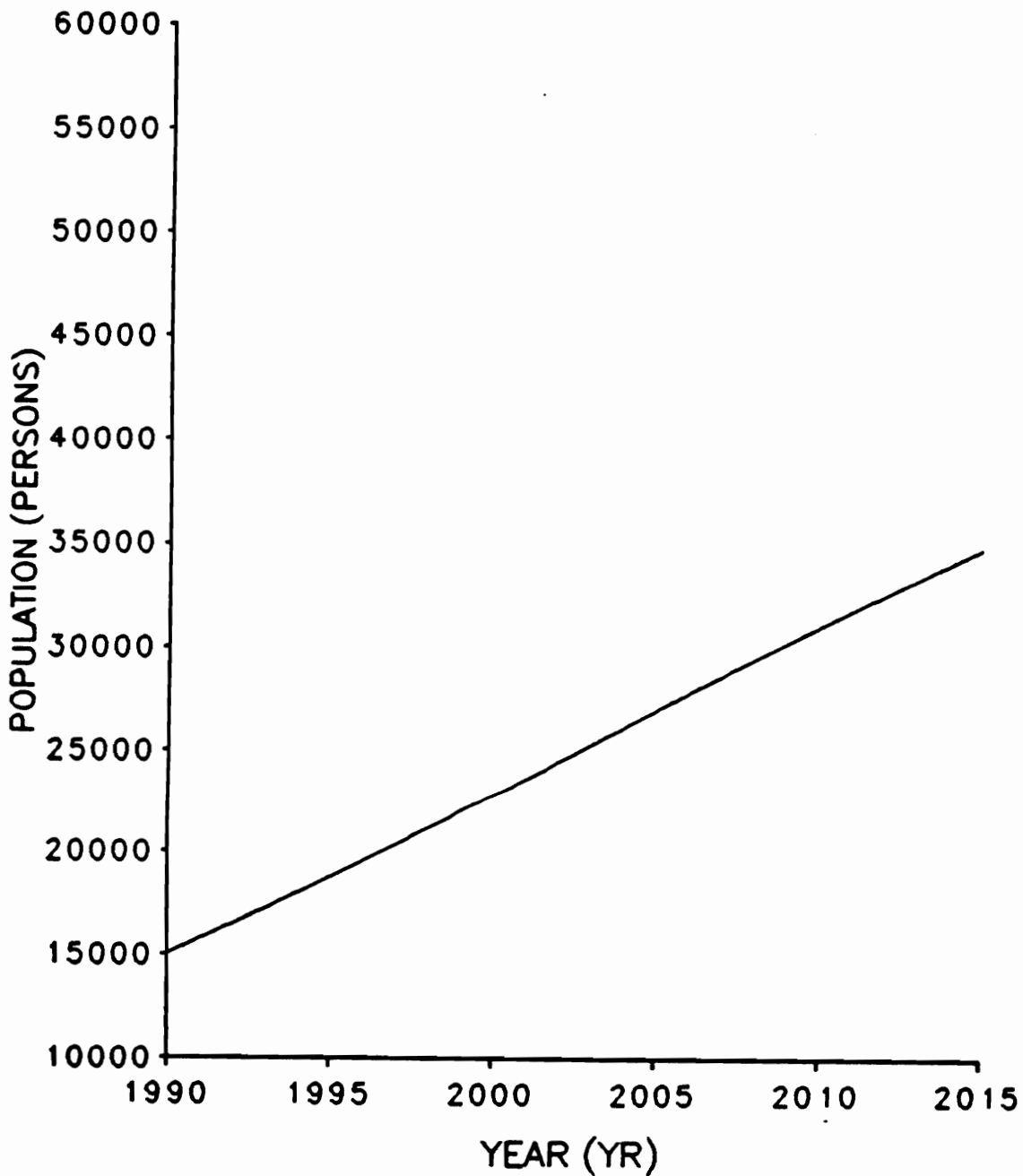


Figure 51. Alternative 2 Population of Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 3A
POPULATION OF CHRISTIANSBURG

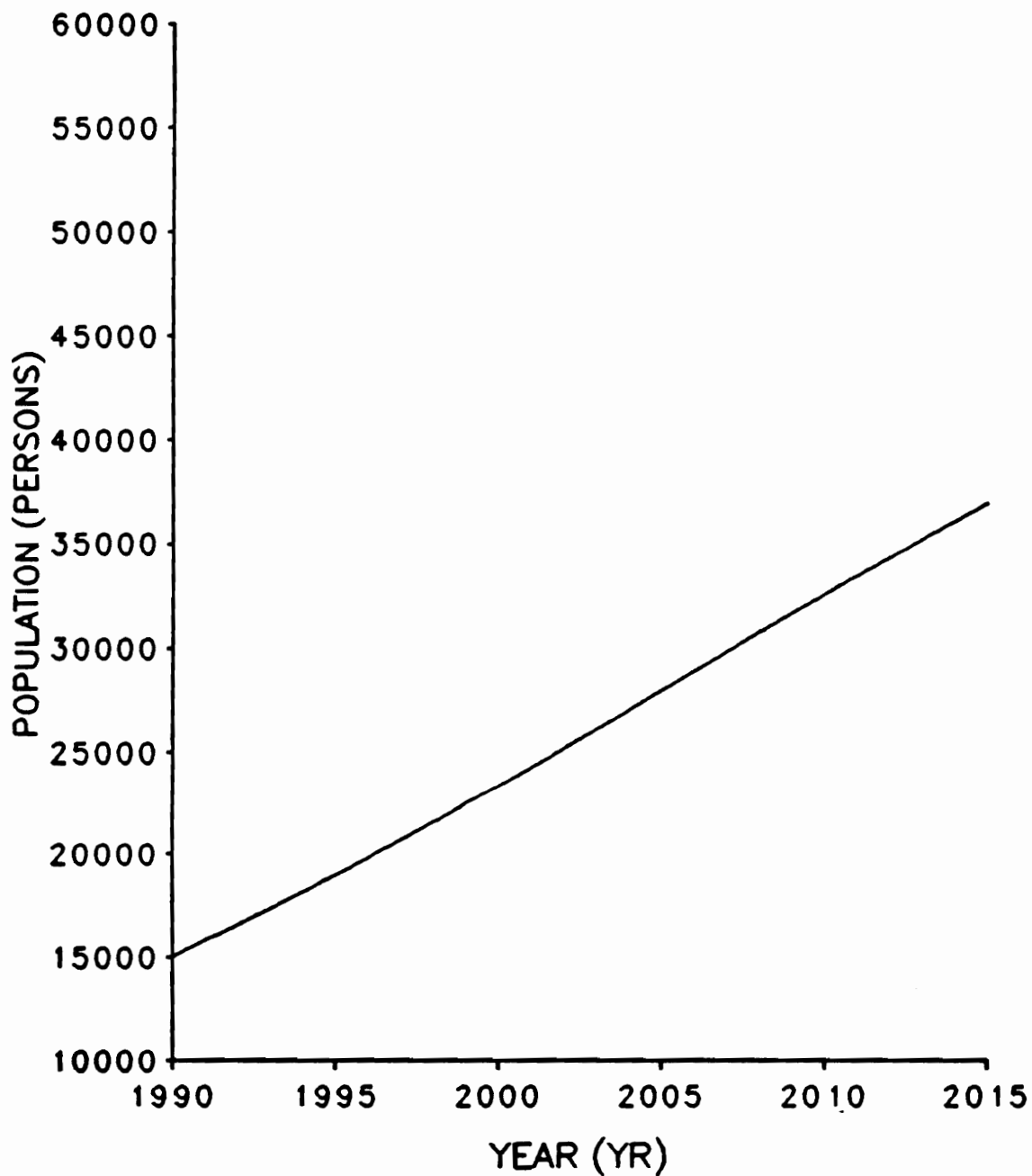


Figure 52. Alternative 3A Population of Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 5
POPULATION OF CHRISTIANSBURG

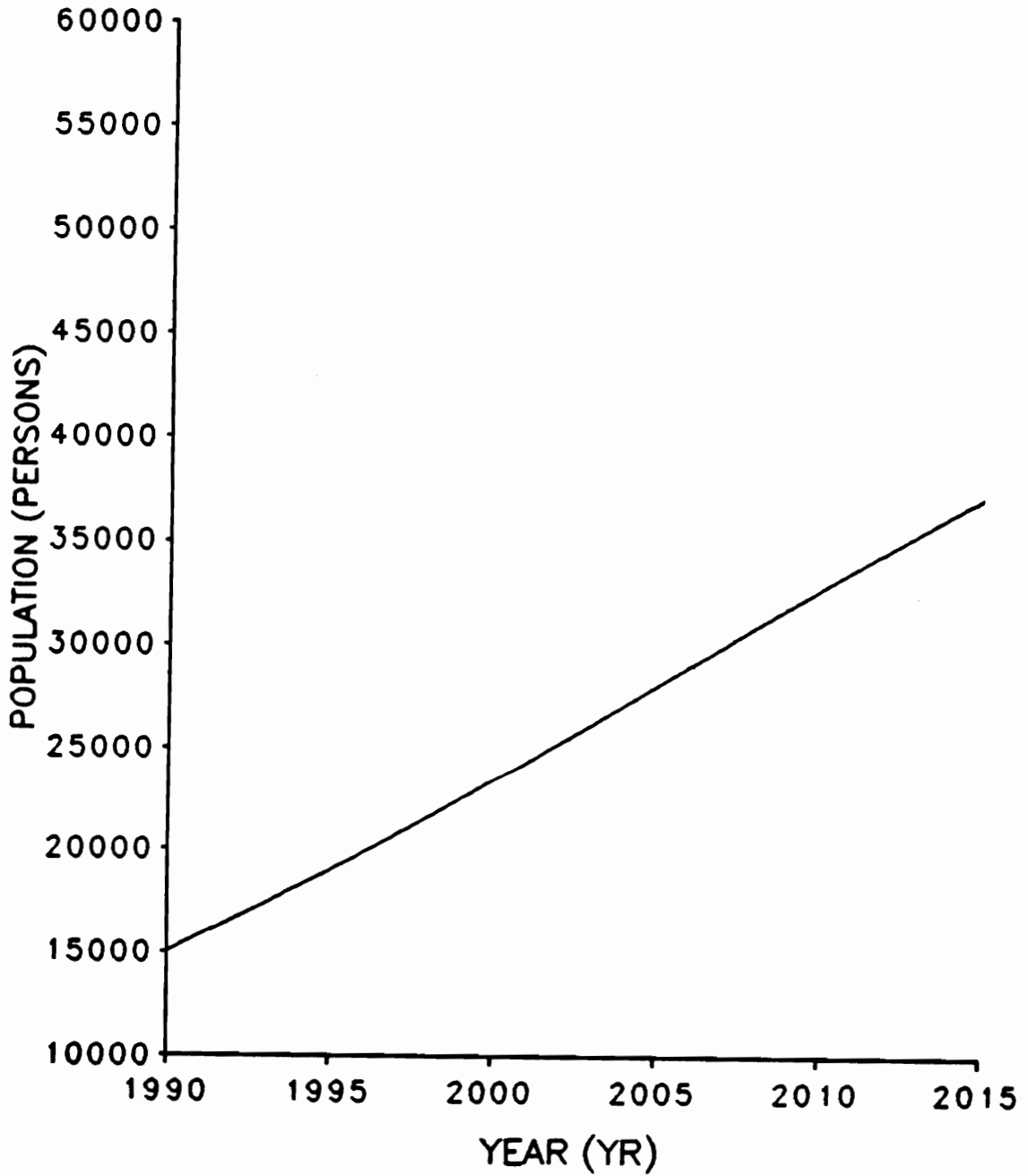


Figure 53. Alternative 5 Population of Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 12
POPULATION OF CHRISTIANSBURG

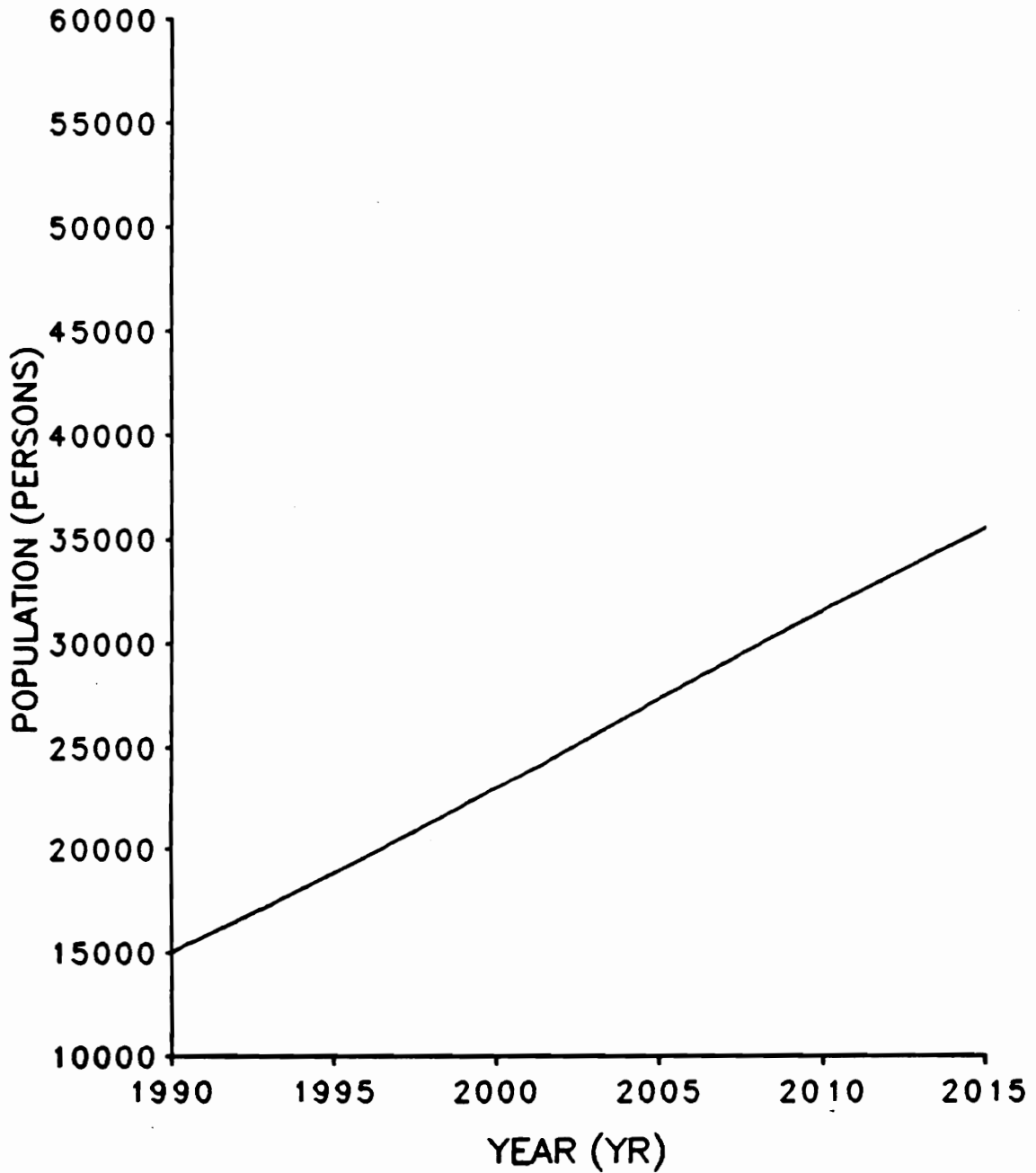


Figure 54. Alternative 12 Population of Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 6
POPULATION OF CHRISTIANSBURG

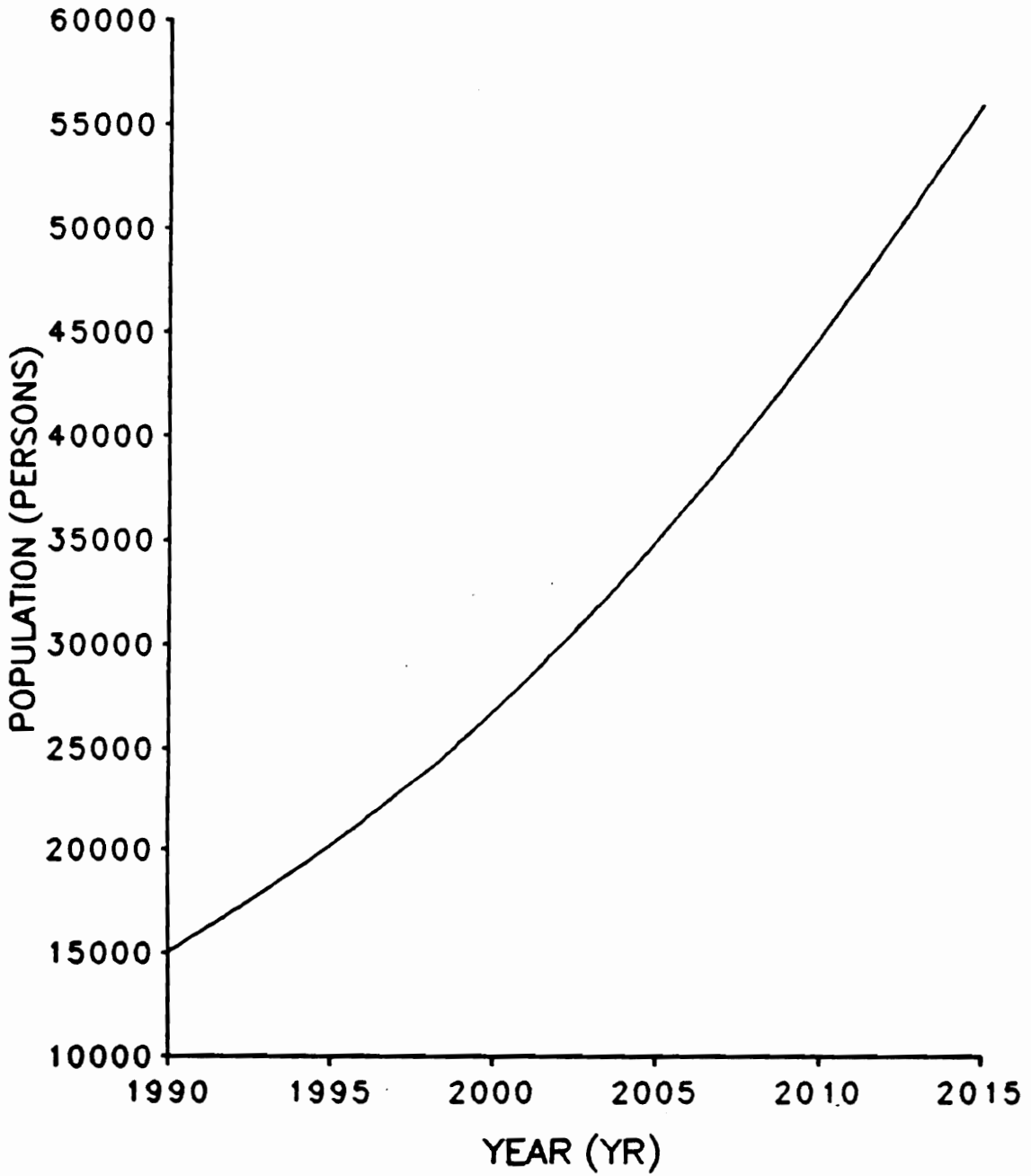


Figure 55. Alternative 6 Population of Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 7
POPULATION OF CHRISTIANSBURG

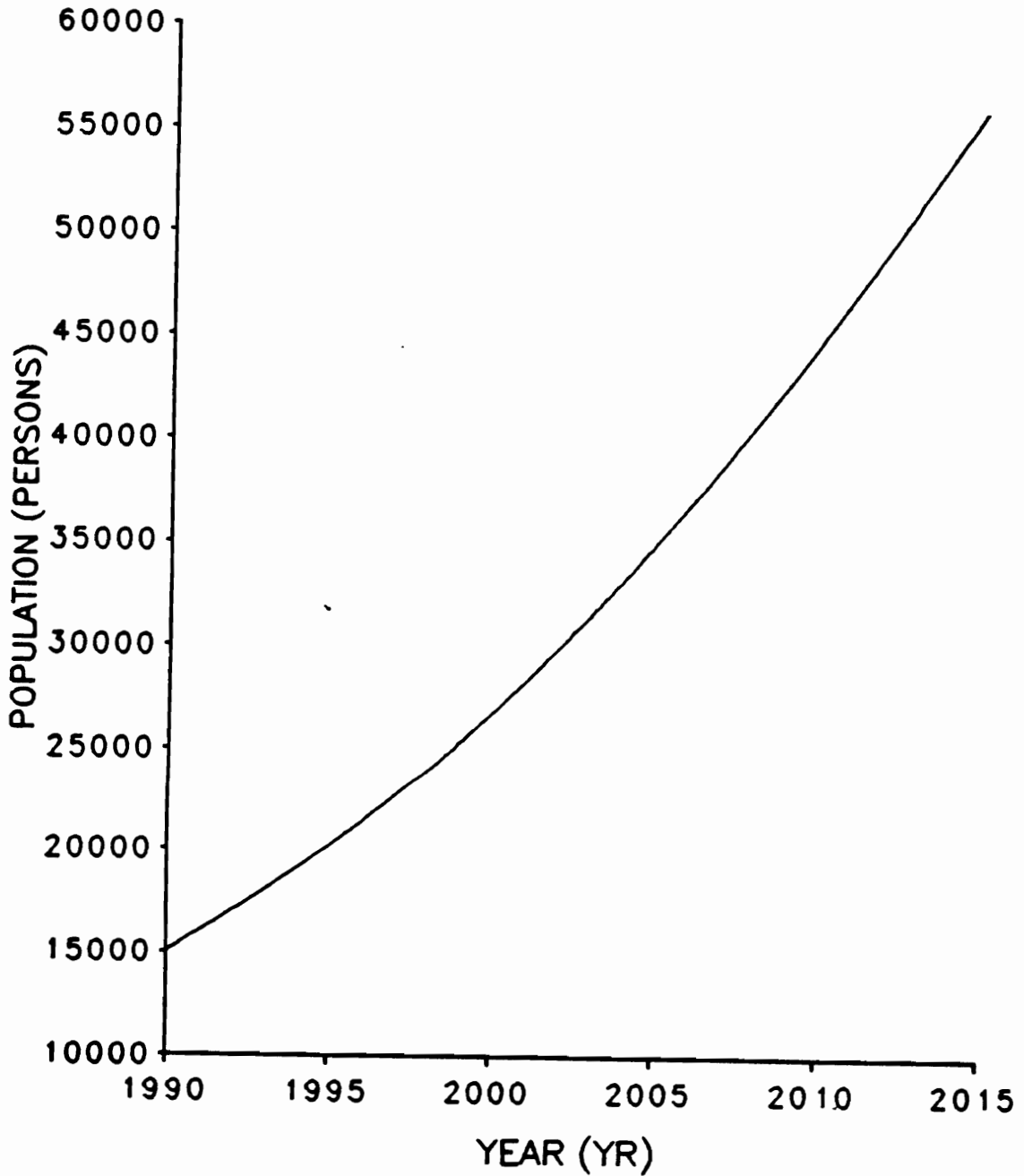


Figure 56. Alternative 7 Population of Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 10
POPULATION OF CHRISTIANSBURG

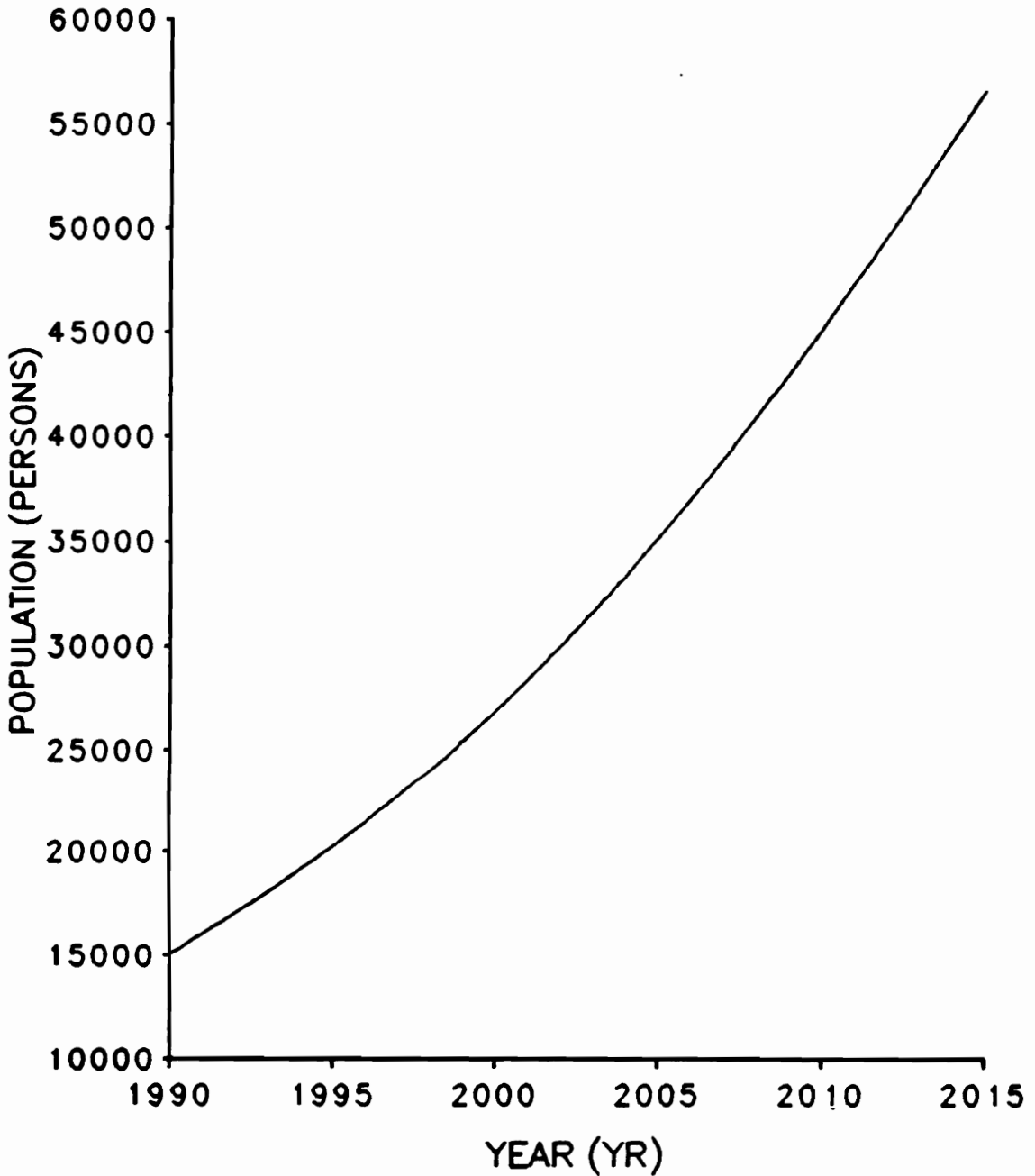


Figure 57. Alternative 10 Population of Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 1
POPULATION OF ROANOKE (CITY AND COUNTY)

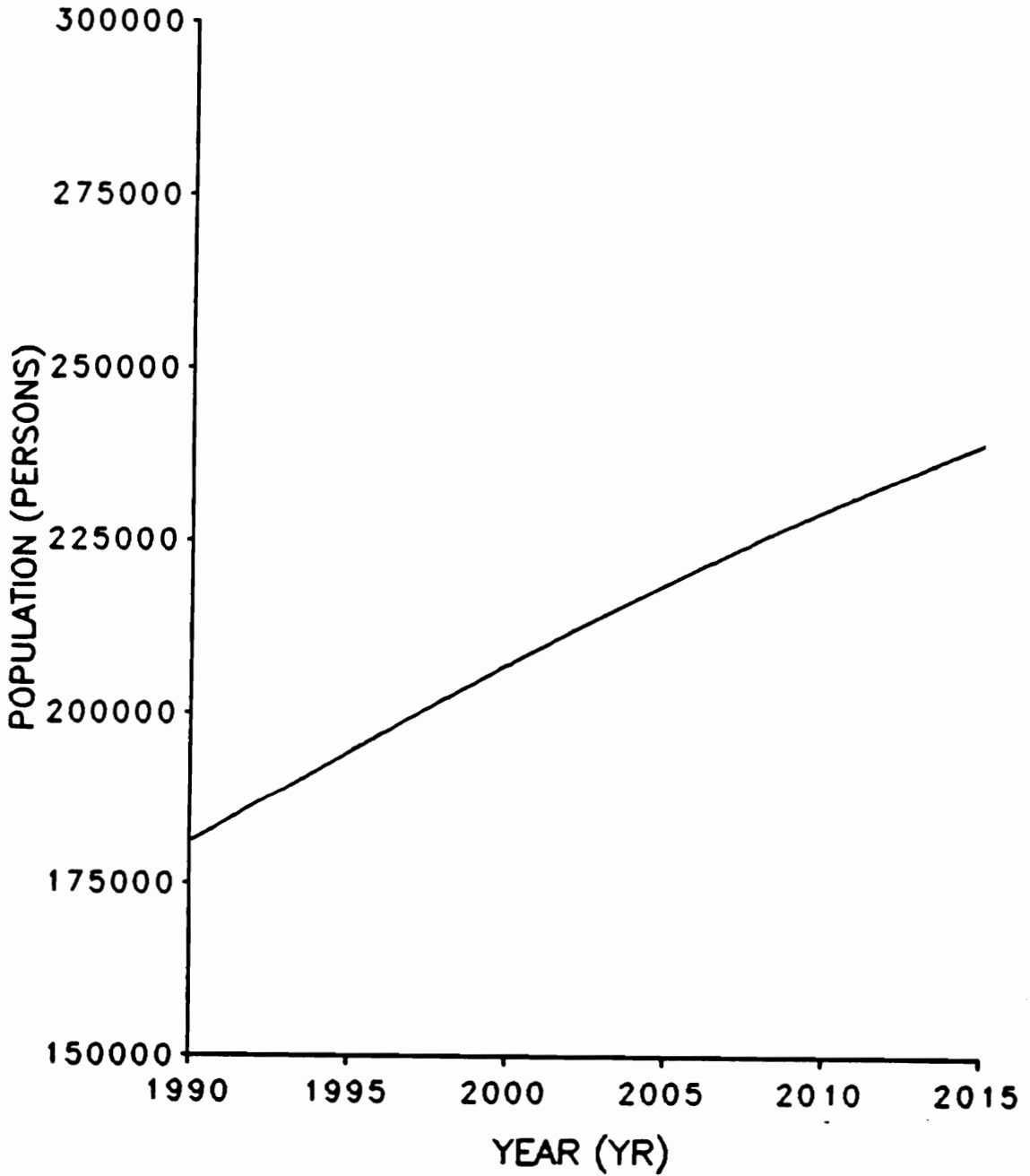


Figure 58. Alternative 1 Population of Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 2
POPULATION OF ROANOKE (CITY AND COUNTY)

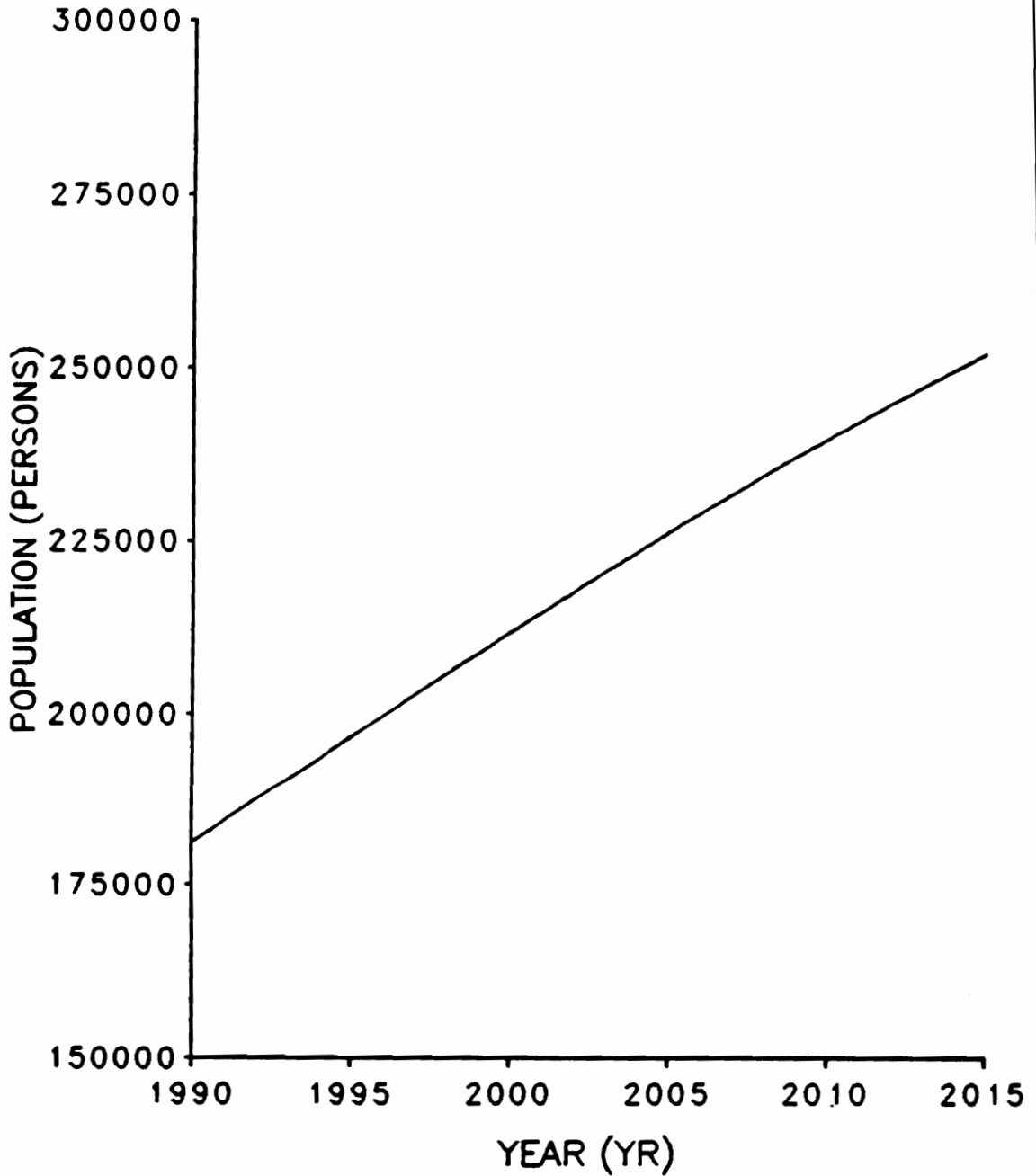


Figure 59. Alternative 2 Population of Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 3A
POPULATION OF ROANOKE (CITY AND COUNTY)

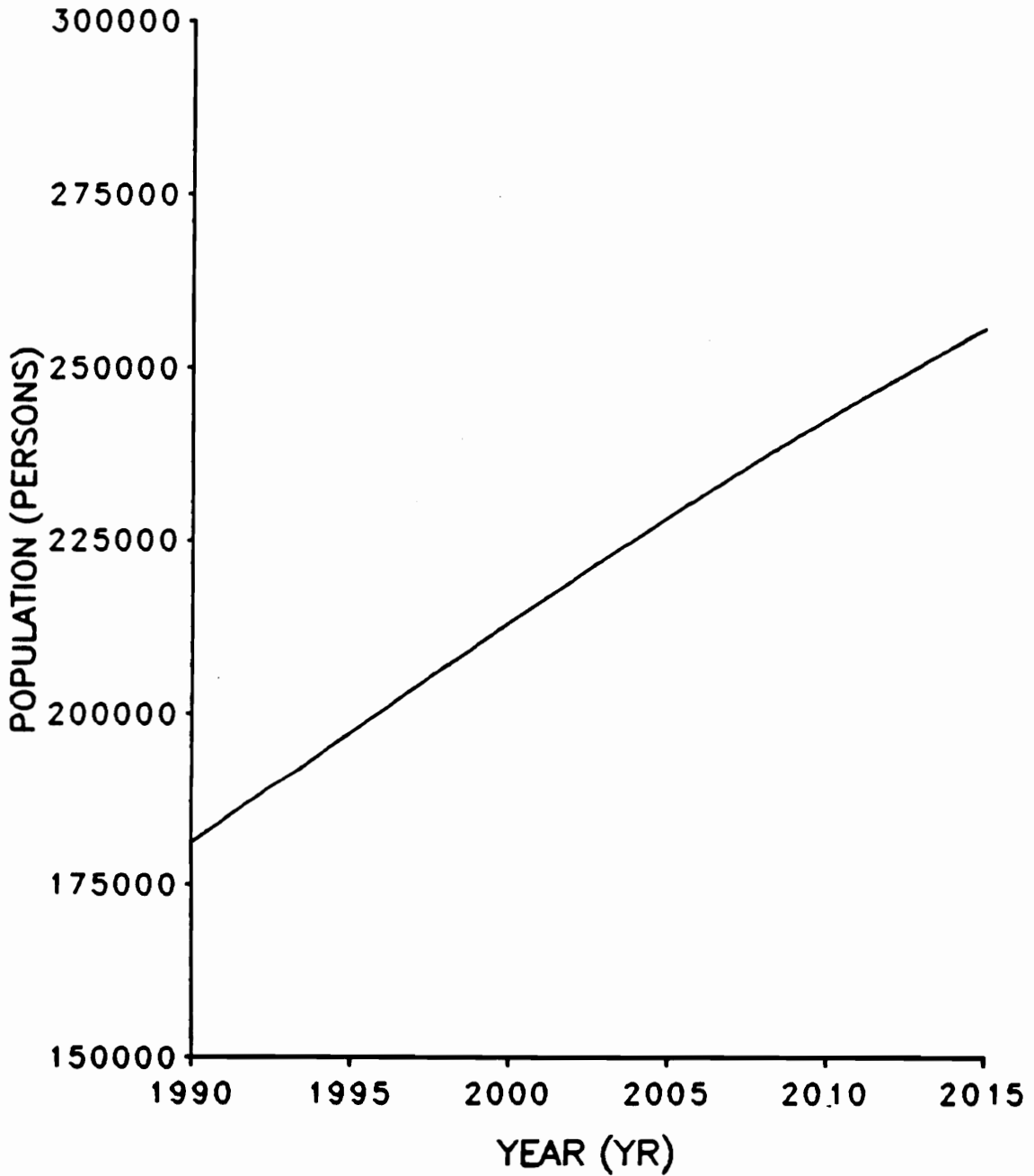


Figure 60. Alternative 3A Population of Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 5
POPULATION OF ROANOKE (CITY AND COUNTY)

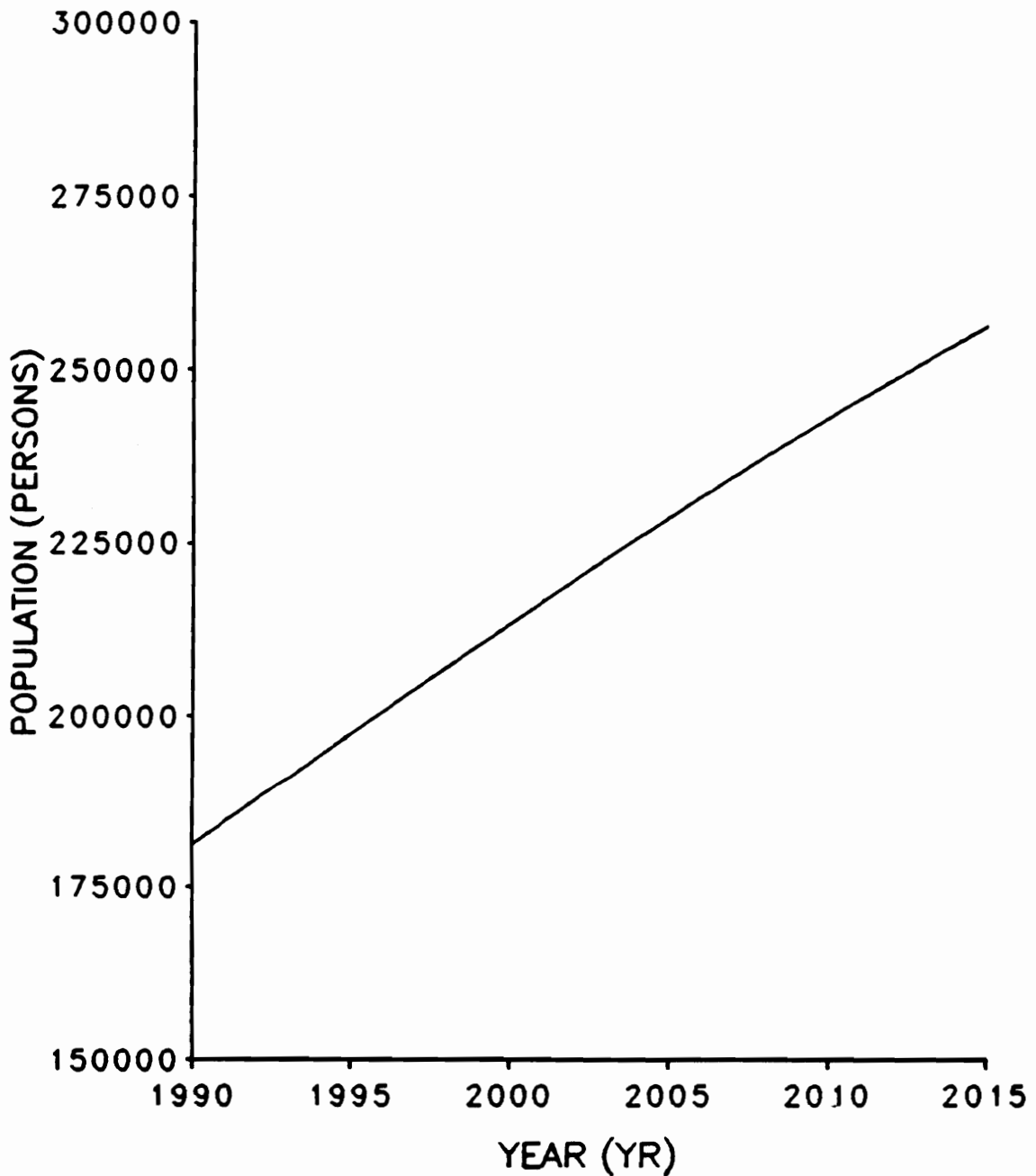


Figure 61. Alternative 5 Population of Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 12
POPULATION OF ROANOKE (CITY AND COUNTY)

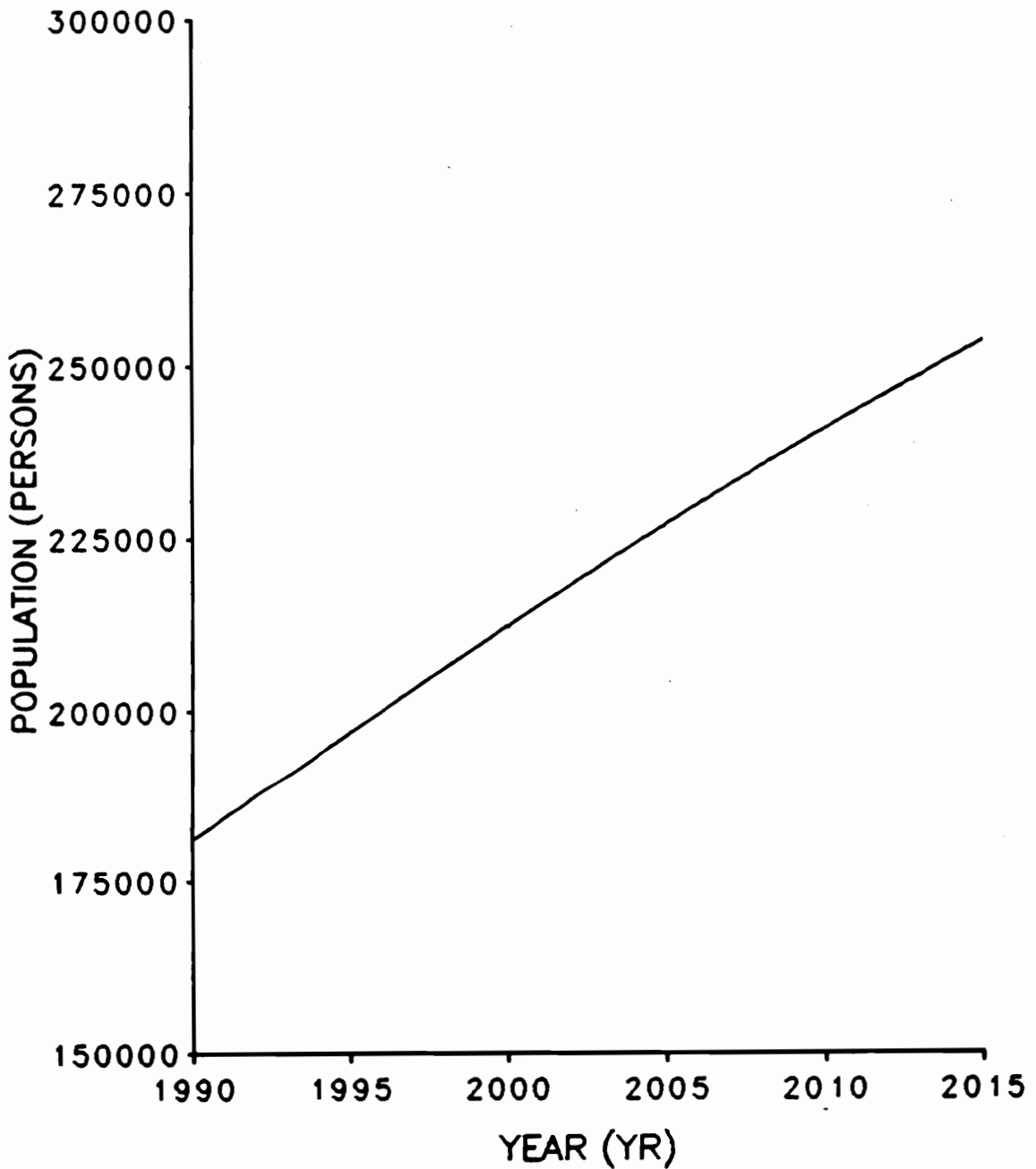


Figure 62. Alternative 12 Population of Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 6
POPULATION OF ROANOKE (CITY AND COUNTY)

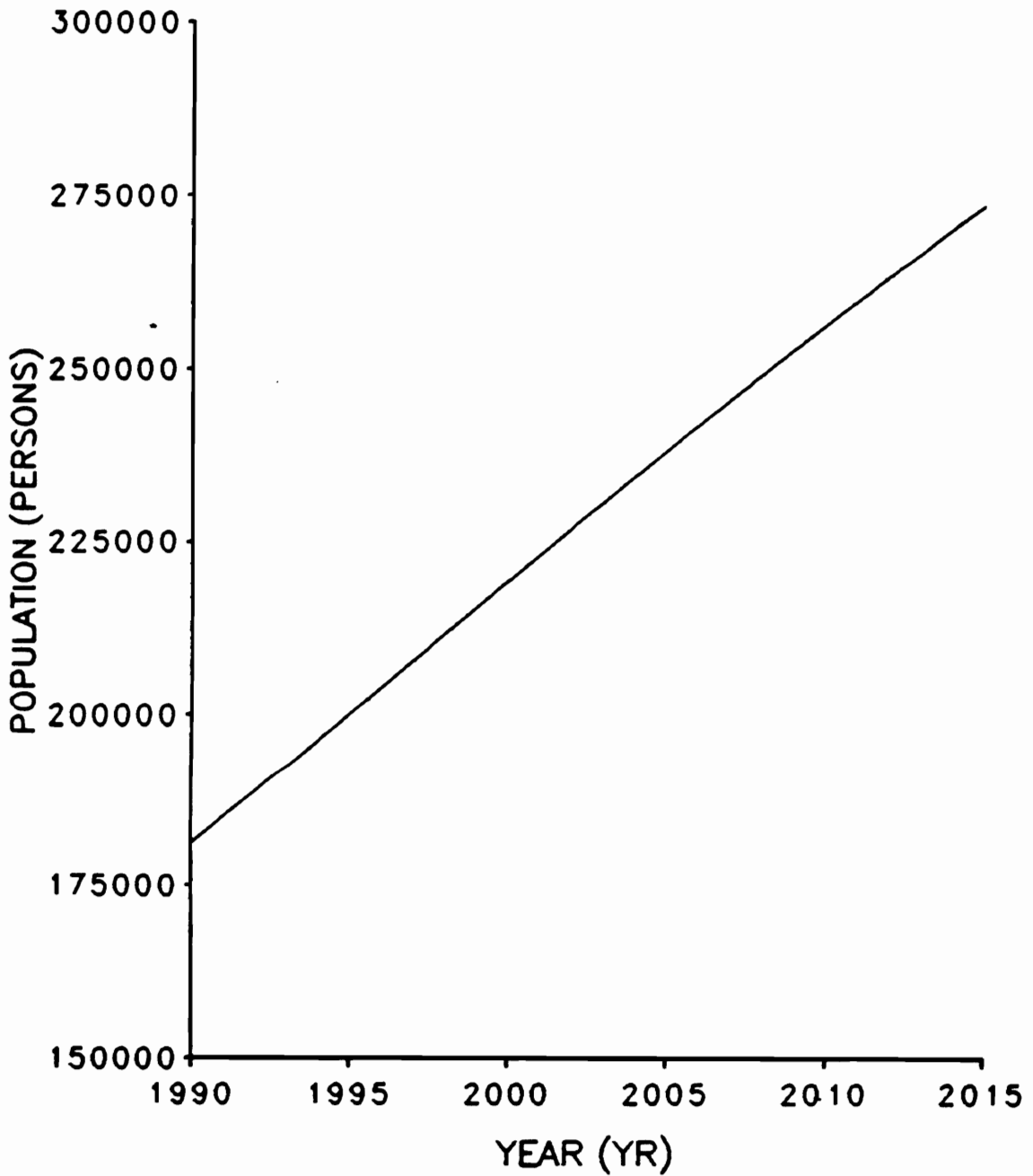


Figure 63. Alternative 6 Population of Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 7
POPULATION OF ROANOKE (CITY AND COUNTY)

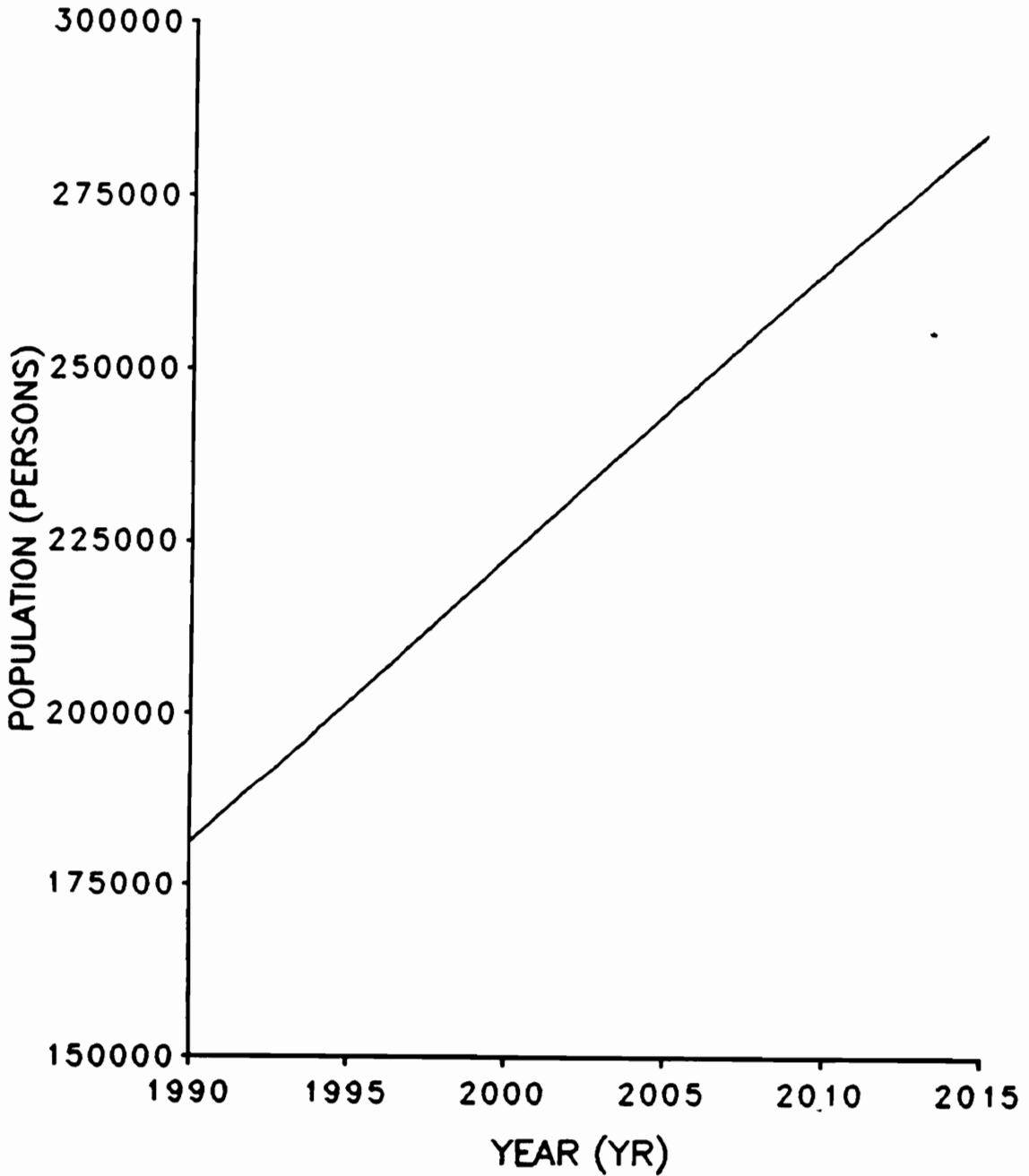


Figure 64. Alternative 7 Population of Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 10
POPULATION OF ROANOKE (CITY AND COUNTY)

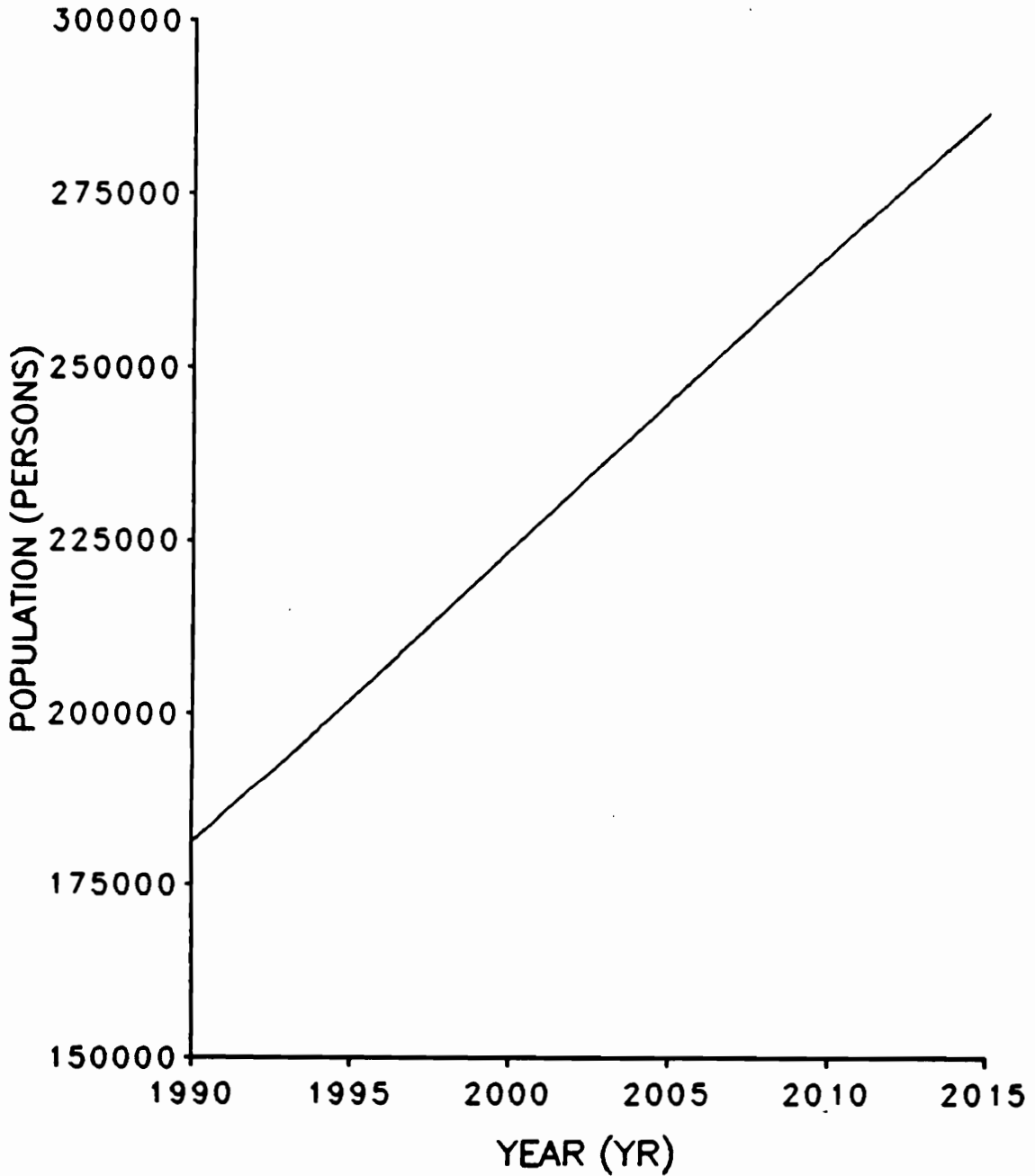


Figure 65. Alternative 10 Population of Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 1
PER CAPITA INCOME IN BLACKSBURG

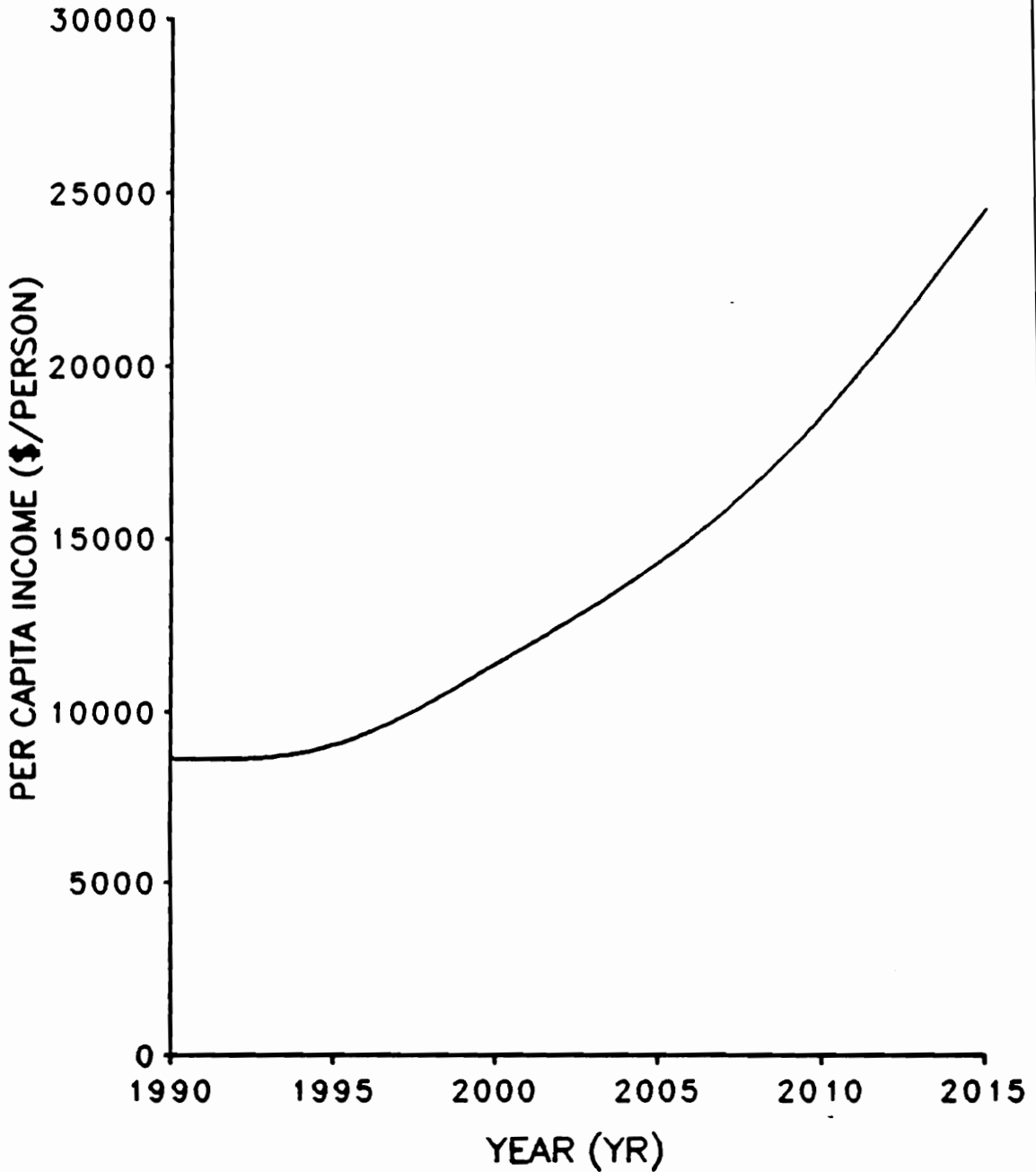


Figure 66. Alternative 1 Per capita income in Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 2
PER CAPITA INCOME IN BLACKSBURG

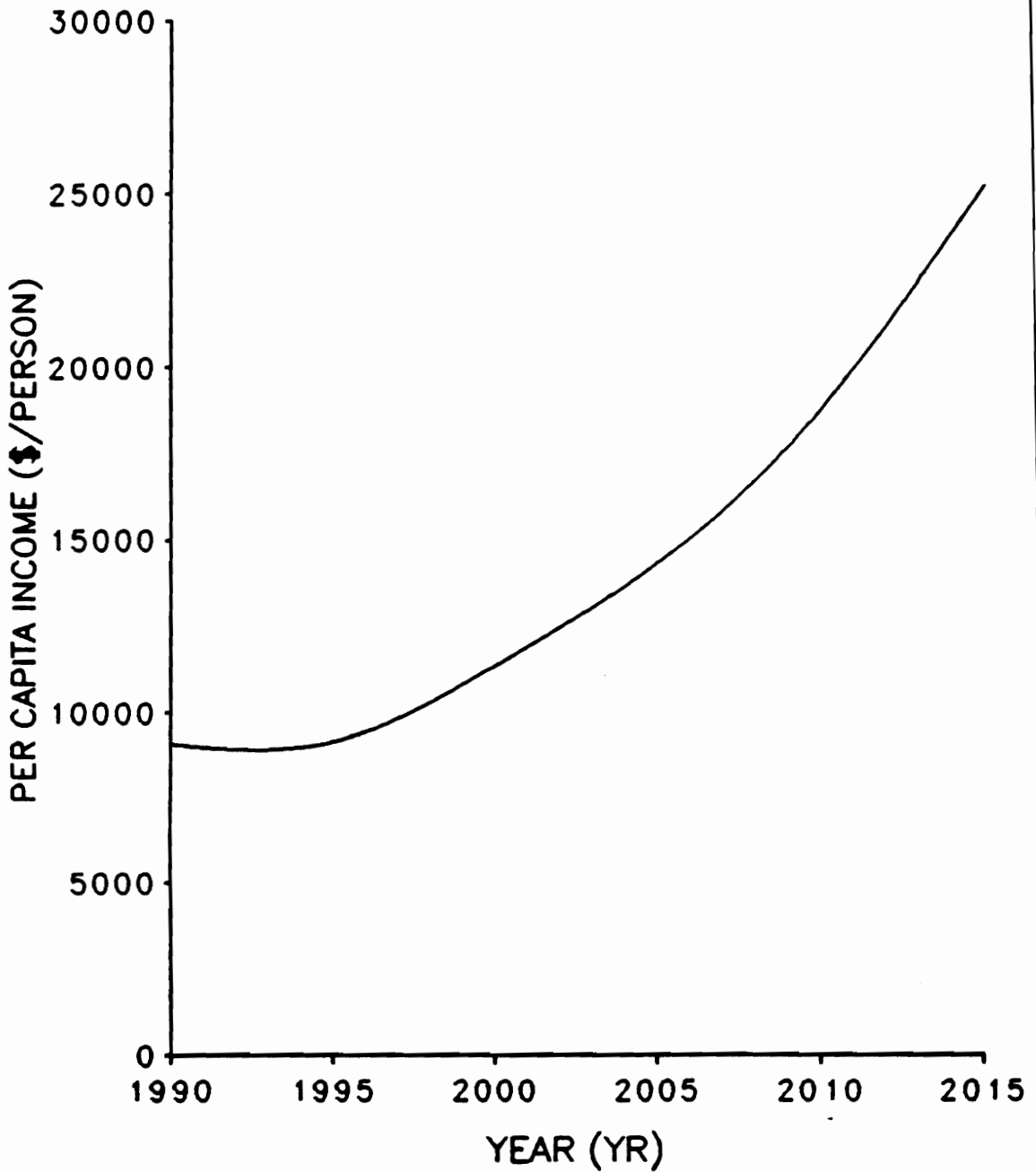


Figure 67. Alternative 2 Per capita income in Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 3A
PER CAPITA INCOME IN BLACKSBURG

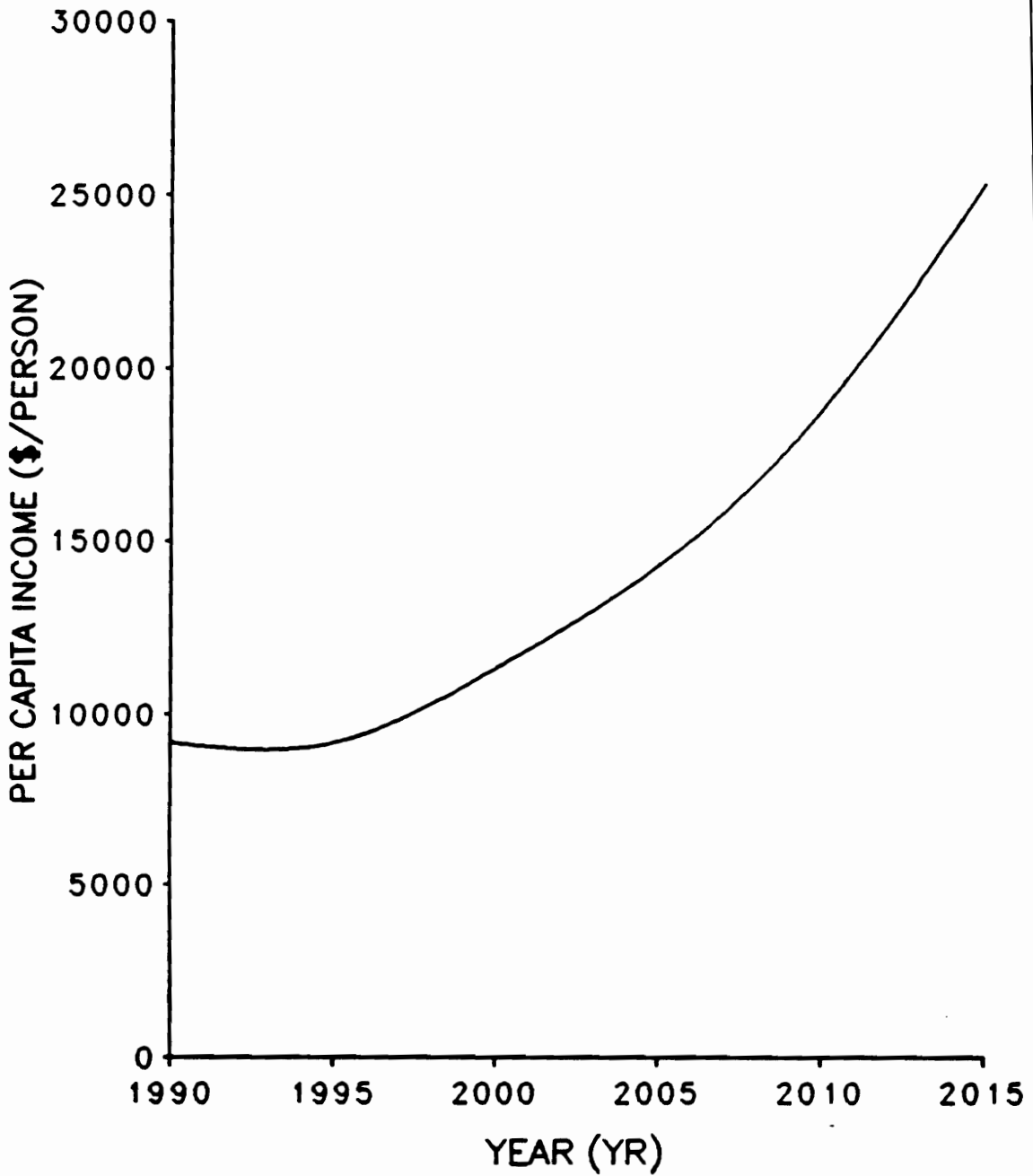


Figure 68. Alternative 3A Per capita Income in Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 5
PER CAPITA INCOME IN BLACKSBURG

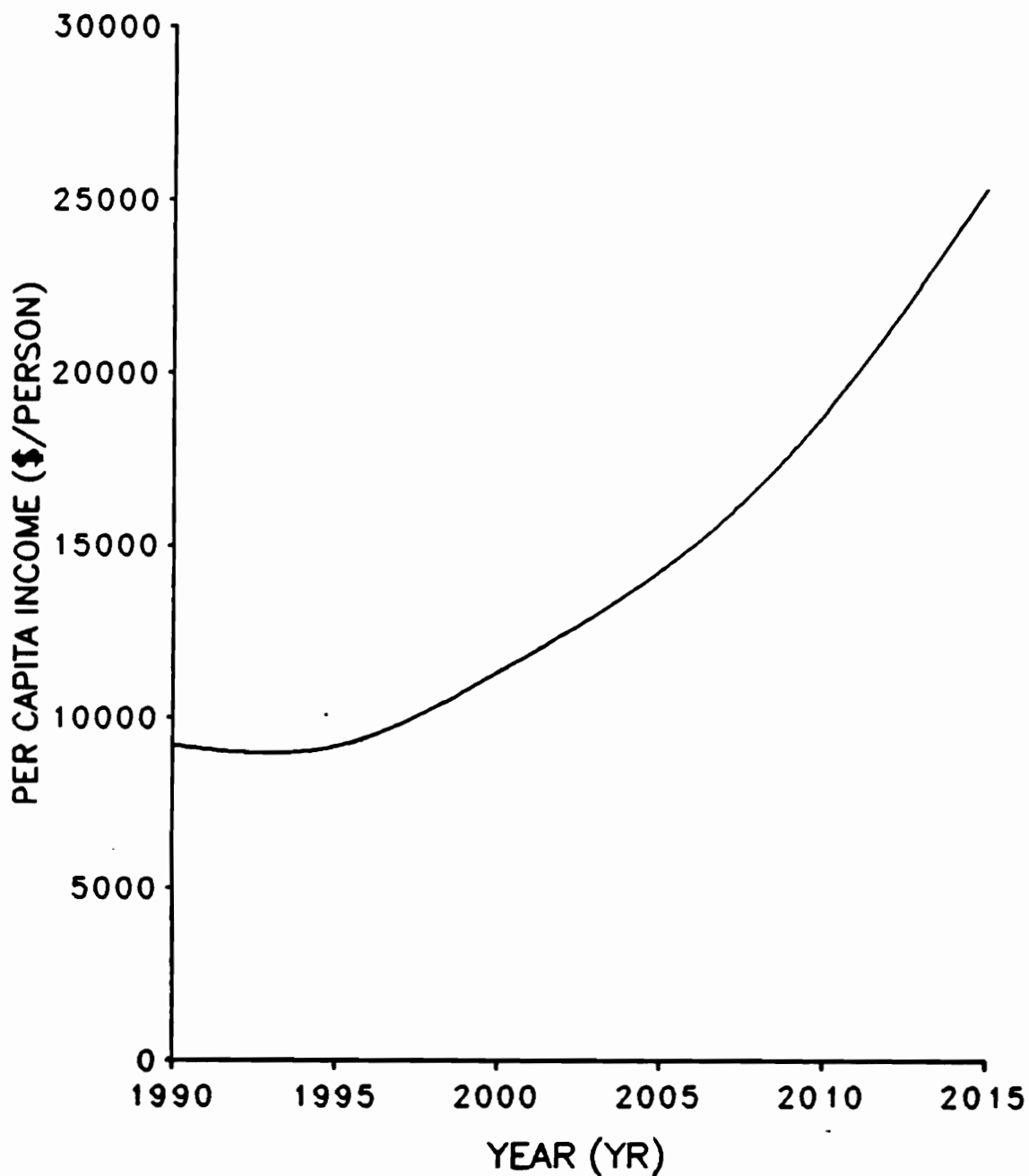


Figure 69. Alternative 5 Per capita income in Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 12
PER CAPITA INCOME IN BLACKSBURG

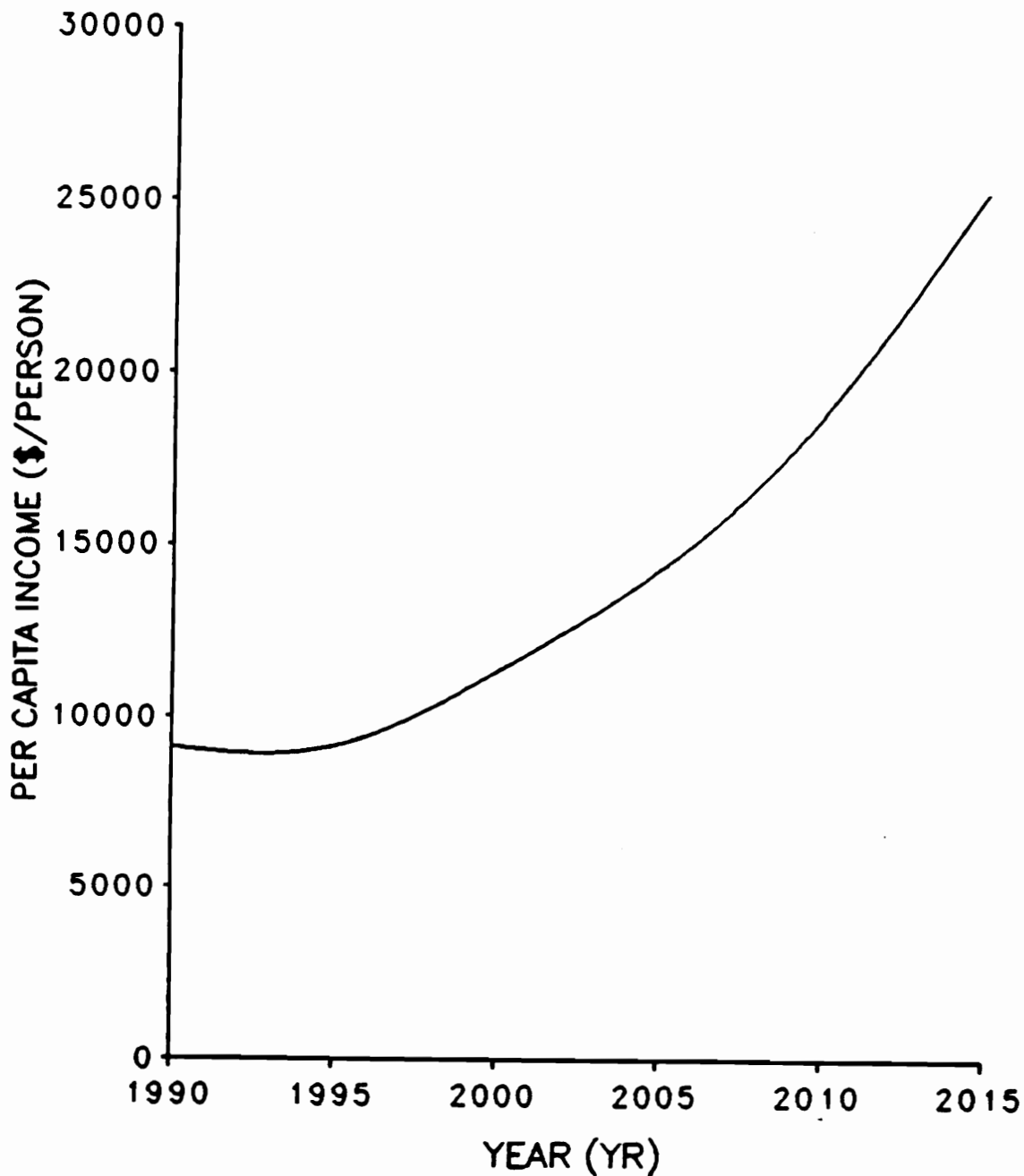


Figure 70. Alternative 12 Per capita Income In Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 6
PER CAPITA INCOME IN BLACKSBURG

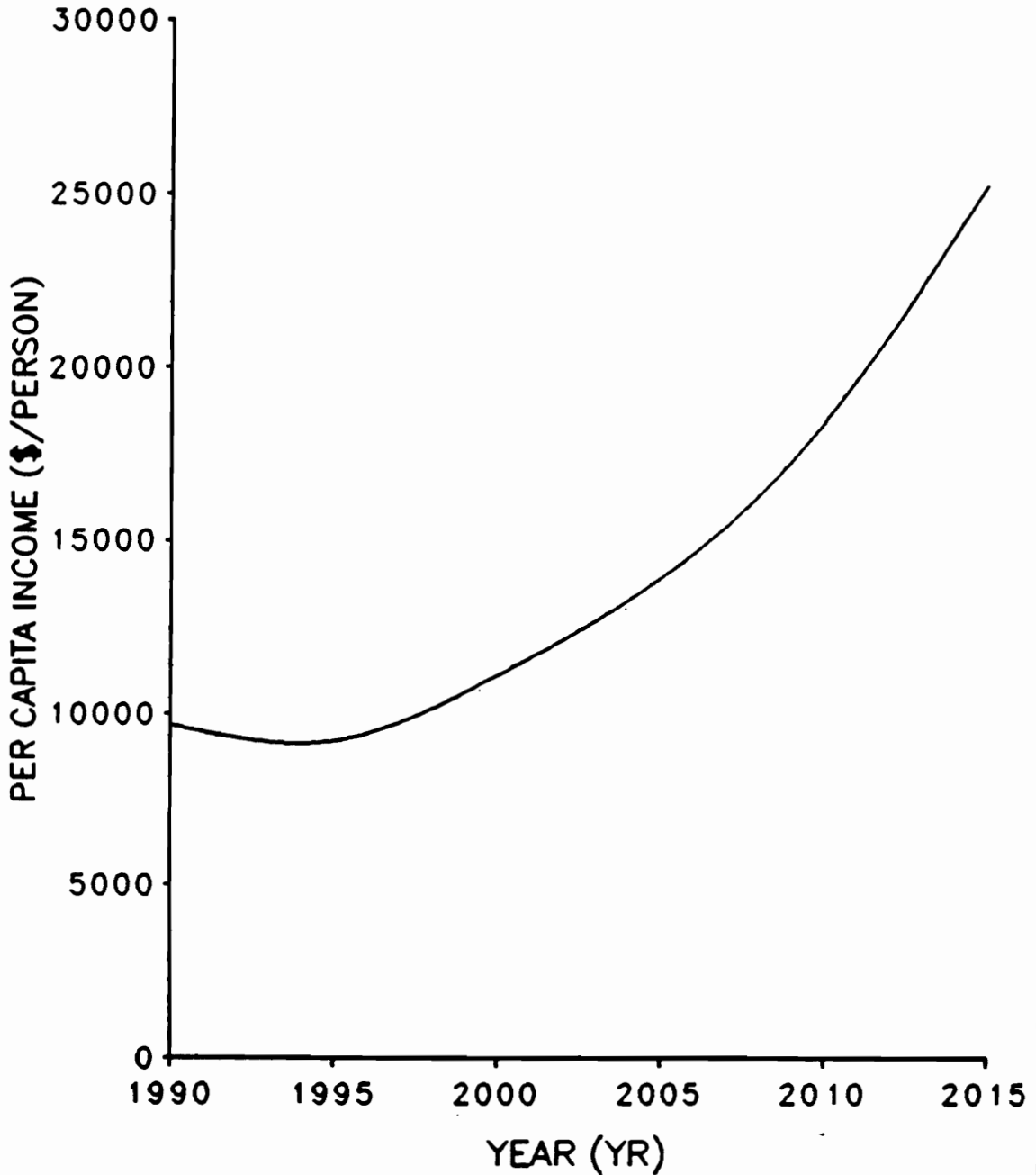


Figure 71. Alternative 6 Per capita income in Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 7
PER CAPITA INCOME IN BLACKSBURG

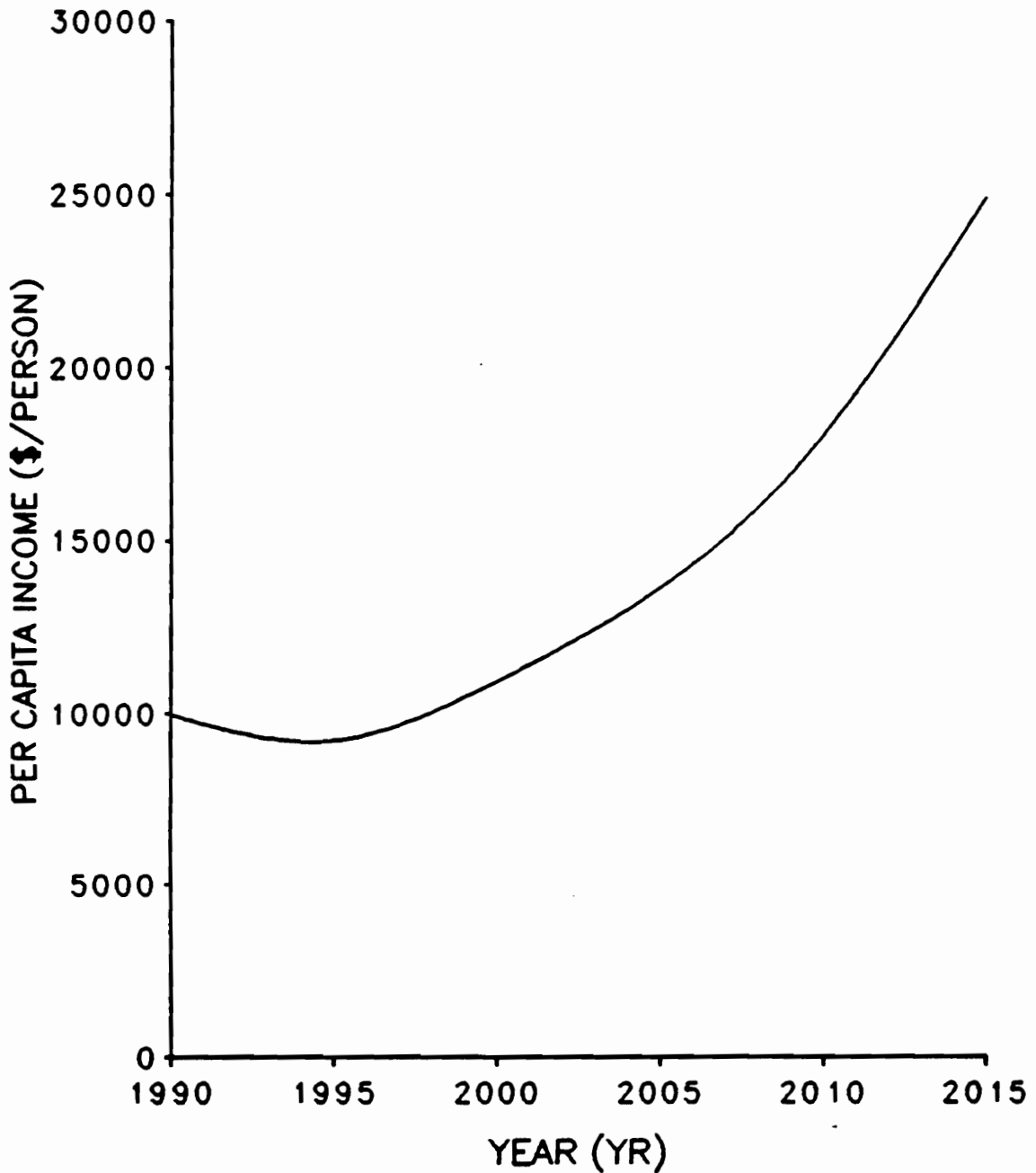


Figure 72. Alternative 7 Per capita income in Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 10
PER CAPITA INCOME IN BLACKSBURG

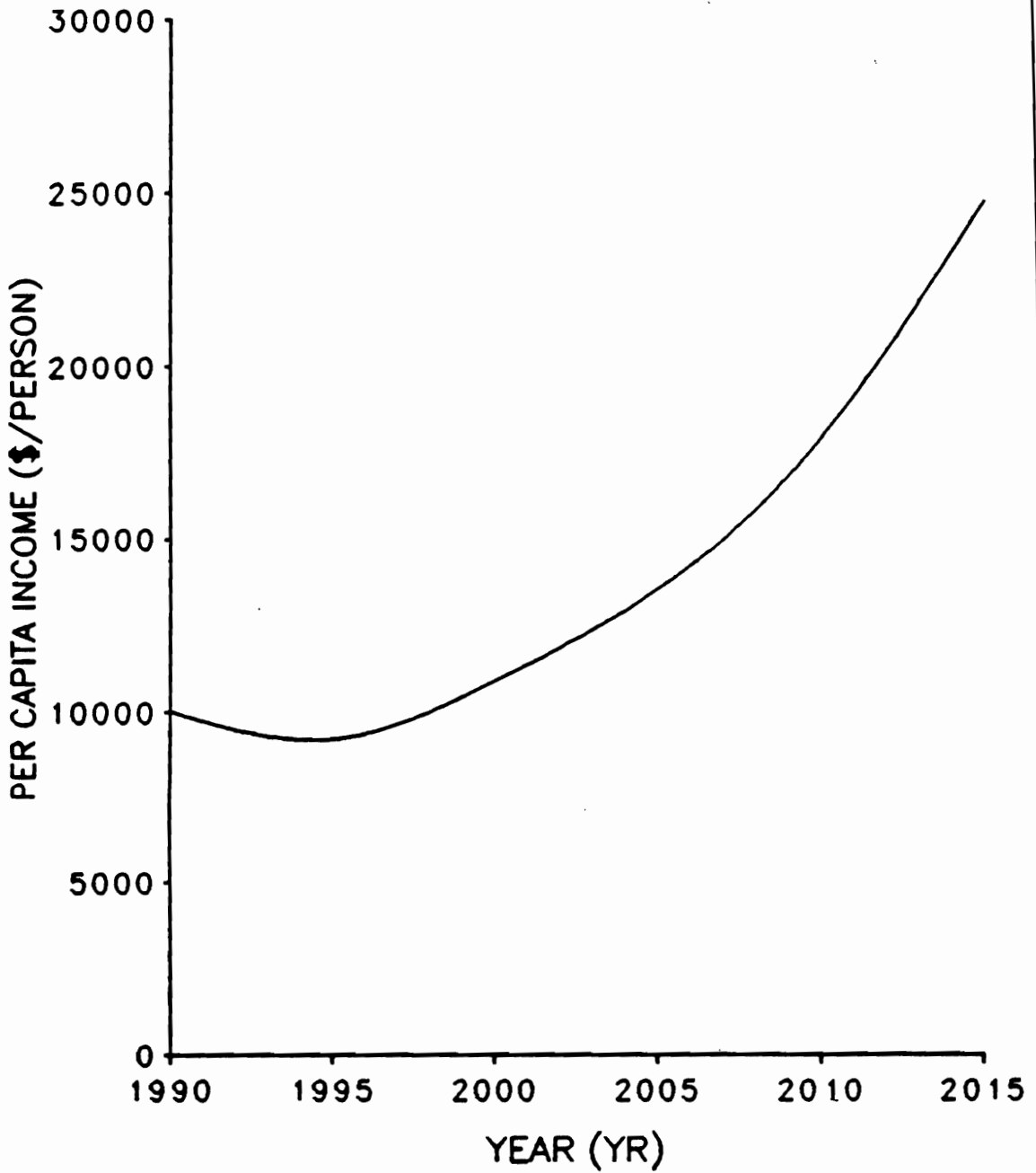


Figure 73. Alternative 10 Per capita income in Blacksburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 1
PER CAPITA INCOME IN CHRISTIANSBURG

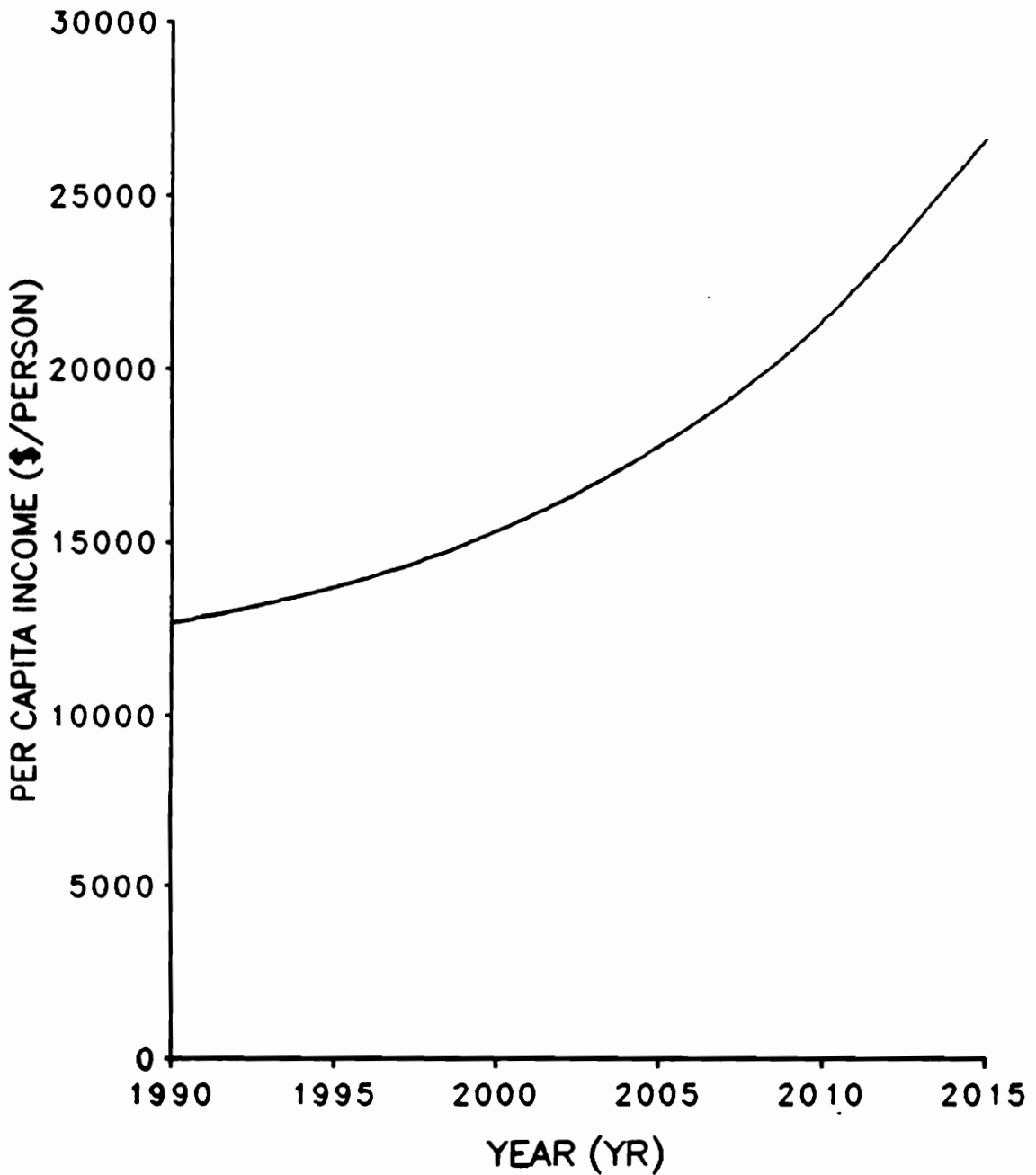


Figure 74. Alternative 1 Per capita Income in Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 2
PER CAPITA INCOME IN CHRISTIANSBURG

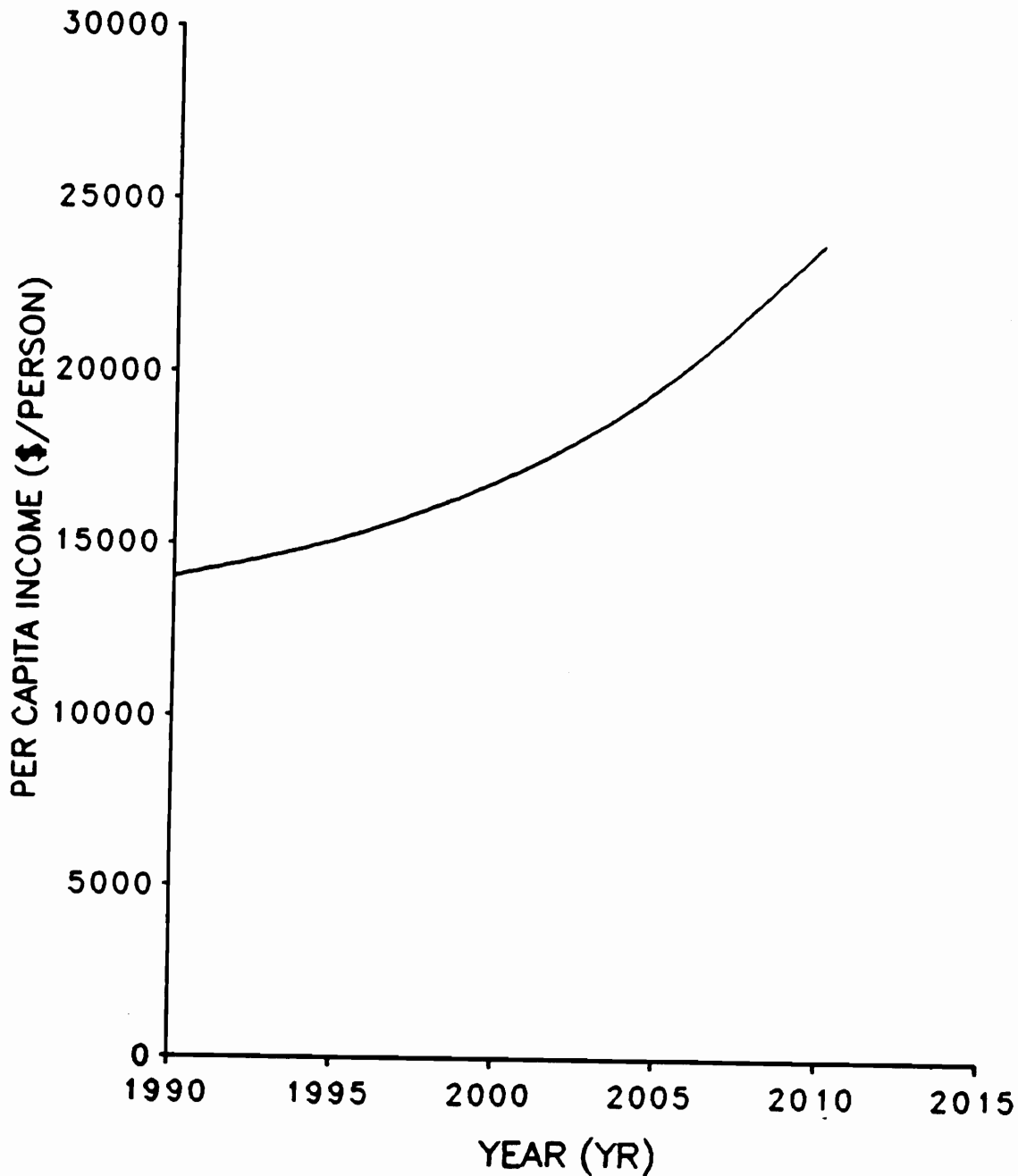


Figure 75. Alternative 2 Per capita income in Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 3A
PER CAPITA INCOME IN CHRISTIANSBURG

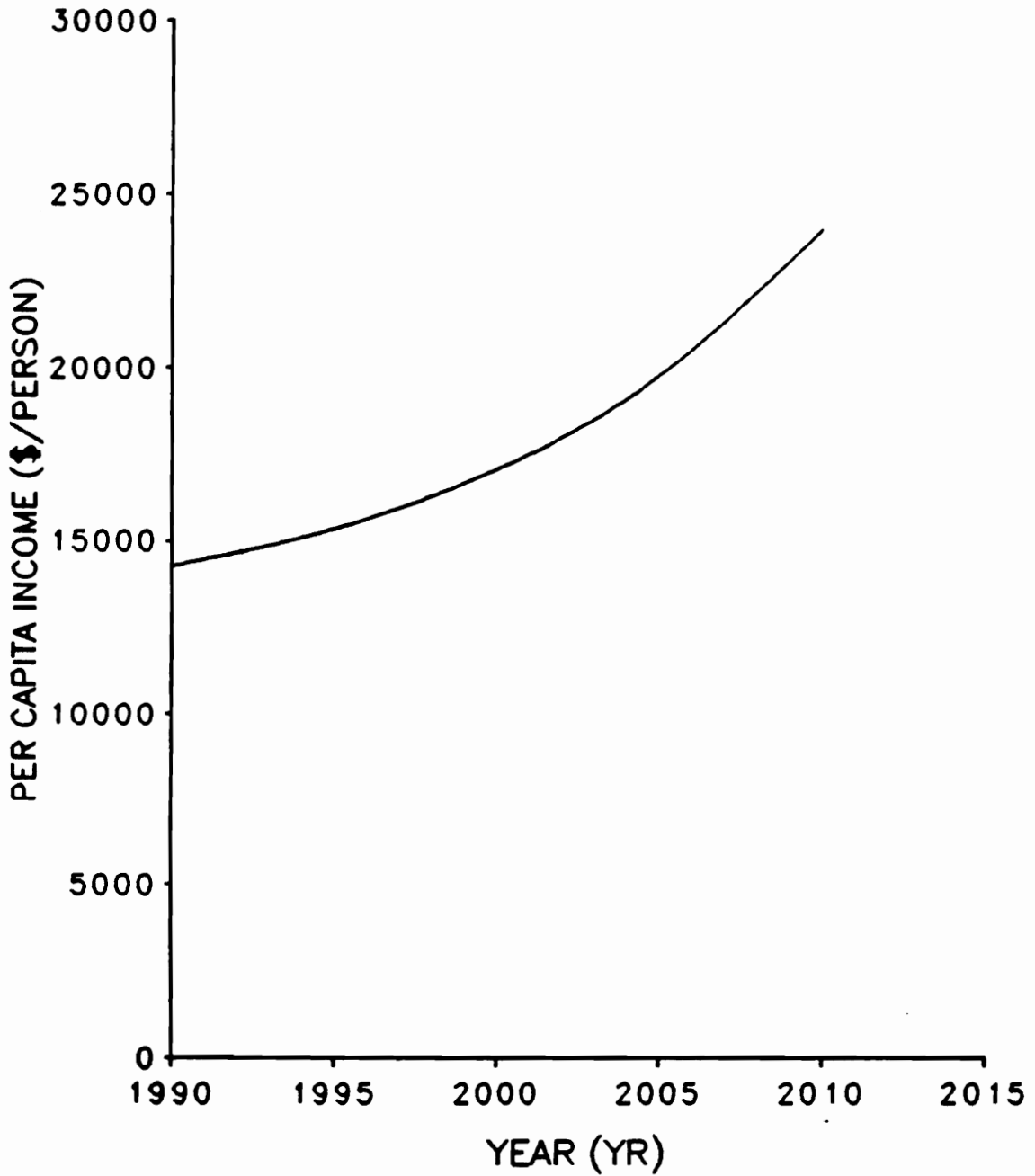


Figure 76. Alternative 3A Per capita income in Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 5
PER CAPITA INCOME IN CHRISTIANSBURG

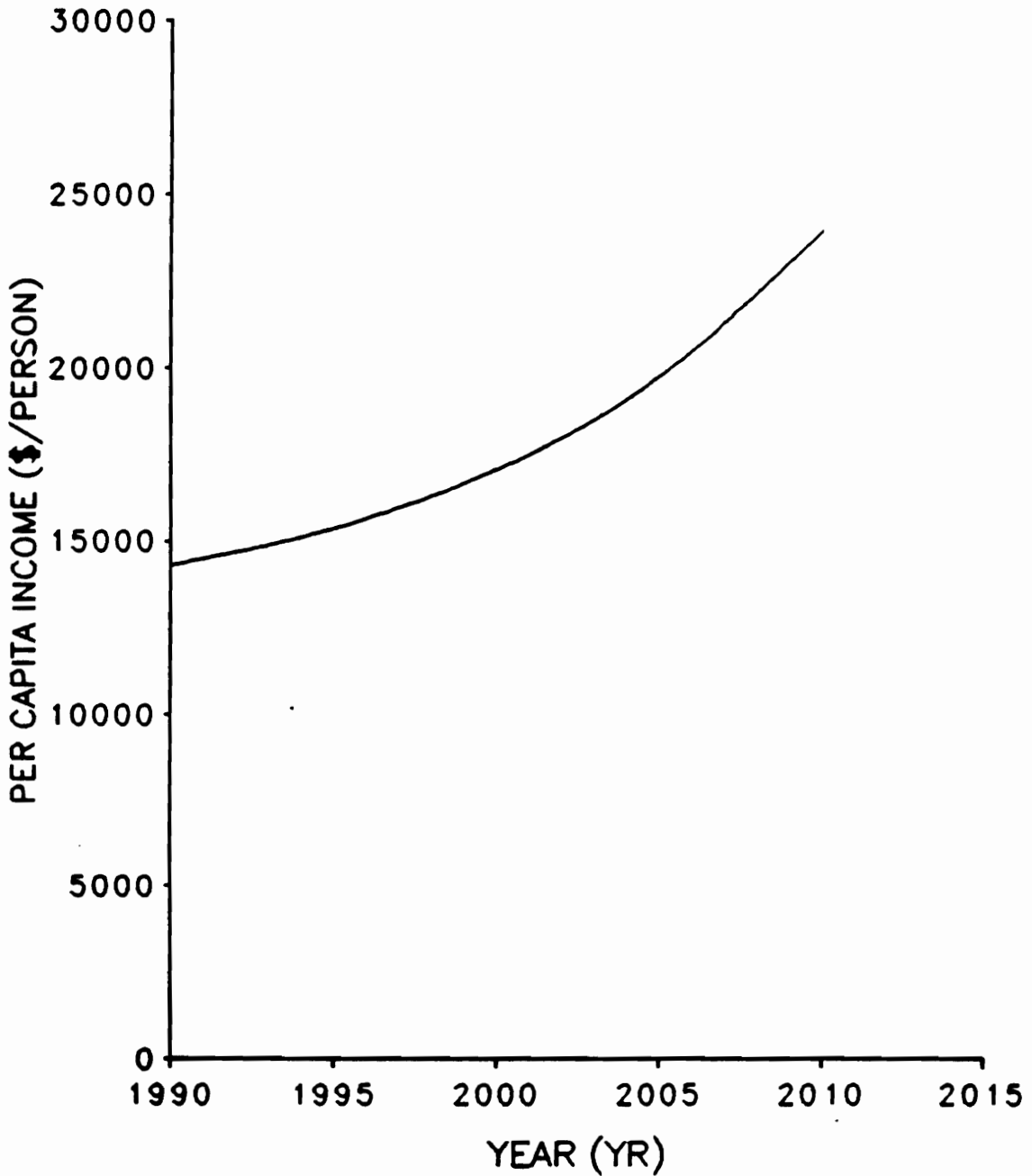


Figure 77. Alternative 5 Per capita income in Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 12
PER CAPITA INCOME IN CHRISTIANSBURG

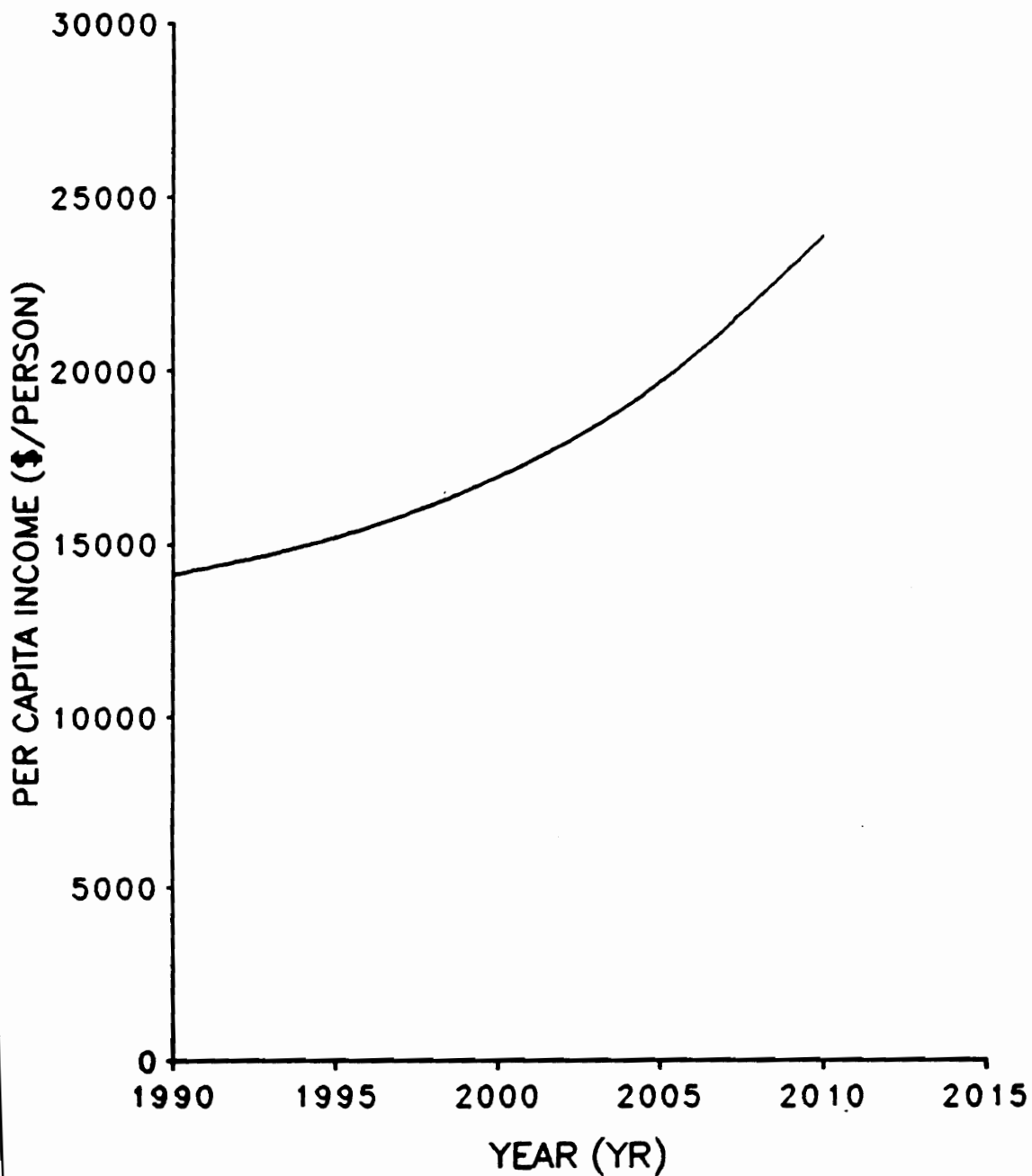


Figure 78. Alternative 12 Per capita income in Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 6
PER CAPITA INCOME IN CHRISTIANSBURG

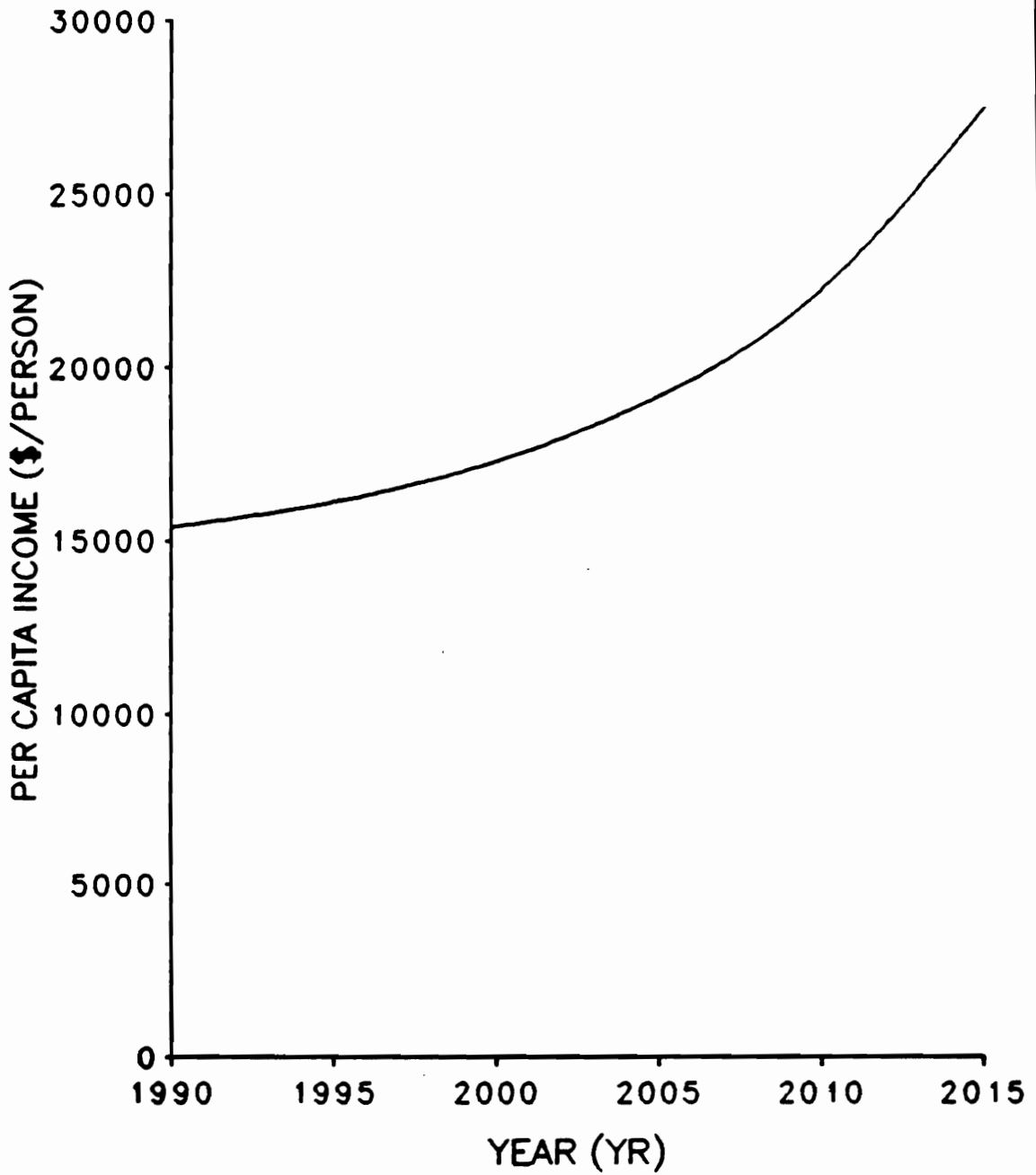


Figure 79. Alternative 6 Per capita income in Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 7
PER CAPITA INCOME IN CHRISTIANSBURG

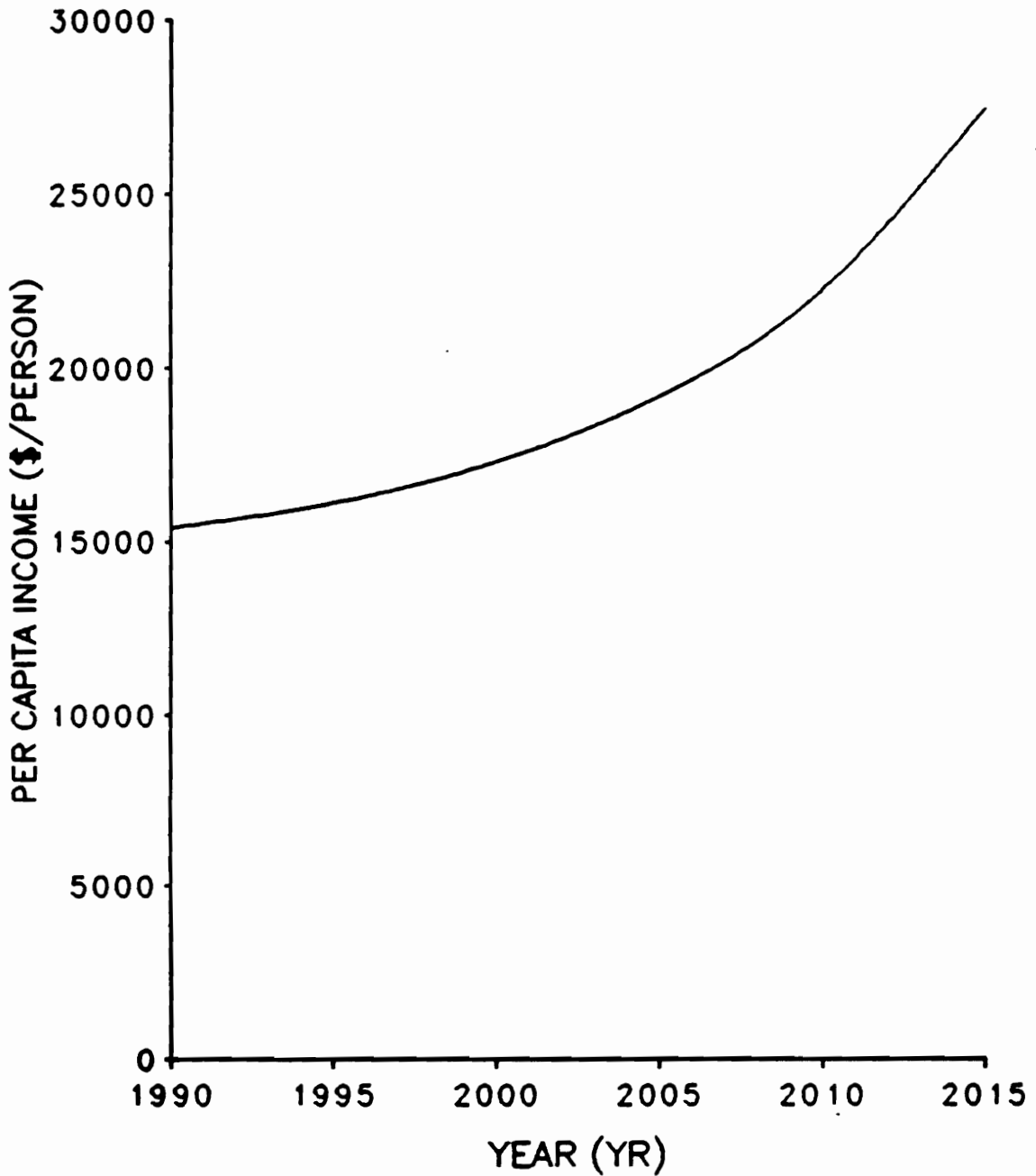


Figure 80. Alternative 7 Per capita income in Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 10
PER CAPITA INCOME IN CHRISTIANSBURG

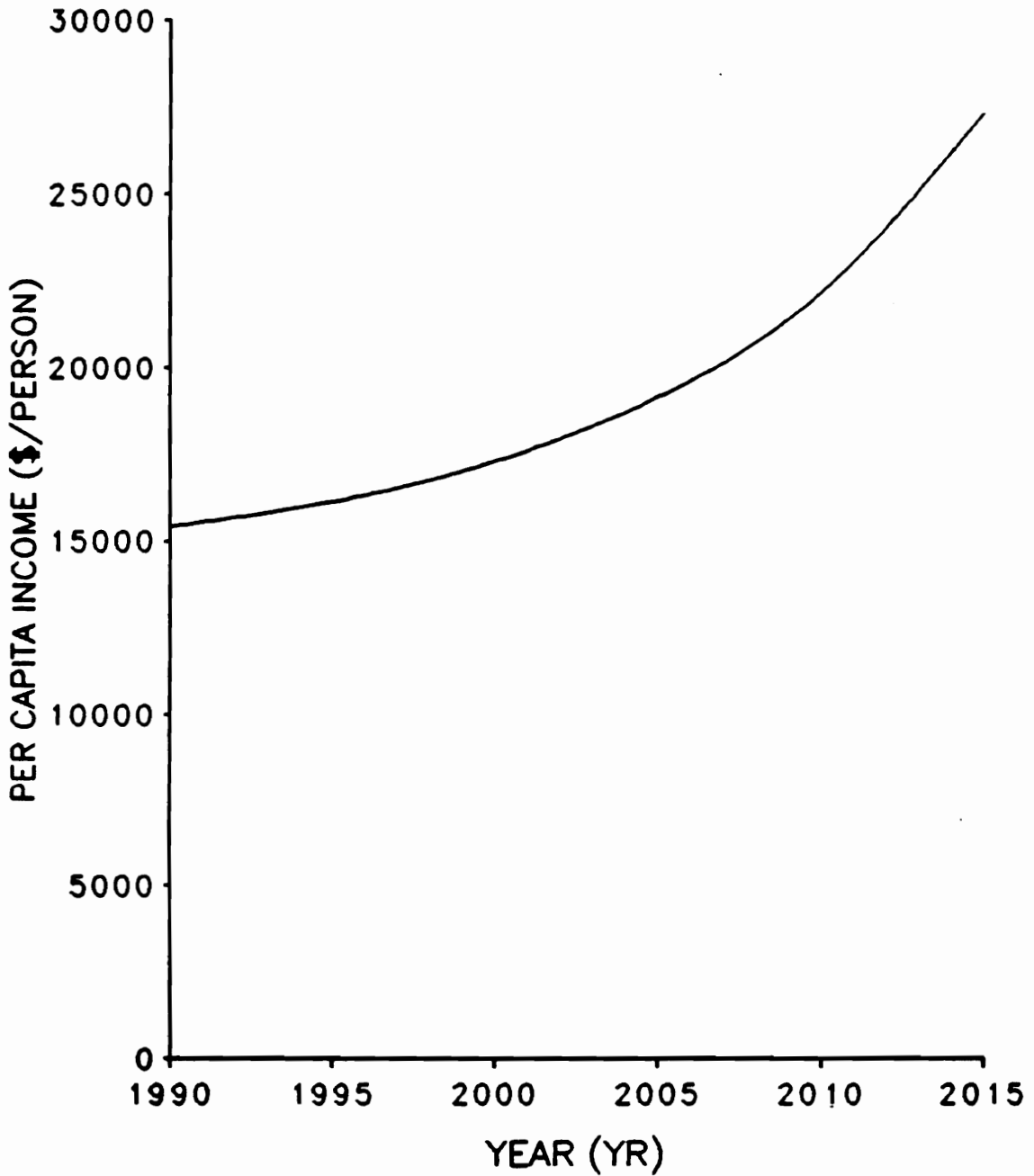


Figure 81. Alternative 10 Per capita income in Christiansburg

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 1
PER CAPITA INCOME IN ROANOKE
(CITY AND COUNTY)

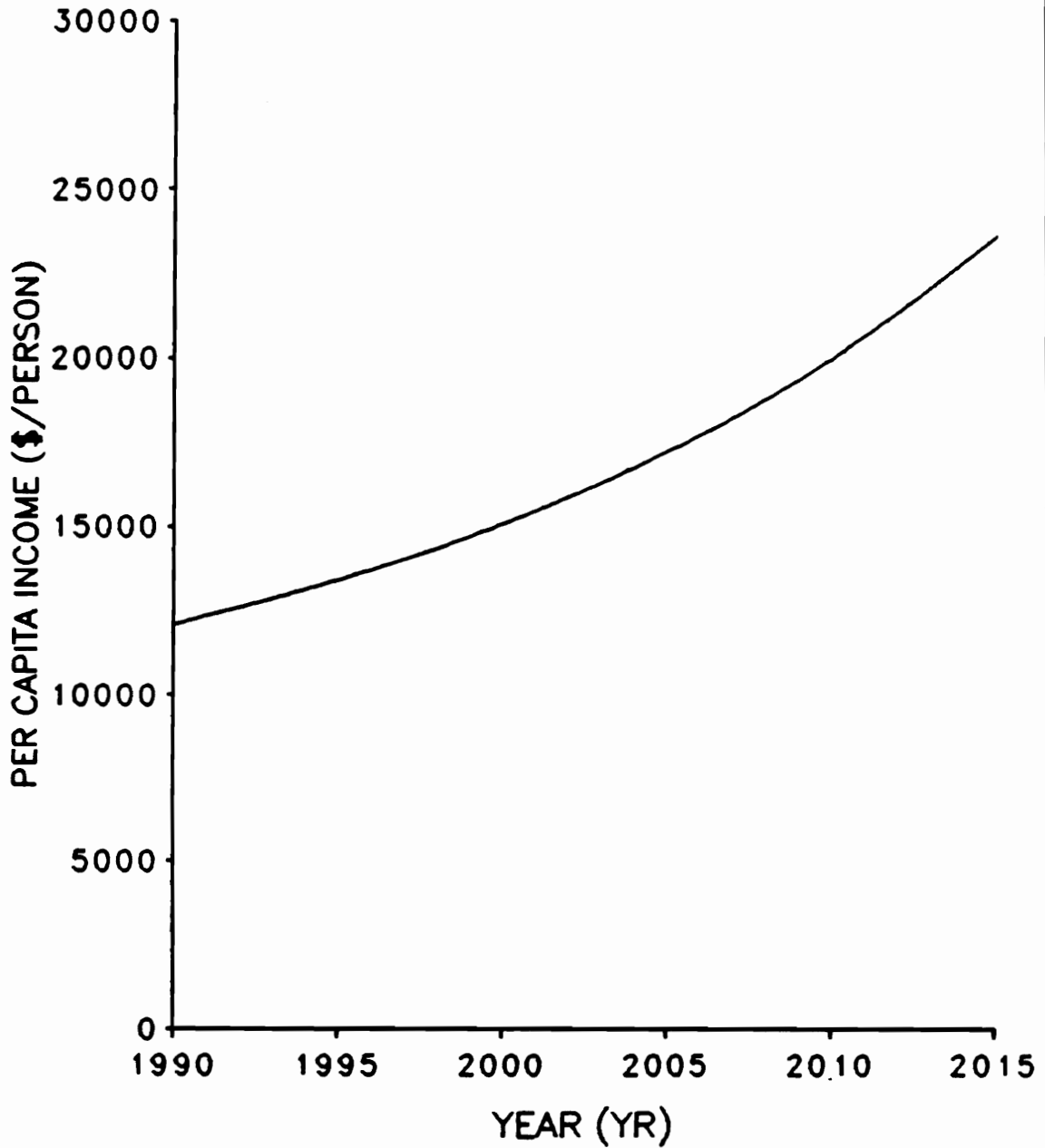


Figure 82. Alternative 1 Per capita income in Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 2
PER CAPITA INCOME IN ROANOKE
(CITY AND COUNTY)

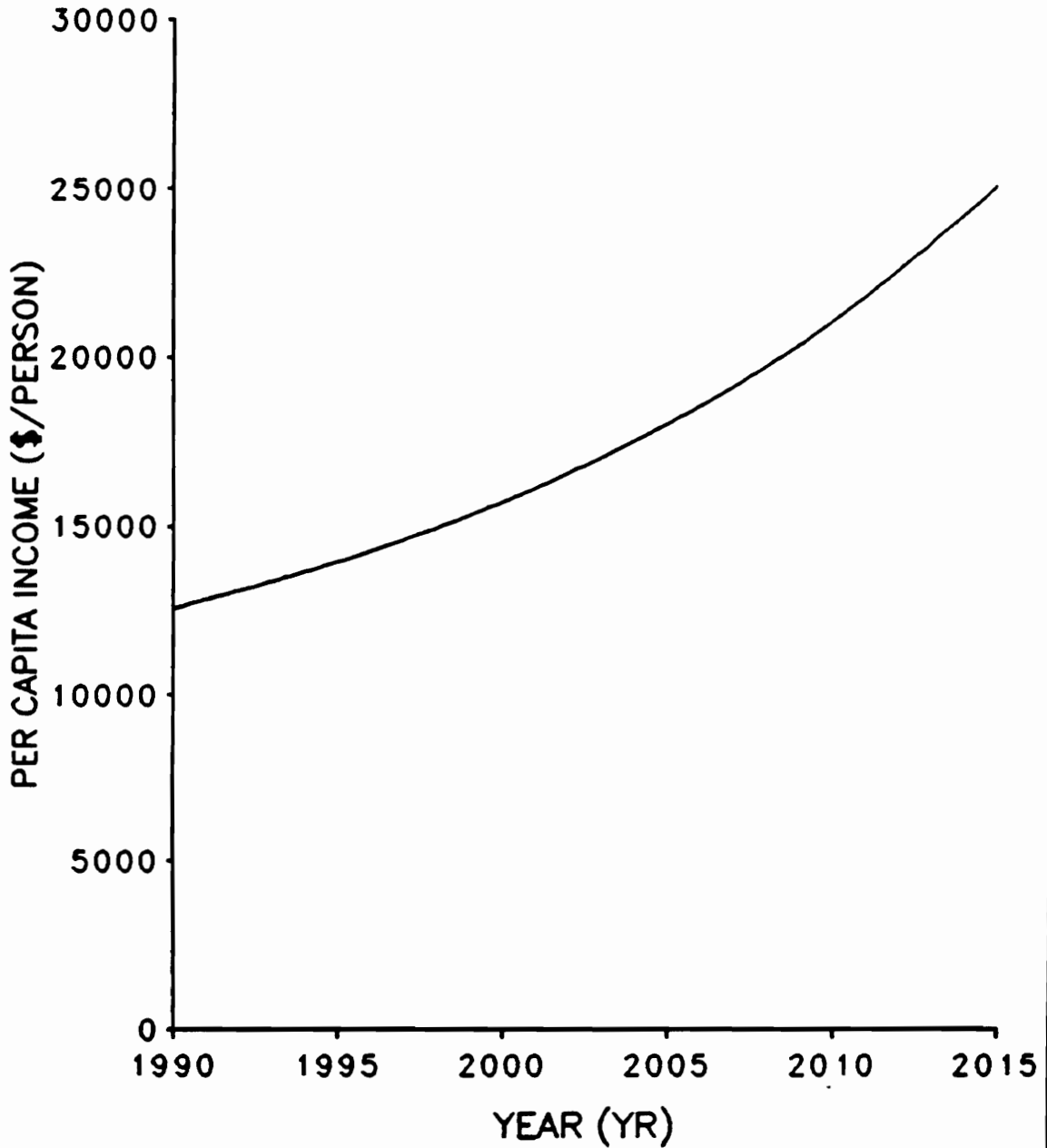


Figure 83. Alternative 2 Per capita Income in Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 3A
PER CAPITA INCOME IN ROANOKE)
(CITY AND COUNTY)

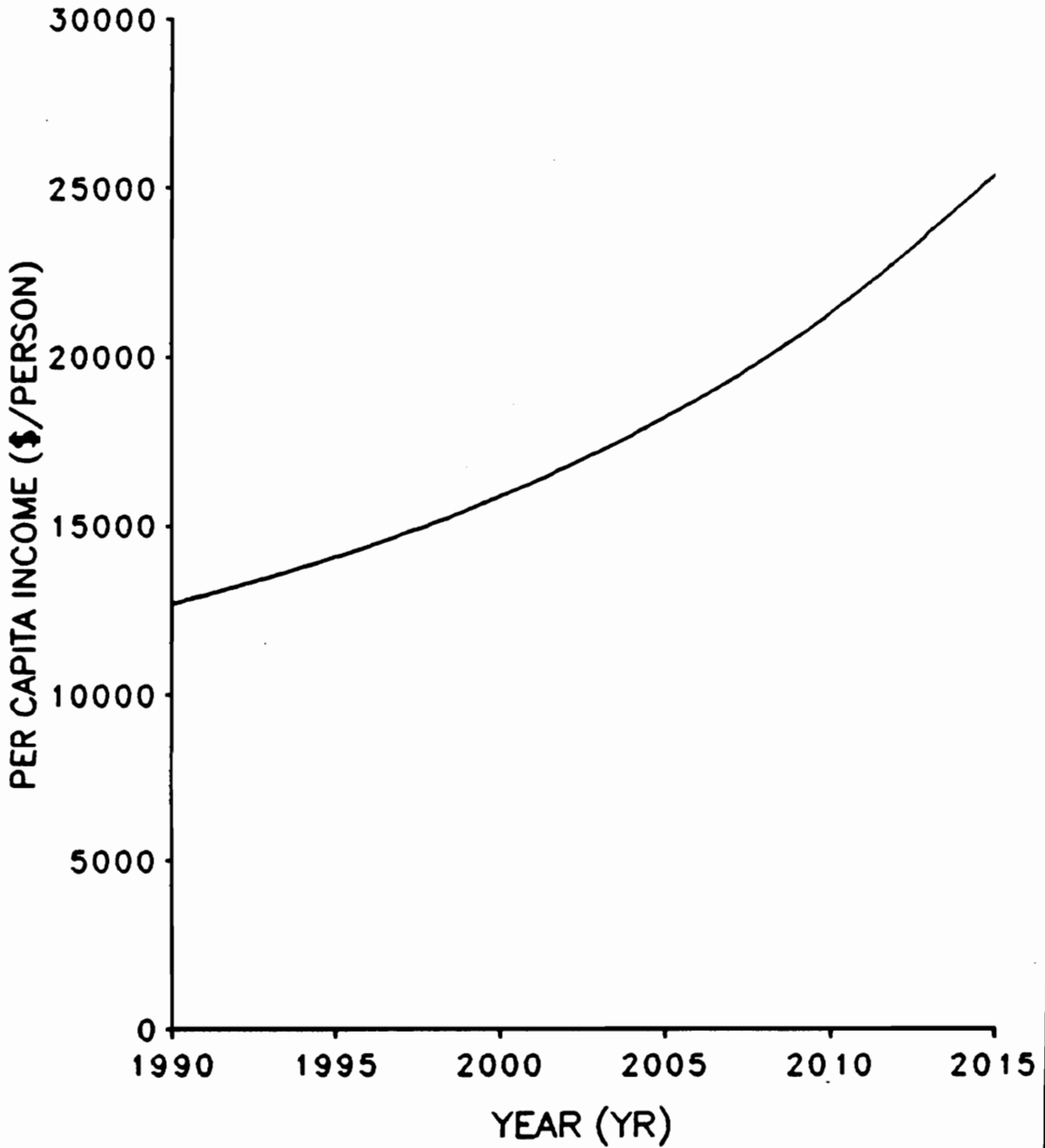


Figure 84. Alternative 3A Per capita income in Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 5
PER CAPITA INCOME IN ROANOKE)
(CITY AND COUNTY)

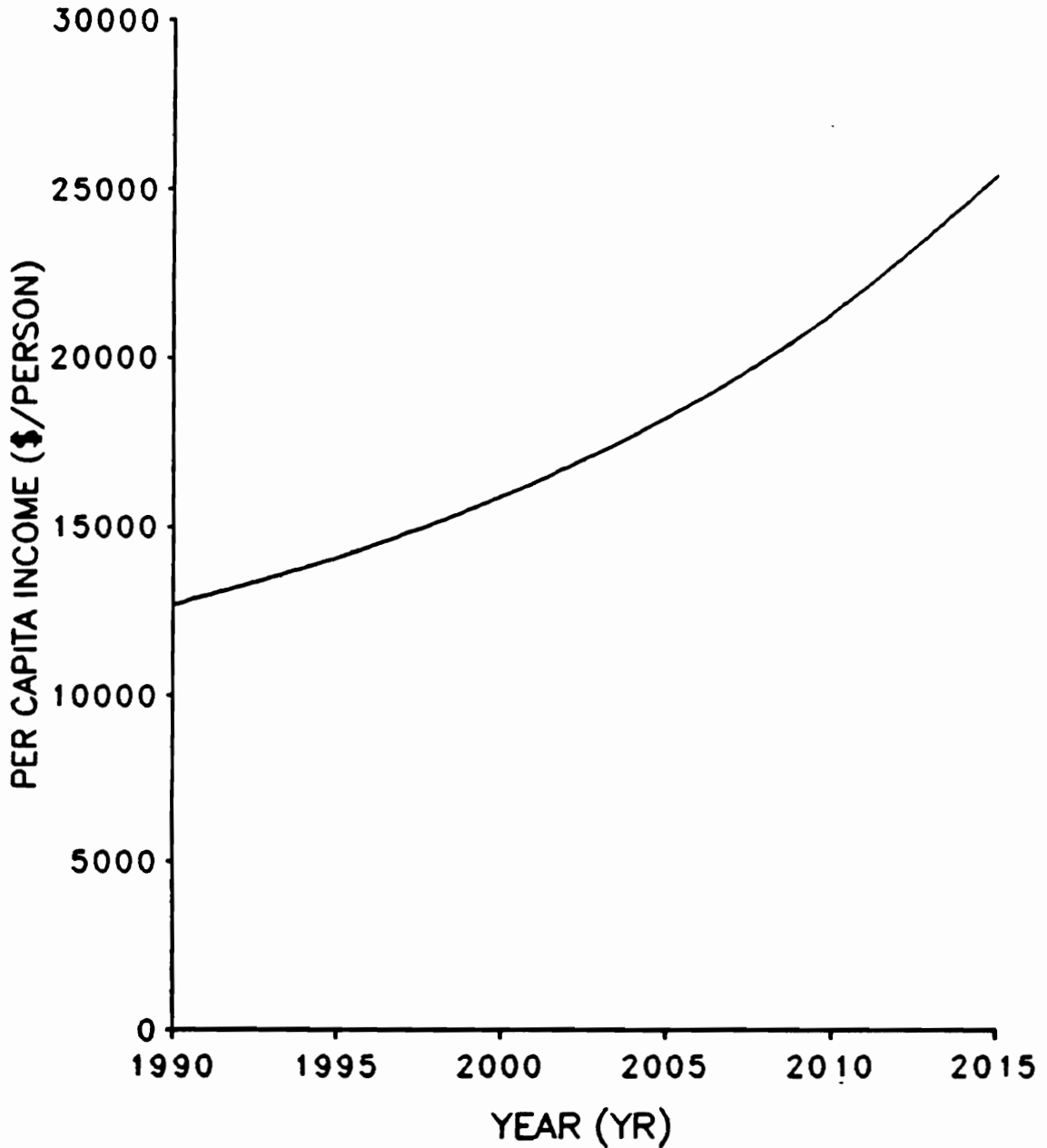


Figure 85. Alternative 5 Per capita income in Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 12
PER CAPITA INCOME IN ROANOKE)
(CITY AND COUNTY)

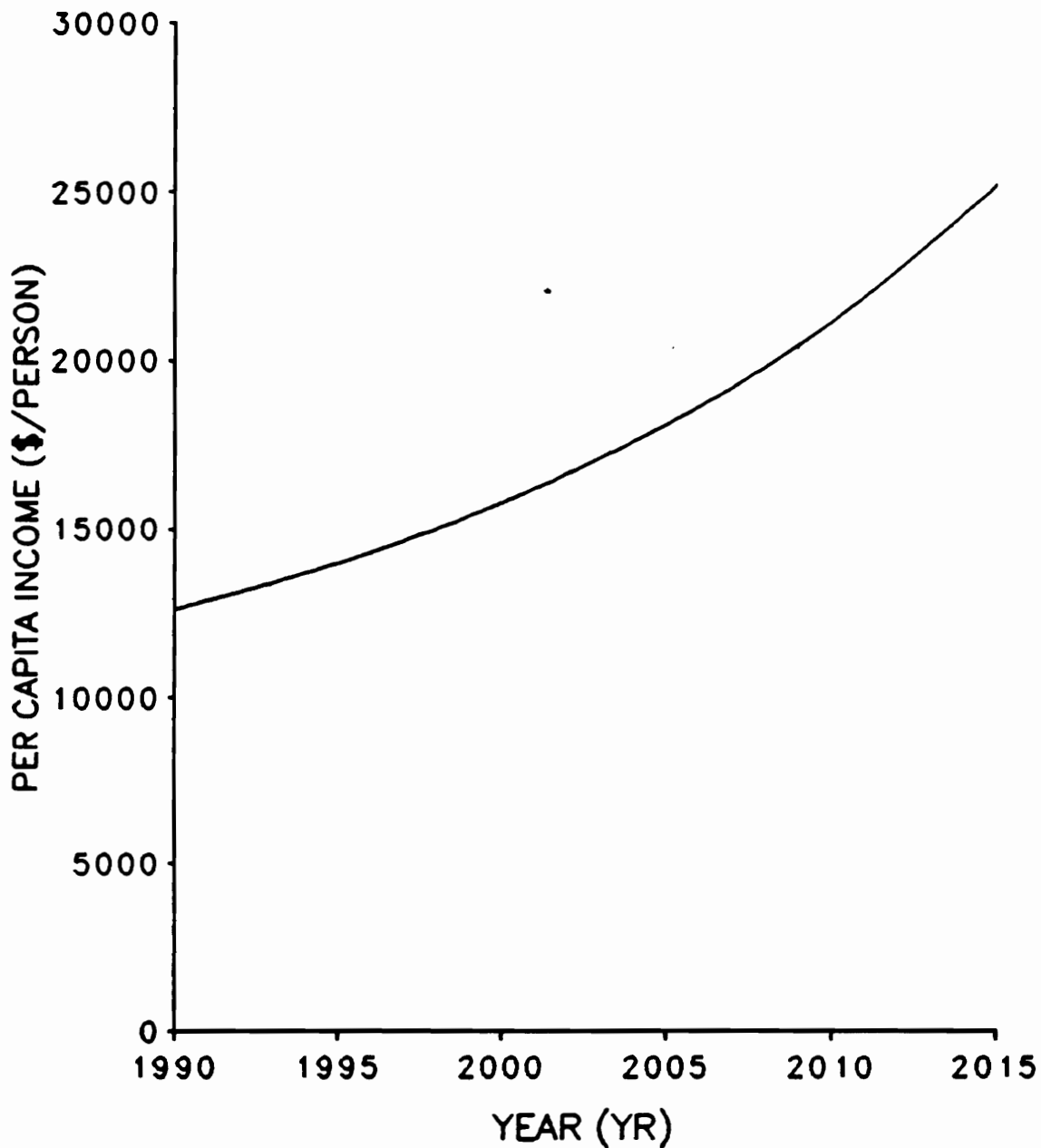


Figure 86. Alternative 12 Per capita income in Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 6
PER CAPITA INCOME IN ROANOKE)
(CITY AND COUNTY)

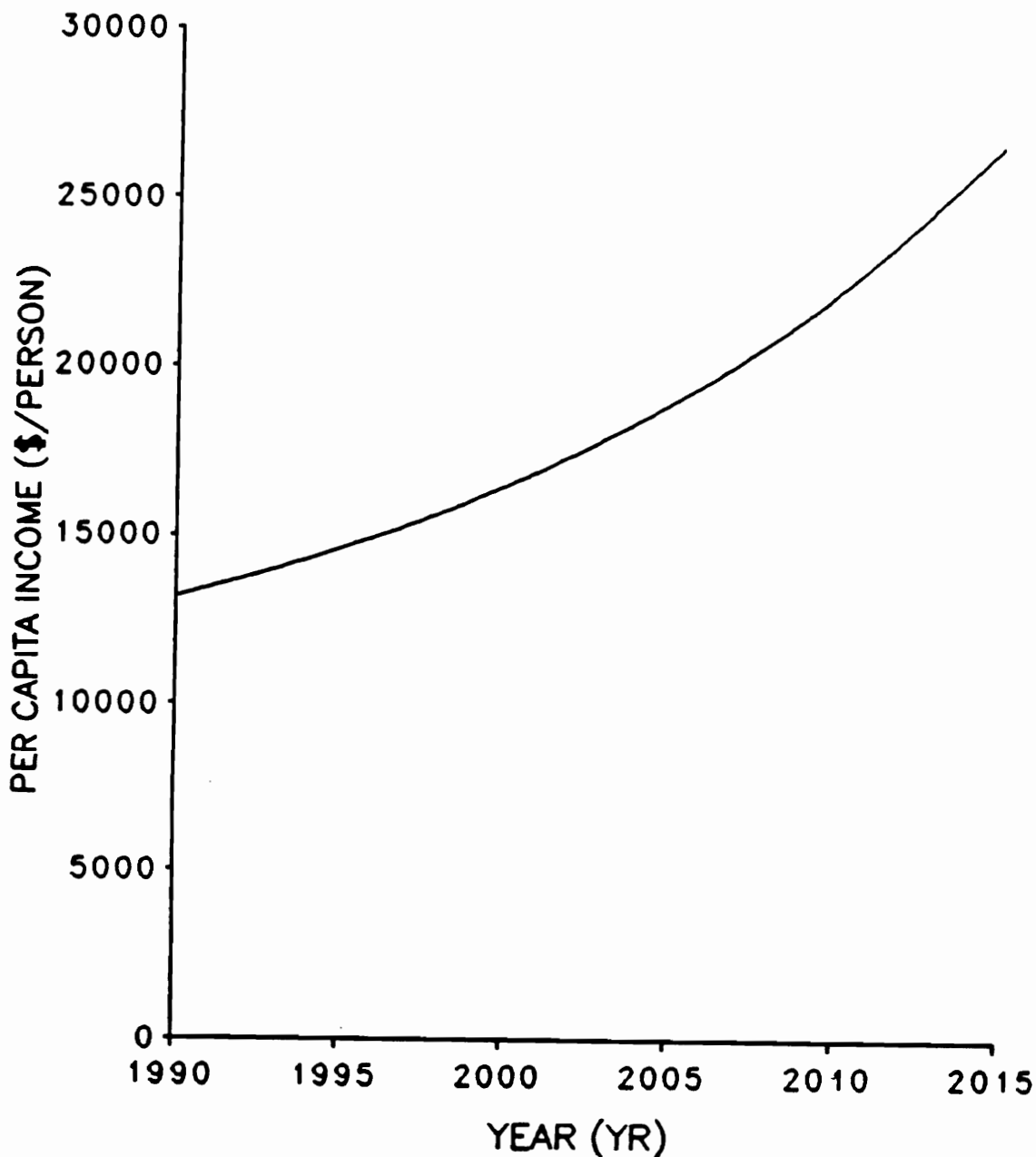


Figure 87. Alternative 6 Per capita income in Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 7
PER CAPITA INCOME IN ROANOKE
(CITY AND COUNTY)

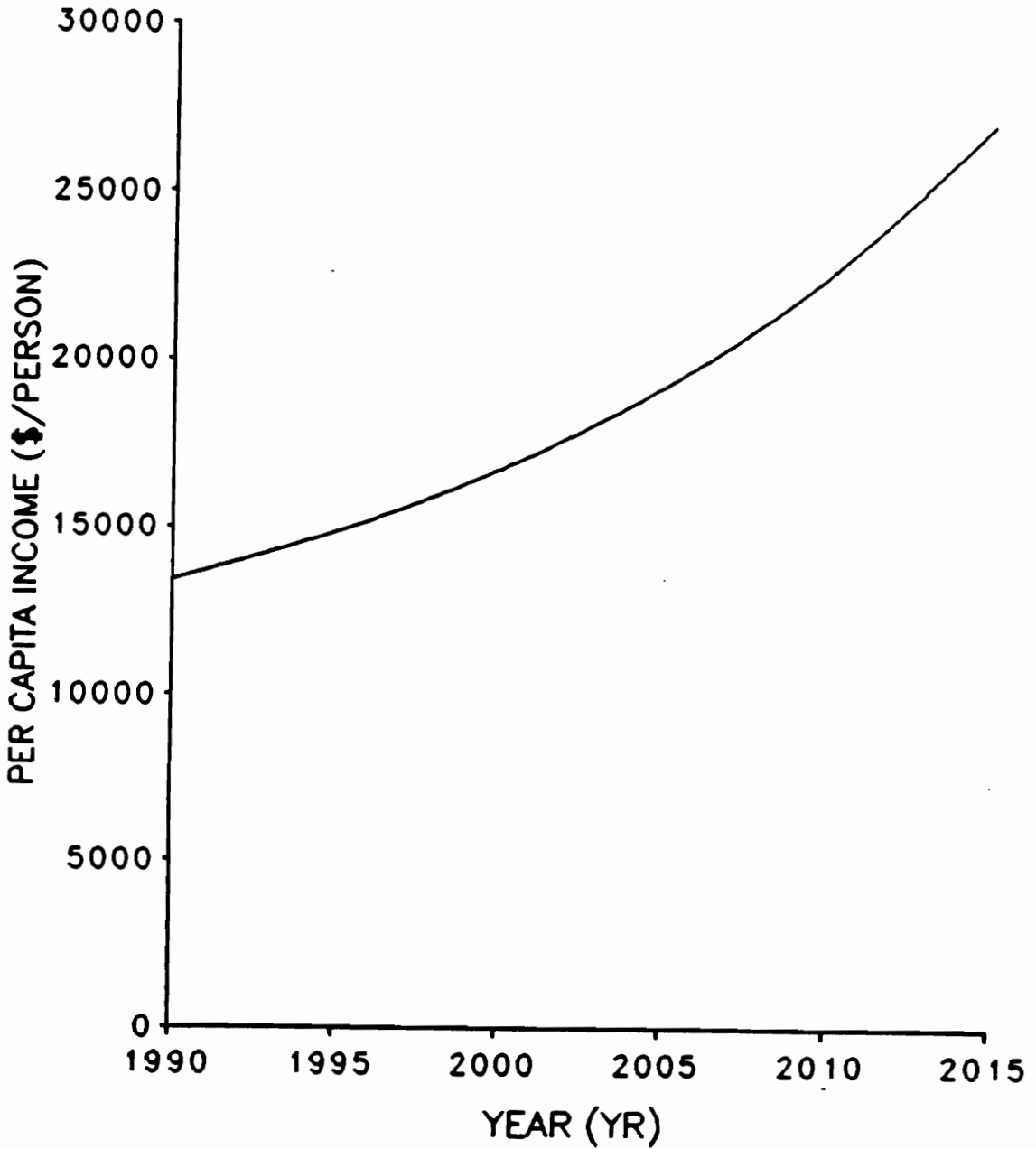


Figure 88. Alternative 7 Per capita income in Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 10
PER CAPITA INCOME IN ROANOKE)
(CITY AND COUNTY)

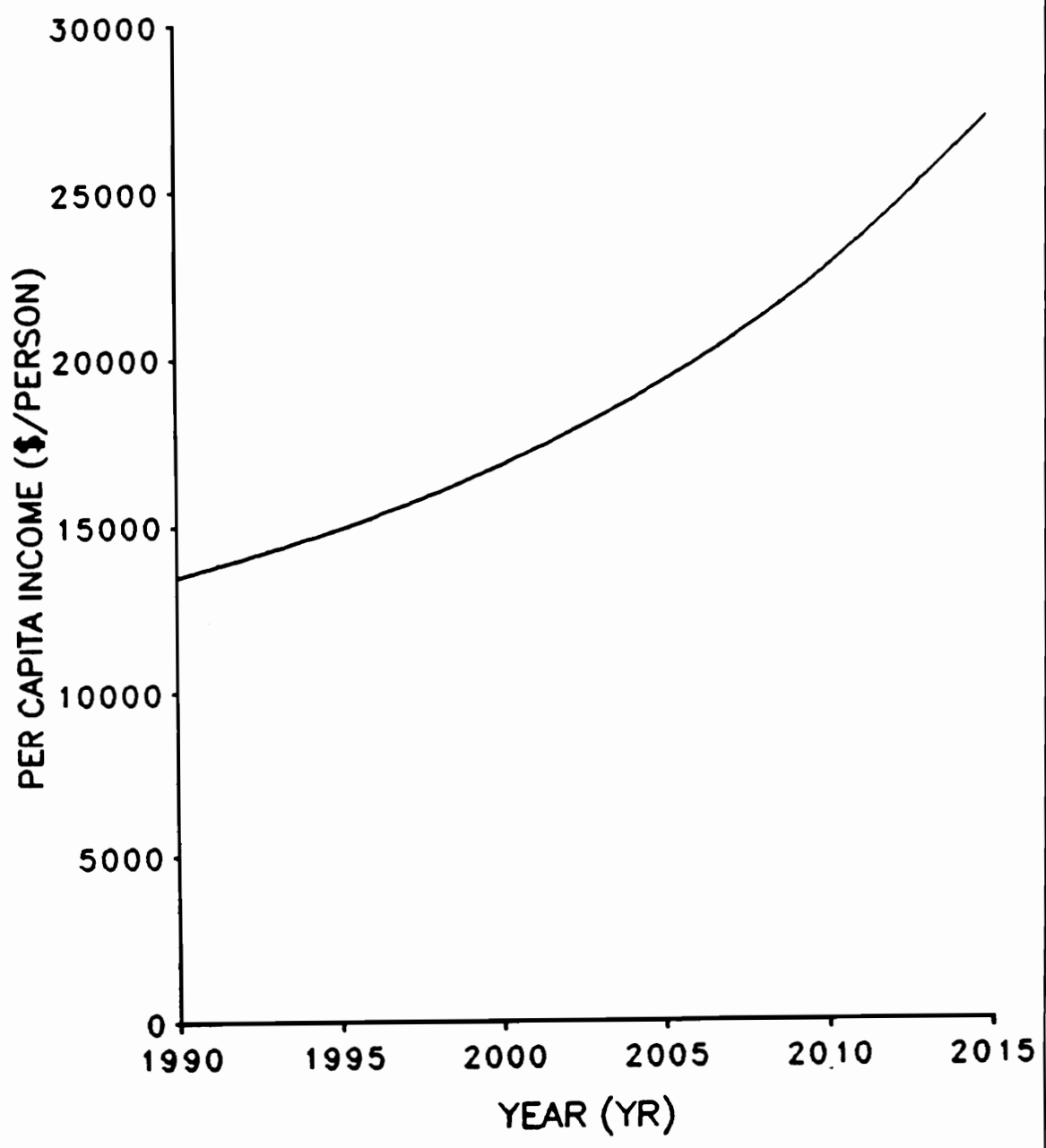


Figure 89. Alternative 10 Per capita income in Roanoke

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 1
FUNDED RESEARCH AT VIRGINIA TECH

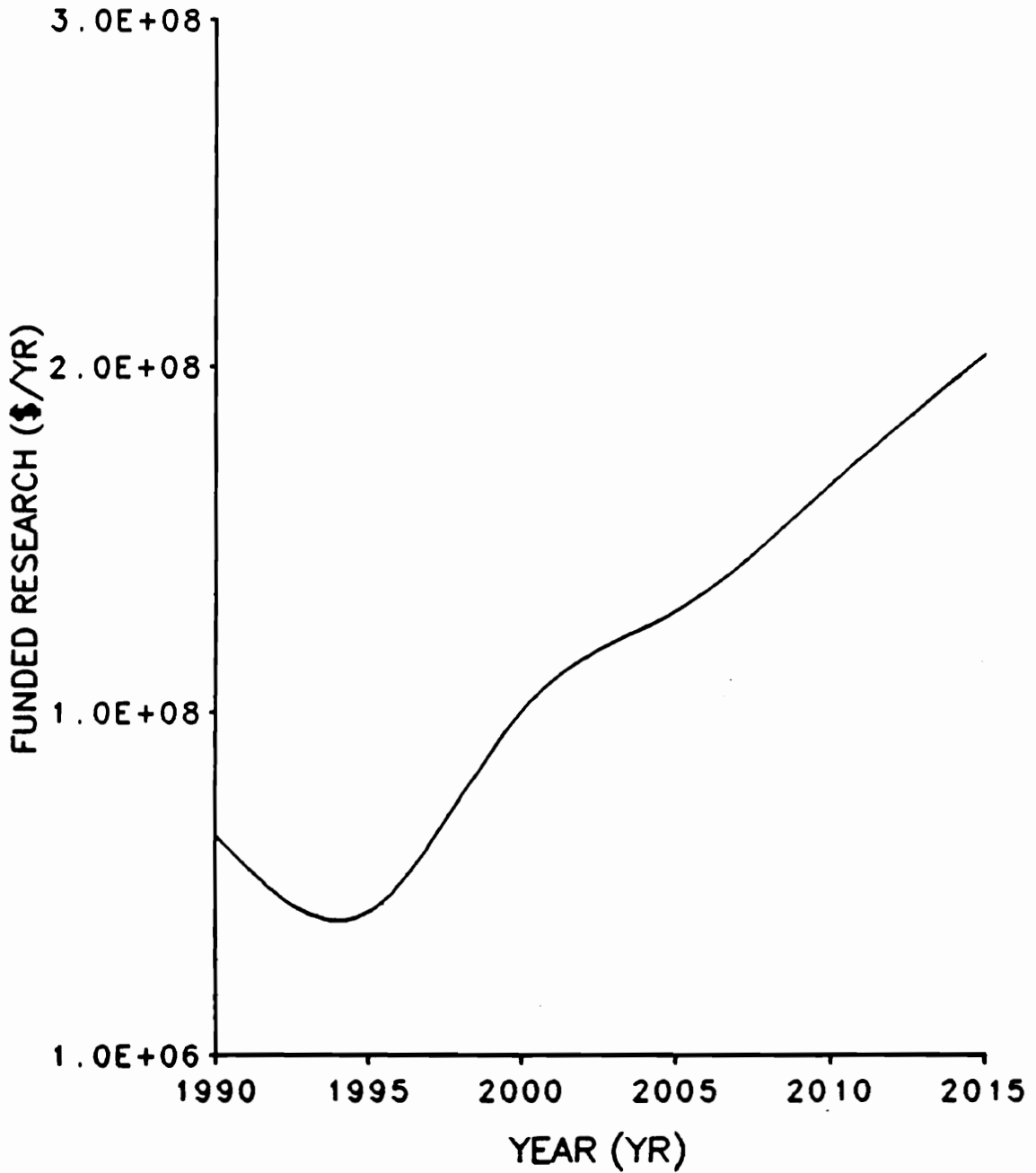


Figure 90. Alternative 1 Funded research at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 2
FUNDED RESEARCH AT VIRGINIA TECH

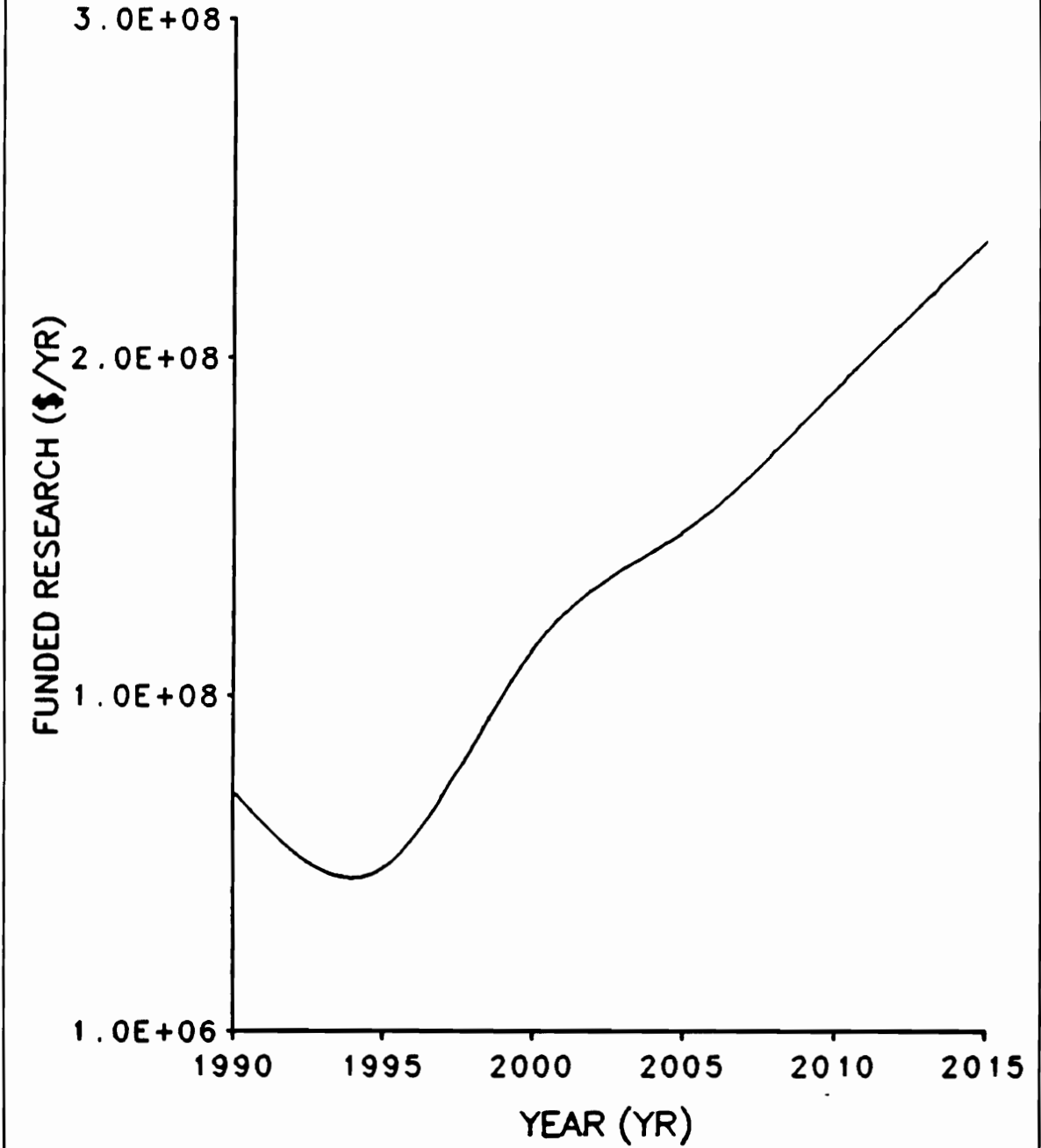


Figure 91. Alternative 2 Funded research at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 3A
FUNDED RESEARCH AT VIRGINIA TECH

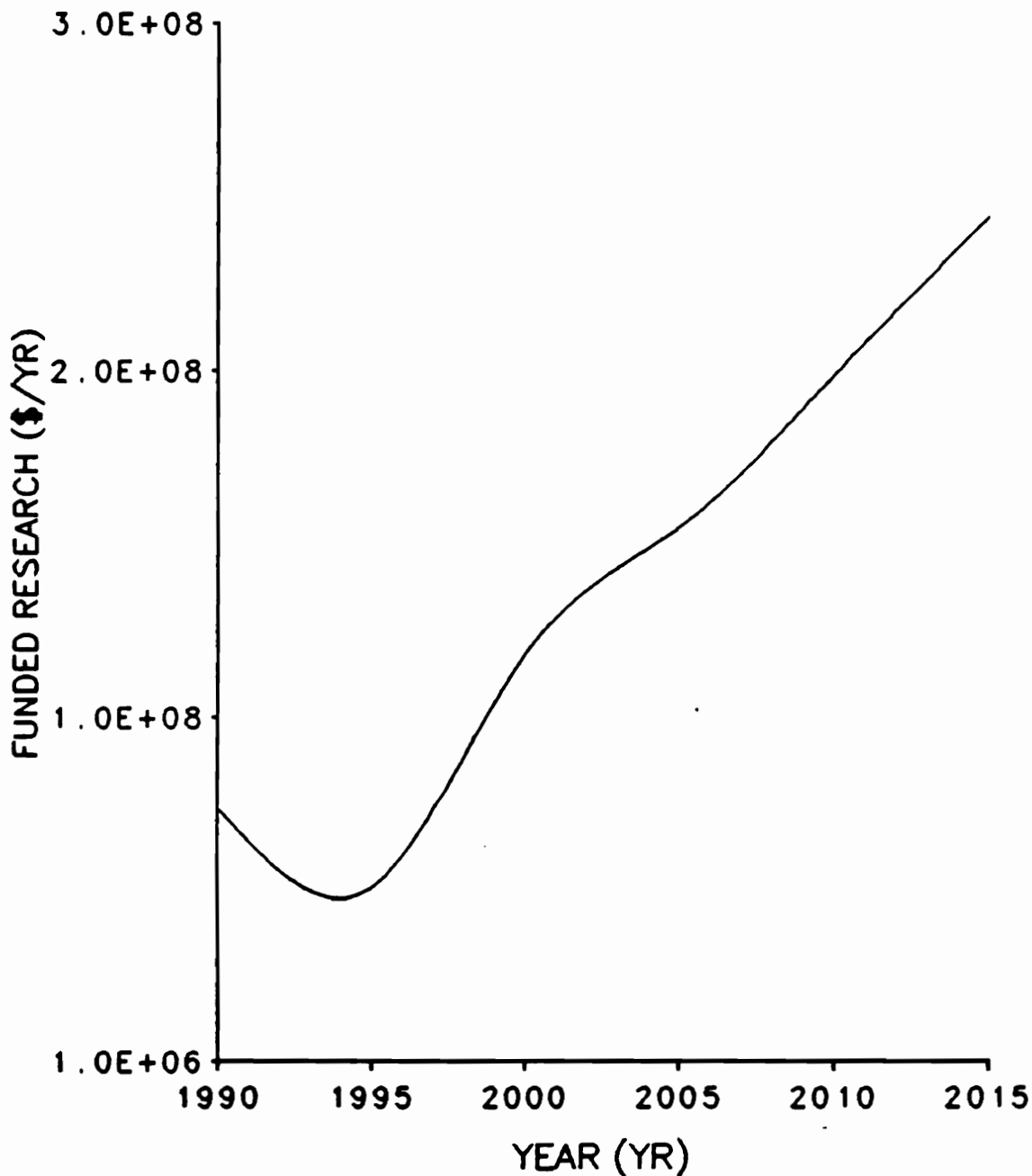


Figure 92. Alternative 3A Funded research at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 5
FUNDED RESEARCH AT VIRGINIA TECH

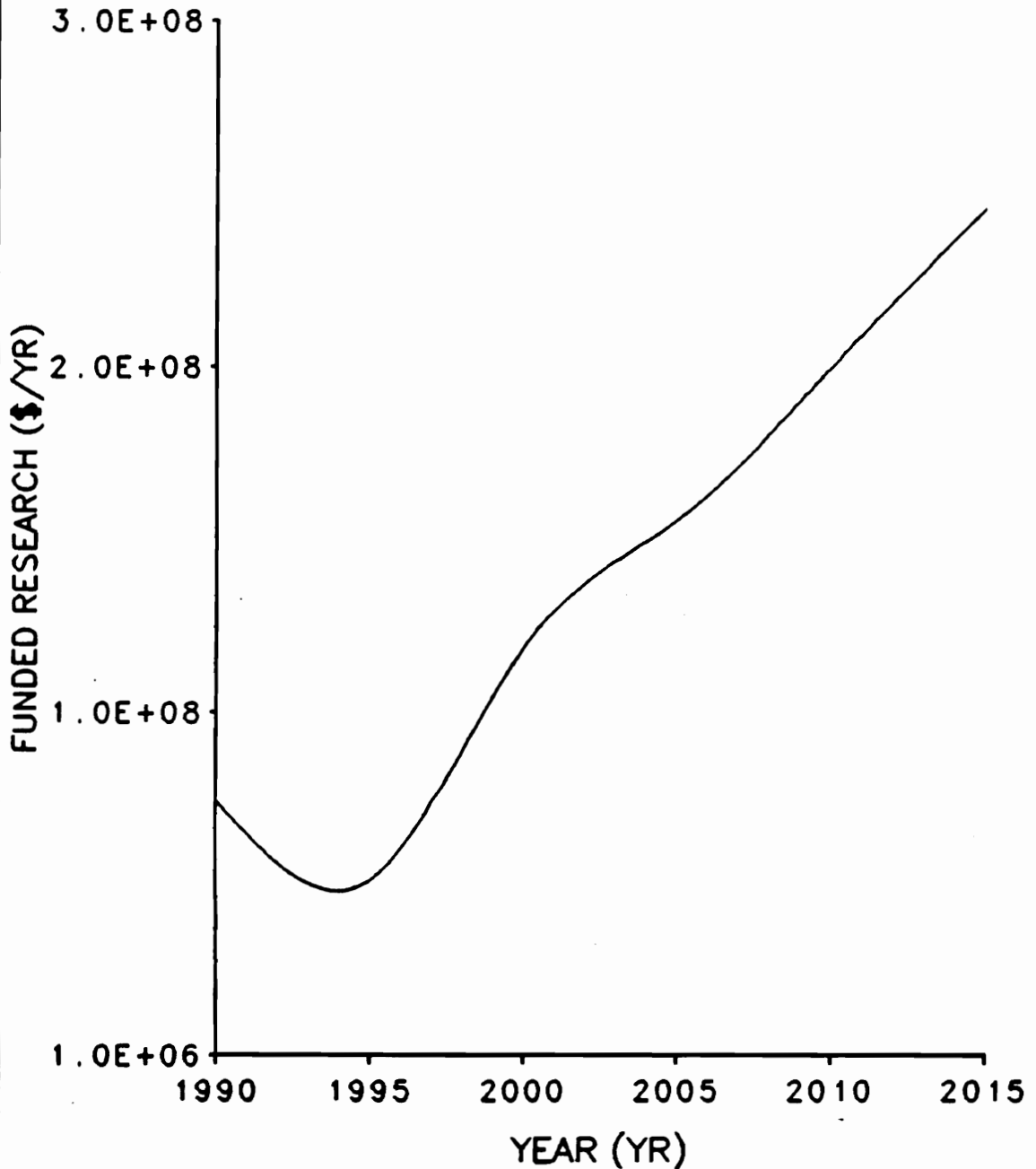


Figure 93. Alternative 5 Funded research at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 12
FUNDED RESEARCH AT VIRGINIA TECH

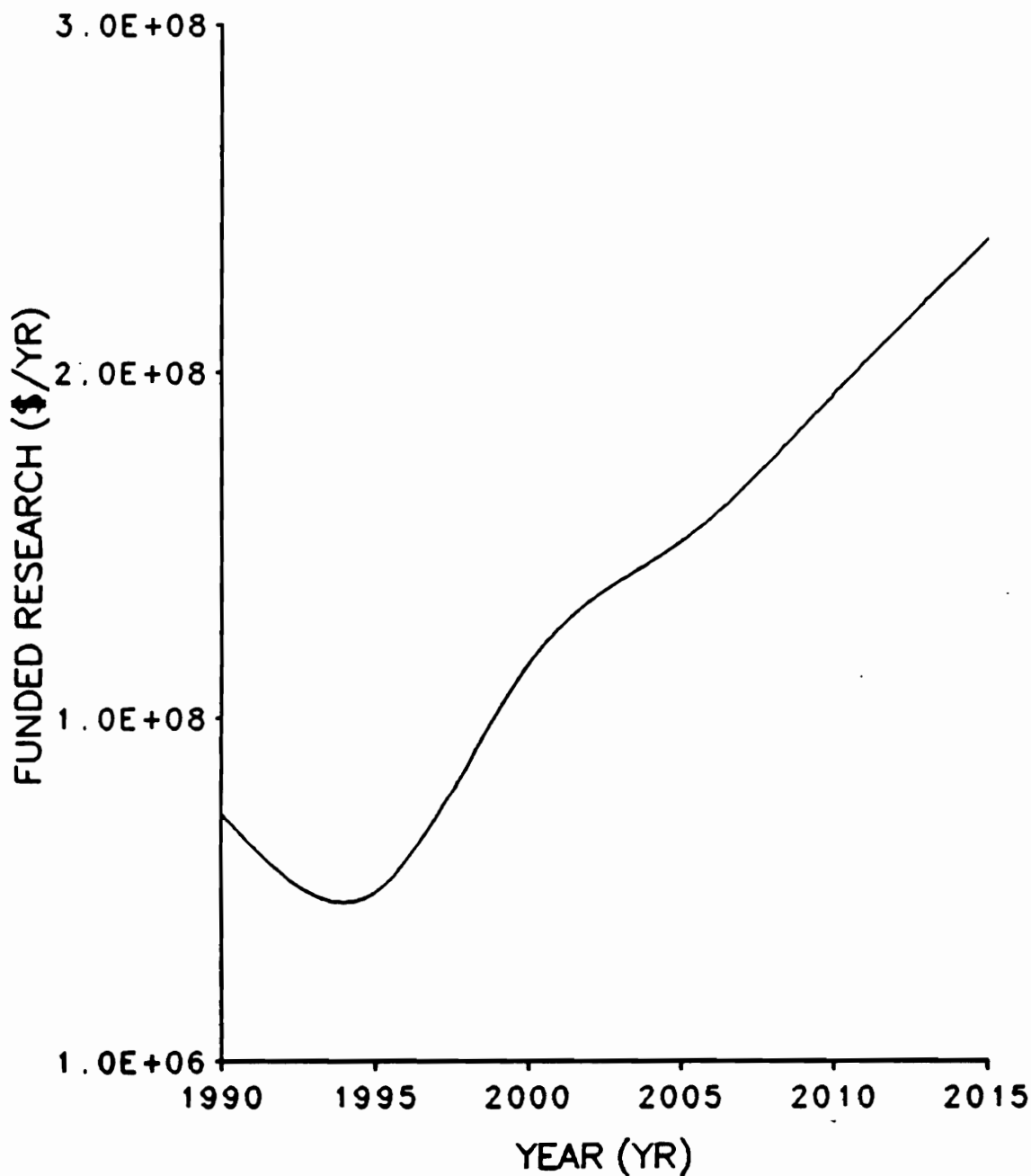


Figure 94. Alternative 12 Funded research at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 6
FUNDED RESEARCH AT VIRGINIA TECH

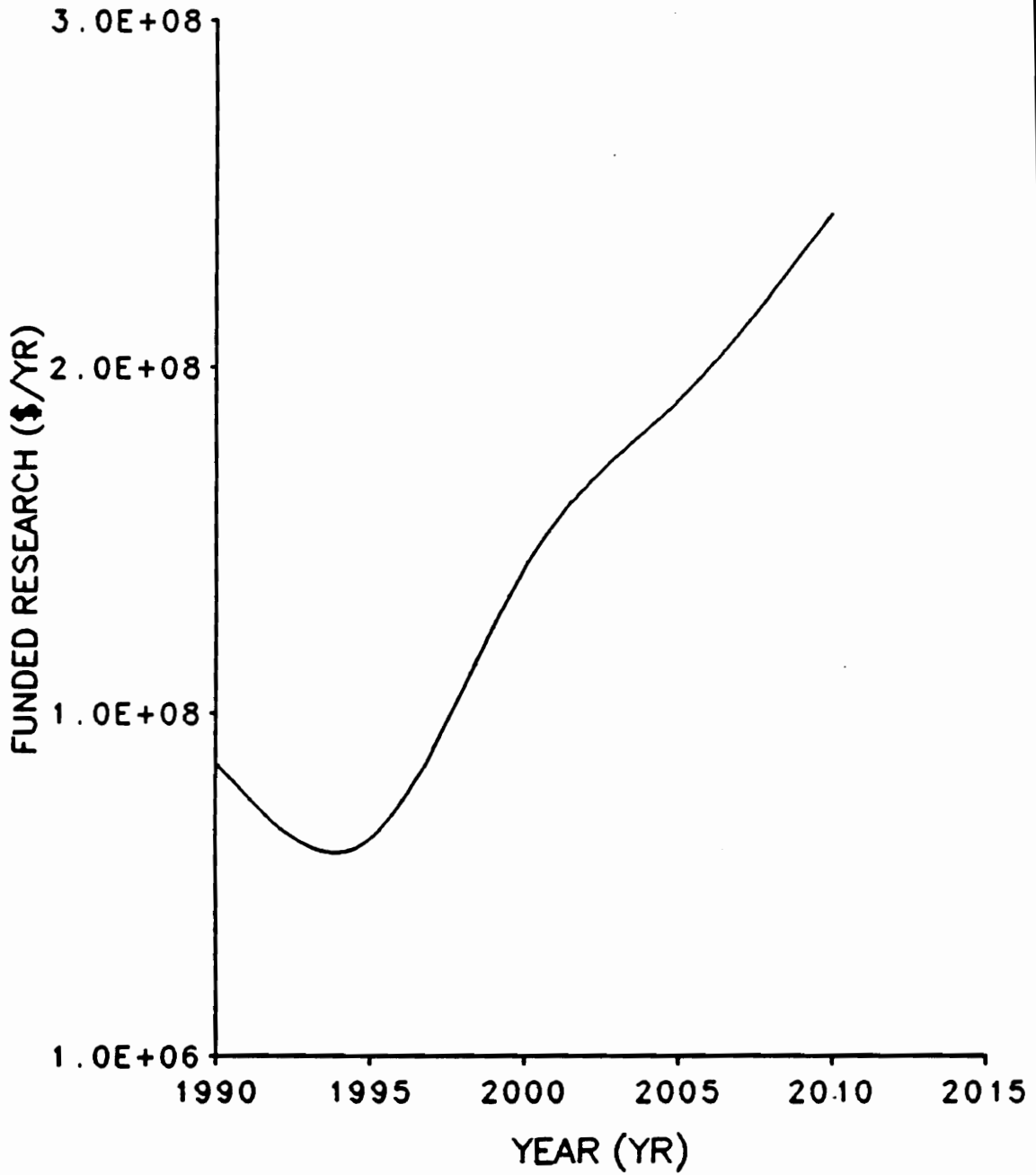


Figure 95. Alternative 6 Funded research at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 7
FUNDED RESEARCH AT VIRGINIA TECH

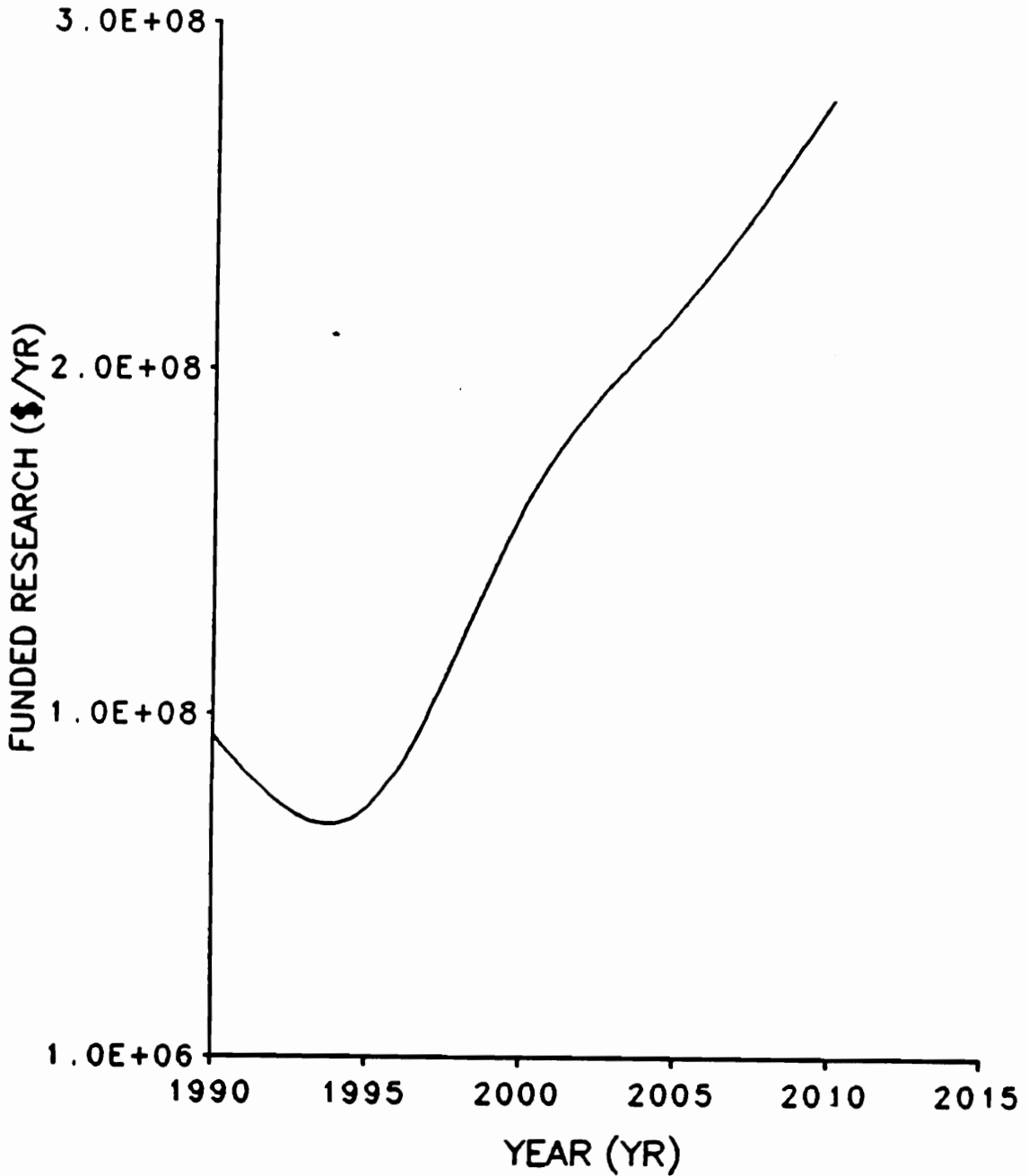


Figure 96. Alternative 7 Funded research at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 10
FUNDED RESEARCH AT VIRGINIA TECH

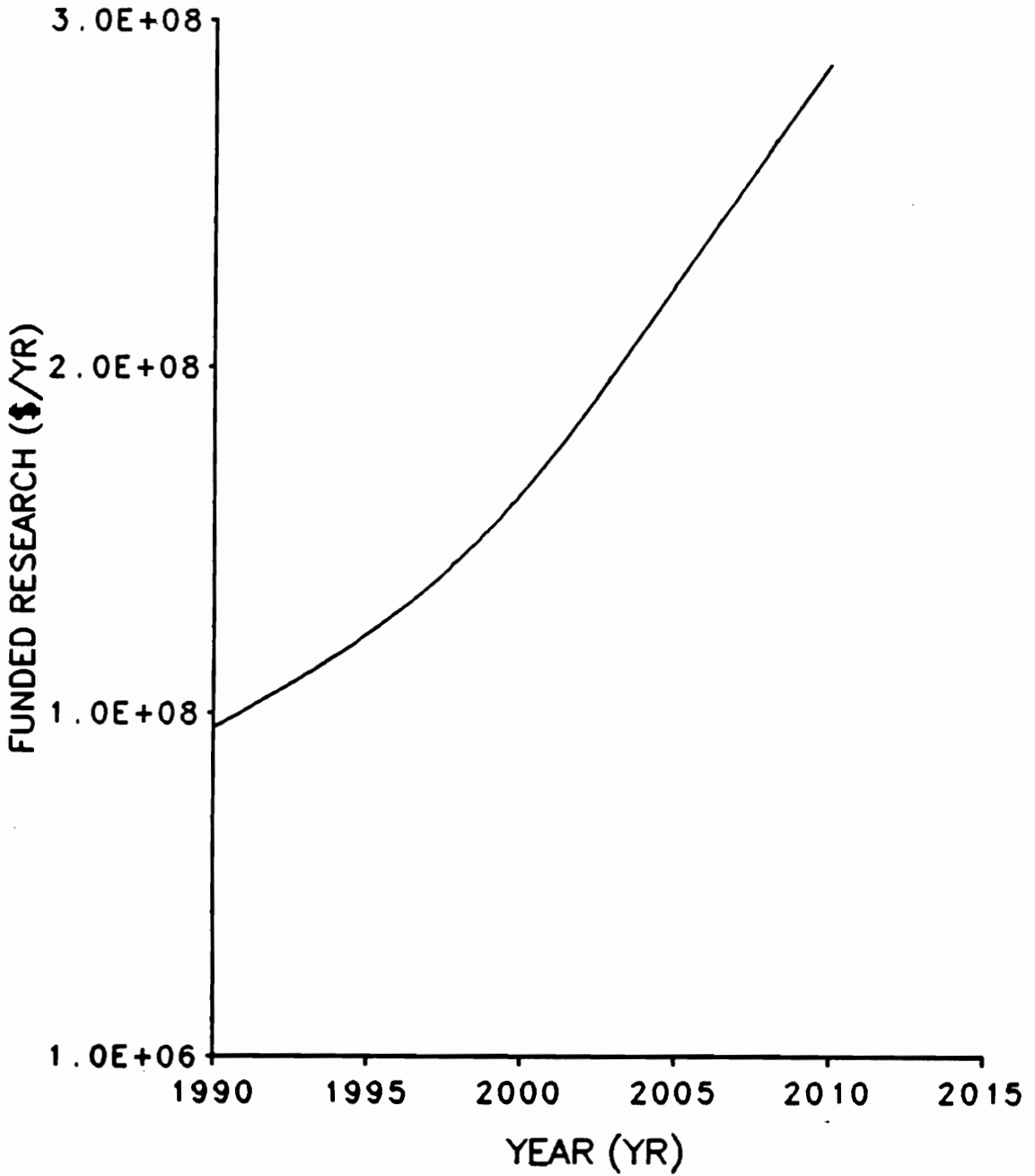


Figure 97. Alternative 10 Funded research at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 1
TOTAL GRADUTE STUDENT AT VIRGINIA TECH

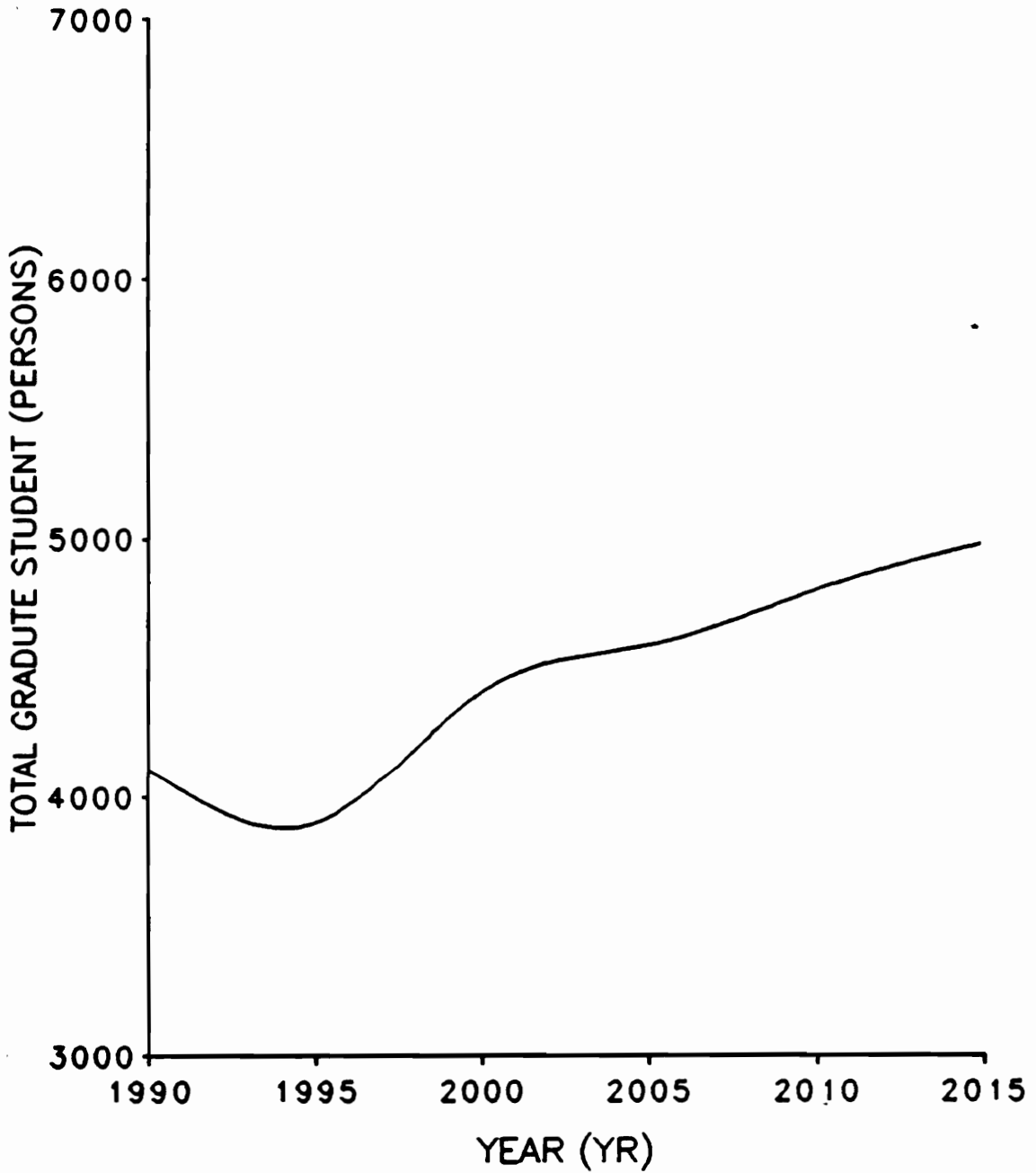


Figure 98. Alternative 1 Total graduate student at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 2
TOTAL GRADUTE STUDENT AT VIRGINIA TECH

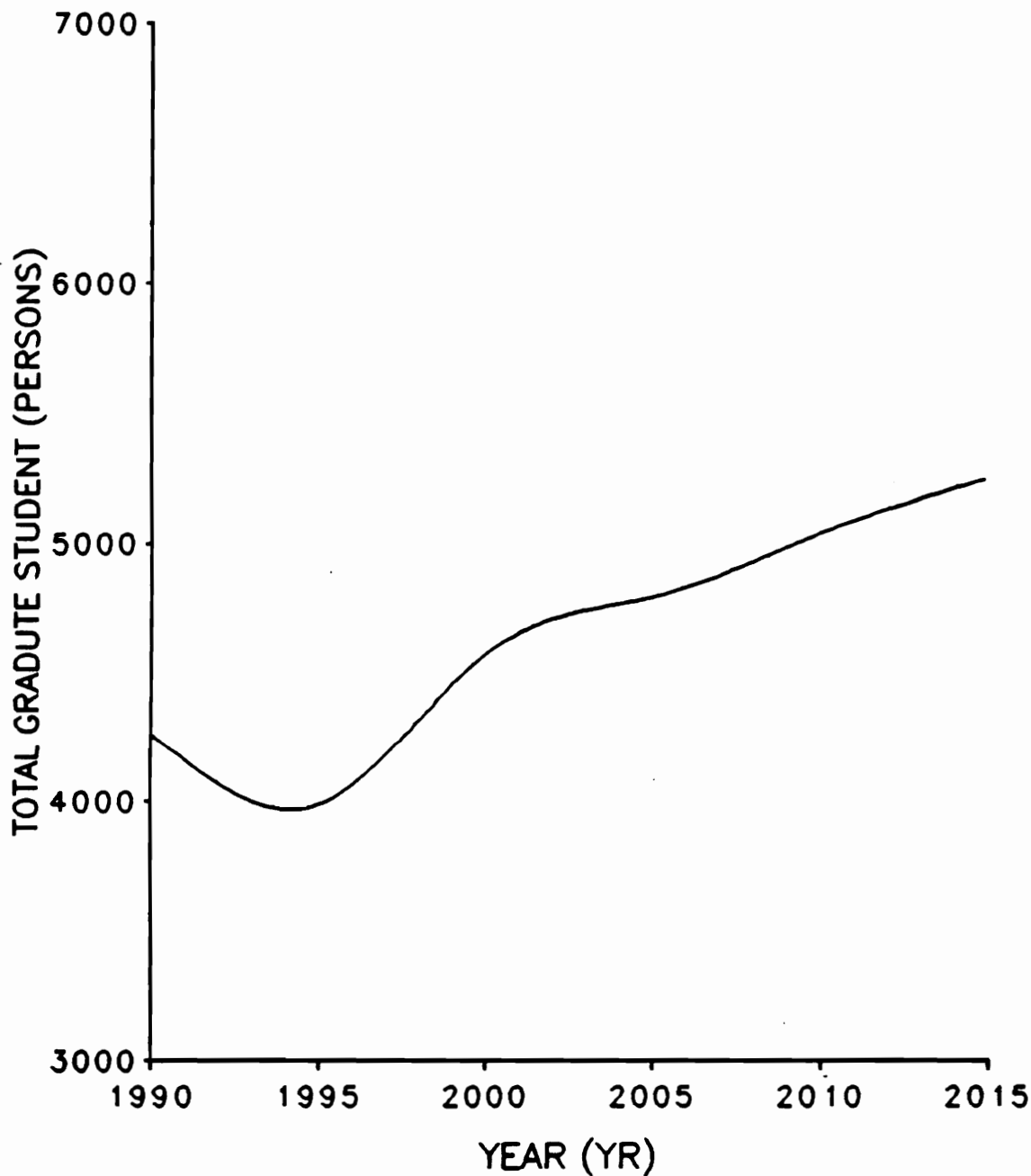


Figure 99. Alternative 2 Total graduate student at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 3A
TOTAL GRADUTE STUDENT AT VIRGINIA TECH

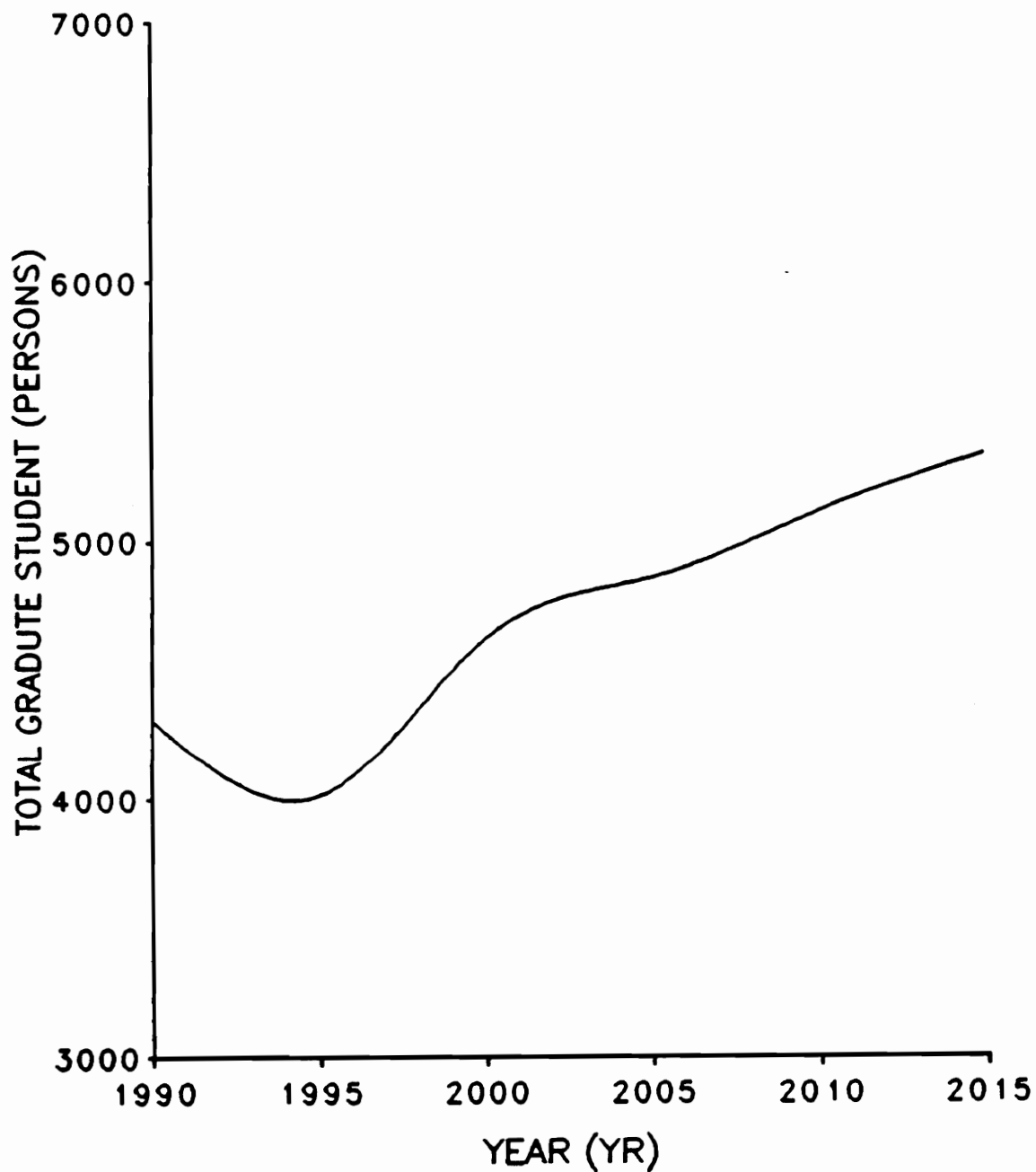


Figure 100. Alternative 3A Total graduate student at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 5
TOTAL GRADUTE STUDENT AT VIRGINIA TECH

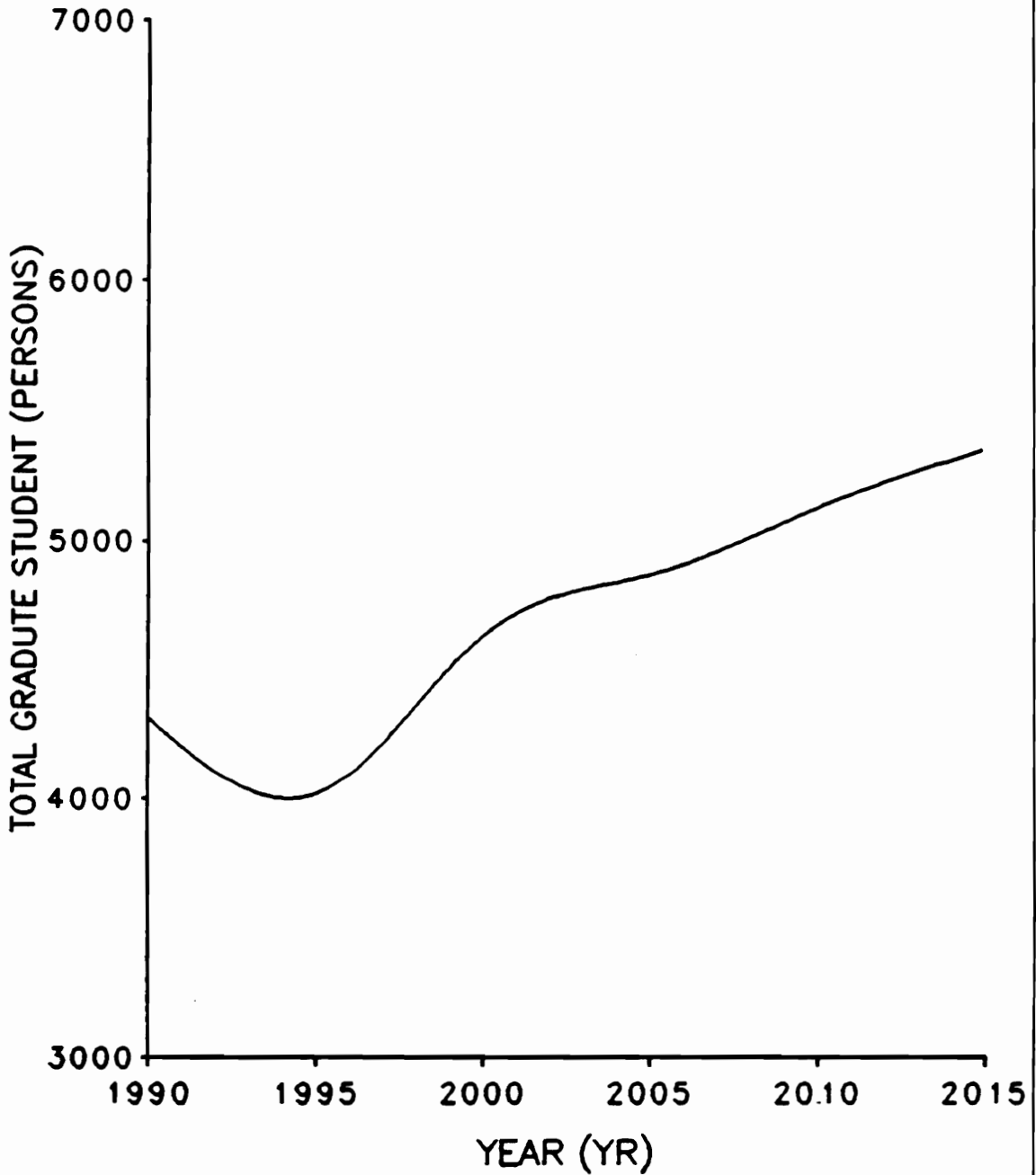


Figure 101. Alternative 5 Total graduate student at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 12
TOTAL GRADUTE STUDENT AT VIRGINIA TECH

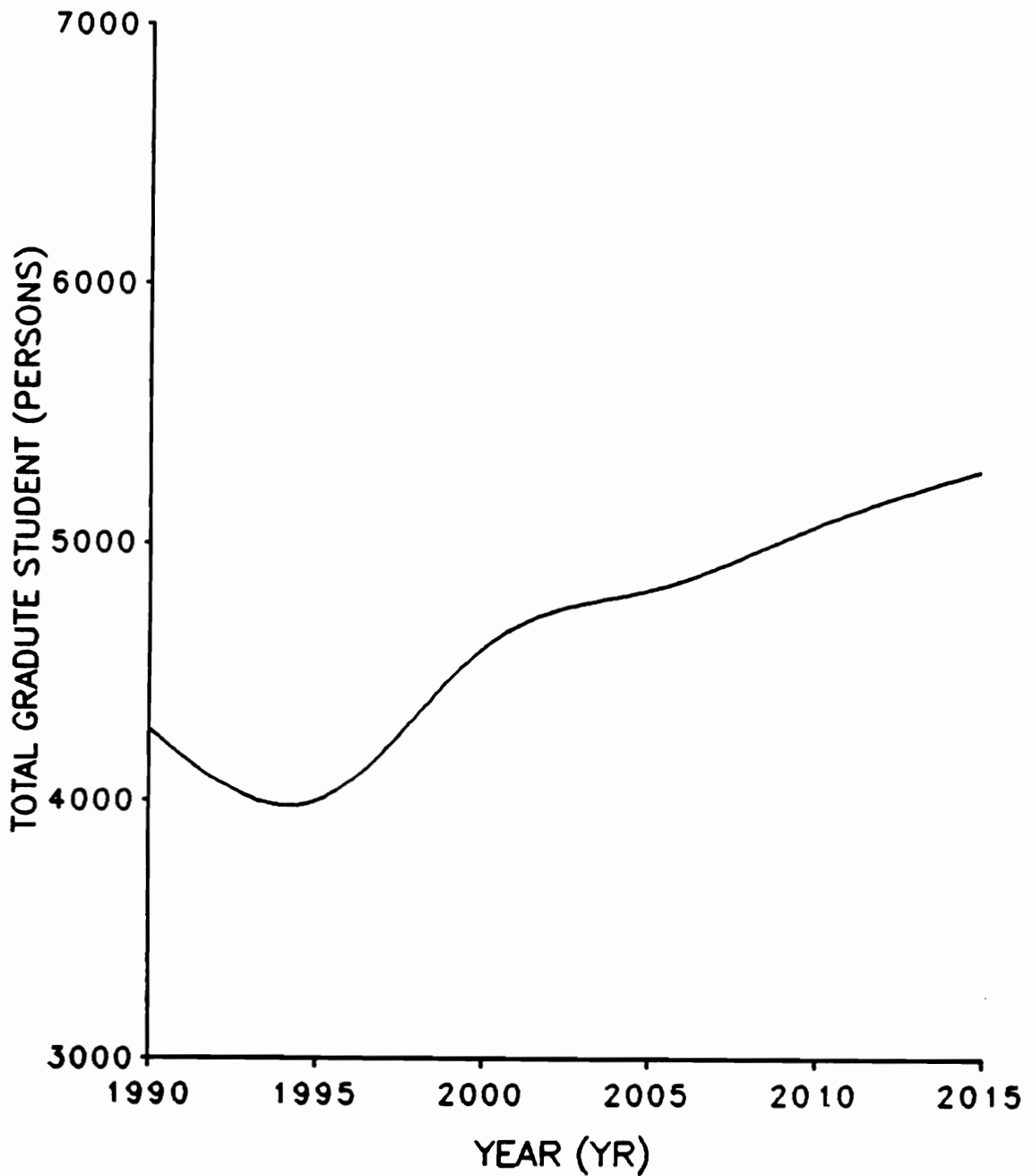


Figure 102. Alternative 12 Total graduate student at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 6
TOTAL GRADUTE STUDENT AT VIRGINIA TECH

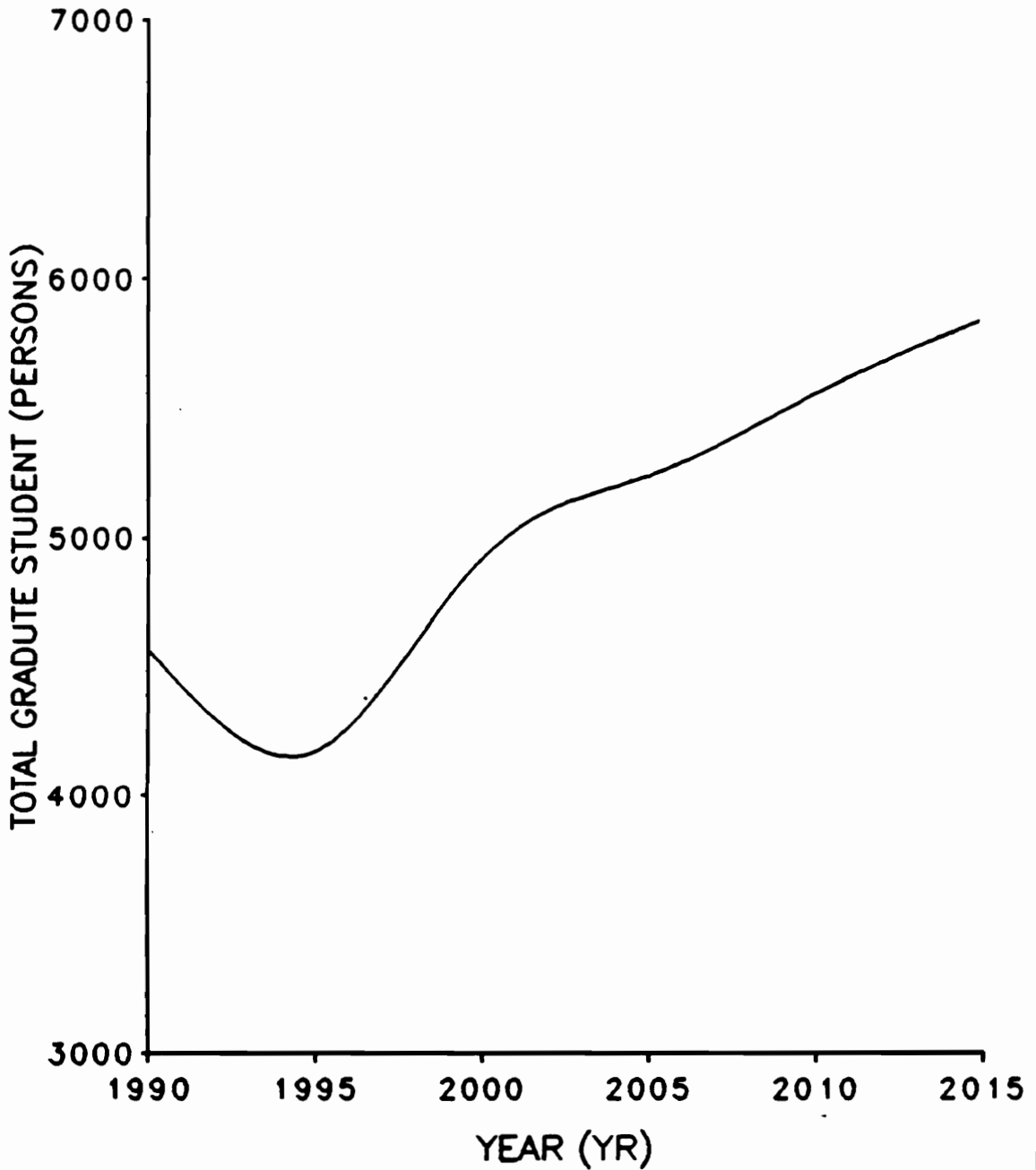


Figure 103. Alternative 6 Total graduate student at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 7
TOTAL GRADUTE STUDENT AT VIRGINIA TECH

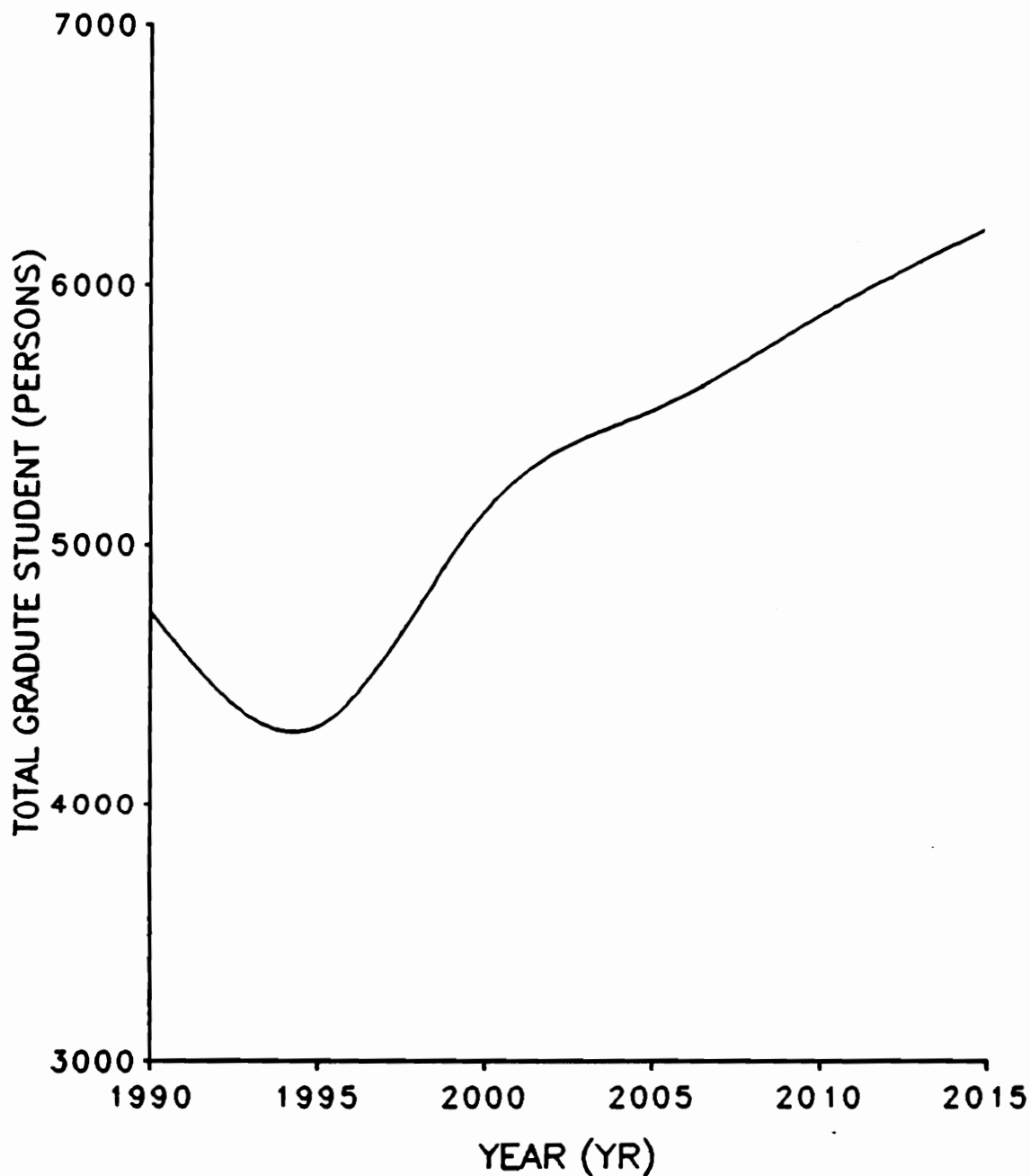


Figure 104. Alternative 7 Total graduate student at Virginia Tech

NON-USER BENEFIT ANALYSIS
ALTERNATIVE 10
TOTAL GRADUTE STUDENT AT VIRGINIA TECH

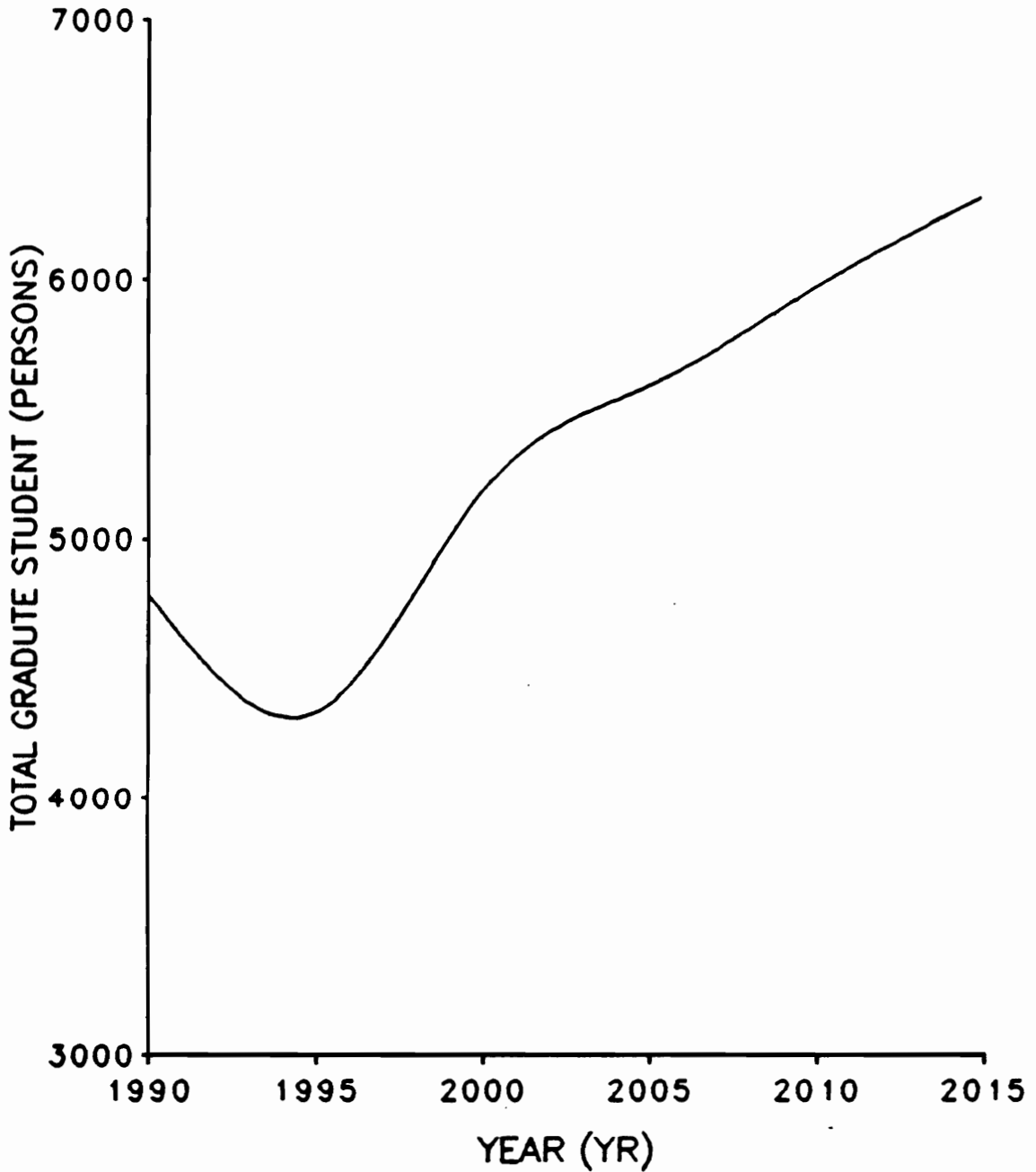


Figure 105. Alternative 10 Total graduate student at Virginia Tech

Appendix E. Glossary of Variables

ACD-ADMISSION CHANGE DELAY (YRS)
ACDR-ASSOC PROF DEPARTURE RATE (PERSONS/YR)
ACHF-ASSOC PROF HIRING FRACTION (DIM)
ACHR-ASSOC PROF HIRING RATE (PERSONS/YR)
ACO-AVER. CAR OCCUPANCY (PERSONS/HR)
ALTX-ALTERNATIVE
APCT-ADMISSION POLICY CHANGE TIME (YRS)
ASSOC-ASSOC PROFESSORS (PERSONS)
ASST-ASST PROFESSORS (PERSONS)
ATAPF-ASST TO ASSOC PROMOTION FACTOR (FRACT/YR)
ATAPR-ASST TO ASSOC PROMOTION RATE (PERSONS/YR)
ATDR-ASST PROF DEPARTURE RATE (PERSONS/YR)
ATFPF-ASSOC TO FULL PROMOTION FACTOR (FRACT/YR)
ATFPR-ASSOC TO FULL PROMOTION RATE (PERSONS/YR)
ATHF-ASST PROF HIRING FRACTION (DIM)

ATHR-ASST PROF HIRING RATE (PERSONS/YR)
BI-BASIC INDUSTRY (\$)
BIAF-BASIC INDUSTRY ATTRACT FACTOR (DIM)
BIAM-BASIC INDUSTRY ATTRACT MULT (DIM)
BICLR-BASIC INDUSTRY CAP-LABORFORCE (\$/PERSON)
BICOR-BASIC INDUSTRY CAP-OUTPUT RATIO (YR)
BID-BASIC INDUSTRY DEPRECIATION (\$/YR)
BII-BASIC INDUSTRY INVESTMENT (\$/YR)
BIJ-BASIC INDUSTRY JOB (PERSON)
BIN-BASIC INDUSTRY INITIAL (\$)
BIO-BASIC INDUSTRY OUTPUT (\$/YR)
BIP-BASIC INDUSTRY PRODUCT (\$/YR)
BS-BUSINESS SERVICES (\$)
BSAF-BUSINESS SERVICESS ATTRACT FACTOR (DIM)
BSAM-BUSINESS SERVICESS ATTRACT MULT (DIM)
BSCLR-BUSINESS SERVICESS CAP-LABORFORCE (\$/PERSON)
BSCOR-BUSINESS SERVICESS CAP-OUTPUT RATIO (YR)
BSD-BUSINESS SERVICES DEPRECIATION (\$/YR)
BSI-BUSINESS SERVICESS INVESTMENT (\$/YR)
BSJ-BUSINESS SERVICESS JOB (PERSON)
BSN-BUSINESS SERVICESSINITIAL (\$)
BSO-BUSINESS SERVICESS OUTPUT (\$/YR)
BSP-BUSINESS SERVICESS PRODUCT (\$/YR)
C-FREE SPEED (MPH)
CLS-CLASS LAB SPACE (SQ FT)
C12-LANE CAPACITY ON LINK 12 (VEH/HR)
C13-LANE CAPACITY ON LINK 13 (VEH/HR)
C21-LANE CAPACITY ON LINK 21 (VEH/HR)

C23-LANE CAPACITY ON LINK 23 (VEH/HR)
 C31-LANE CAPACITY ON LINK 31 (VEH/HR)
 C32-LANE CAPACITY ON LINK 32 (VEH/HR)
 EDACP-EMPLOYMENT DURATION ASSOC PROF (YRS)
 EDATP-EMPLOYMENT DURATION ASST PROF (YRS)
 EDFP-EMPLOYMENT DURATION FULL PROF (YRS)
 F-FACULTY (PERSONS)
 FBIOE-FRACT.BASIC INDUSTRY OUTPUT TO ELECT (DIM)
 FBIOI-FRACT.BASIC INDUSTRY OUTPUT TO INPUT (DIM)
 FBIOM-FRACT.BASIC INDUSTRY OUTPUT TO MATLS (DIM)
 FBIOT-FRACT.BASIC INDUSTRY OUTPUT TO TRANS (DIM)
 FBIOTN-FRACT.BASIC INDUSTRY OUTPUT TO TRANS NORMAL (DIM)
 FBIOW-FRACT.BASIC INDUSTRY OUTPUT TO WATER (DIM)
 FBIPI-FRACT.BASIC INDUSTRY PRODUCT INVEST (DIM)
 FBIPL-FRACT.BASIC INDUSTRY PRODUCT TO LABOR (DIM)
 FBIPTS-FRACT.BASIC INDUSTRY PRODUCT TO TRANS SUBSIDY (DIM)
 FBIPW-FRACT.BASIC INDUSTRY PRODUCT TO WAGES (DIM)
 FBSOE-FRACT.BUSINESS SERVICESS OUTPUT TO ELECT (DIM)
 FBSOI-FRACT.BUSINESS SERVICESS OUTPUT TO INPUT (DIM)
 FBSOM-FRACT.BUSINESS SERVICESS OUTPUT TO MATLS (DIM)
 FBSOT-FRACT.BUSINESS SERVICESS OUTPUT TO TRANS (DIM)
 FBSOTN-FRACT.BUSINESS SERVICESS OUTPUT TO TRANS NORMAL (DIM)
 FBSOW-FRACT.BUSINESS SERVICESS OUTPUT TO WATER (DIM)
 FBSPI-FRACT.BUSINESS SERVICESS PRODUCT INVEST (DIM)
 FBSPL-FRACT.BUSINESS SERVICESS PRODUCT TO LABOR (DIM)
 FBSPTS-FRACT.BUSINESS SERVICESS PRODUCT TO TRANS SUBSIDY (DIM)
 FBSPTX-FRACT.BASIC INDUSTRY PRODUCT TO TAXES (DIM)
 FBSPTX-FRACT.BUSINESS SERVICESS PRODUCT TO TAXES (DIM)

FBSPW-FRACT.BUSINESS SERVICESS PRODUCT TO WAGES (DIM)
FBSPW-FRACT.HOUSHOLD SERVICESS PRODUCT TO WAGES (DIM)
FDTPH-FRACT DAILY TRAFFIC IN PEAR HOUR (DIM)
FFP-FRACT FRES PASSING (1/YR)
FFRFS-FRACT FUNDED RESEARCH FACULTY SALARIES (DIM)
FFRSFS-FRACT FUNDED RES. TO STAFF SUPPORT
FFRSS-FRACT FUNDED RESEARCH STUDENT SALARIES (DIM)
FFT12-FREE FLOW TRAVEL TIME ON LINE 12 (MIN)
FFT13-FREE FLOW TRAVEL TIME ON LINE 13 (MIN)
FFT21-FREE FLOW TRAVEL TIME ON LINE 21 (MIN)
FFT23-FREE FLOW TRAVEL TIME ON LINE 23 (MIN)
FFT31-FREE FLOW TRAVEL TIME ON LINE 31 (MIN)
FFT32-FREE FLOW TRAVEL TIME ON LINE 32 (MIN)
FH-FACULTY HIRING (PERSONS/YR)
FHF-FULL PROF HIRING FRACTION (DIM)
FHR-FULL PROF HIRING RATE (PERSONS/YR)
FHSE-FRACT.HOUSHOLD SERVICESS OUTPUT TO ELECT (DIM)
FHSEI-FRACT.HOUSHOLD SERVICESS OUTPUT TO INPUT (DIM)
FHSEM-FRACT.HOUSHOLD SERVICESS OUTPUT TO MATLS (DIM)
FHSEOT-FRACT.HOUSHOLD SERVICESS OUTPUT TO TRANS (DIM)
FHSEOTN-FRACT.HOUSHOLD SERVICESS OUTPUT TO TRANS NORMAL (DIM)
FHSEOW-FRACT.HOUSHOLD SERVICESS OUTPUT TO WATER (DIM)
FHSEPI-FRACT.HOUSHOLD SERVICESS PRODUCT INVEST (DIM)
FHSEPL-FRACT.HOUSHOLD SERVICESS PRODUCT TO LABOR (DIM)
FHSEPTS-FRACT.HOUSHOLD SERVICESS PRODUCT TO TRANS SUBSIDY (DIM)
FHSEPTX-FRACT.HOUSHOLD SERVICESS PRODUCT TO TAXES (DIM)
FJP-FRACT JUNIORS PASSING (1/YR)
FOBF-FRACT OPER BUDGET TO FACULTY (DIM)

FOBS-FRACT OPER BUDGET TO STAFF (DIM)
FP-FACULTY POSITIONS (PERSONS)
FPDR-FULL PROF DEPARTURE RATE (PERSONS/YR)
FPF-FRACT PROPOSALS FUNDED (DIM)
FR-FUNDED RESEARCH (\$/YR)
FRES-FRESHMEN (PERSONS)
FRO-FRACT RESEARCH TO OVERHEAD (DIM)
FROB-FRACT RES OVERHD TO BUDGET (DIM)
FSG-FRACT SENIORS GRADUATING (1/YR)
FSP-FRACT SOPH PASSING (1/YR)
FTSP-FRES TO SOPH PASSING (PERSONS/YR)
FULL-FULL PROFESSORS (PERSONS)
GA-GRADUATE ASSISTANTS (PERSONS)
GRA-GRADUATE RESEARCH ASSISTANTS (PERSONS)
HD-HIRING DELAY (YRS)
HS-HOUSHOLD SERVICES (\$)
HSAF-HOUSHOLD SERVICESS ATTRACT FACTOR (DIM)
HSAM-HOUSHOLD SERVICESS ATTRACT MULT (DIM)
HSCLRL-HOUSHOLD SERVICESS CAP-LABORFORCE (\$/PERSON)
HSCOR-HOUSHOLD SERVICESS CAP-OUTPUT RATIO (YR)
HSD-HOUSHOLD SERVICES DEPRECIATION (\$/YR)
HSI-HOUSHOLD SERVICESS INVESTMENT (\$/YR)
HSJ-HOUSHOLD SERVICESS JOB (PERSON)
HSN-HOUSHOLD SERVICES INITIAL (\$)
HSO-HOUSHOLD SERVICESS OUTPUT (\$/YR)
HSP-HOUSHOLD SERVICESS PRODUCT (\$/YR)
IM-IN-MIGRATION (PERSONS/YR)
IMN-IN-MIGRATION NORMAL (1/YR)

J-TOTAL NO. OF JOBS(JOBS)
JTSP-JUNIOR TO SENIOR PASSING (PERSONS/YR)
JUN-JUNIORS (PERSONS)
LBI-LIFETIME BASIC INDUSTRY (YR)
LBS-LIFETIME BUSINESS SERVICES (YR)
LF-LABORFORCE (PERSONS)
LHS-LIFETIME HOUSHOLD SERVICES (YR)
LPD-LAND PER DWELLING (ACRES/UNIT)
LPF-LABORFORCE PARTICIPATION FRACTION (DIM)
LSF12-LEVEL OF SERVICE FACTOR ON LINK 12 (DIM)
LSF13-LEVEL OF SERVICE FACTOR ON LINK 13 (DIM)
LSF21-LEVEL OF SERVICE FACTOR ON LINK 21 (DIM)
LSF23-LEVEL OF SERVICE FACTOR ON LINK 23 (DIM)
LSF31-LEVEL OF SERVICE FACTOR ON LINK 31 (DIM)
LSF32-LEVEL OF SERVICE FACTOR ON LINK 32 (DIM)
LZR-LAND ZONED RESIDENTIAL (ACRES)
LZRN-LAND ZONED RESIDENTIAL NORMAL (ACRES)
NBIAR-NEW BASIC INDUSTRY ATTRACT RATE
NBSAR-NEW BUSINESS SERVICES ATTRACT RATE (DIM)
NGF-NET GROWTH FACTOR (1/YR)
NHSAR-NEW HOUSHOLD SERVICES ATTRACT RATE (DIM)
NPG-NET POPULATION GROWTH (PERSONS/YR)
N12-NO. OF LANES PER DIRECTION ON LINK 12
N13-NO. OF LANES PER DIRECTION ON LINK 13
N21-NO. OF LANES PER DIRECTION ON LINK 21
N23-NO. OF LANES PER DIRECTION ON LINK 23
N31-NO. OF LANES PER DIRECTION ON LINK 31
N32-NO. OF LANES PER DIRECTION ON LINK 32

OB-OPERATING BUDGET (\$/YR)
OM-OUT-MIGRATION (PERSONS/YR)
OMN-OUT-MIGRATION NORMAL (1/YR)
OS-OFFICE SPACE (SQ FT)
P-POPULATION (PERSONS)
PCI-PER CAPITA INCOME (\$/PERSON)
PN-POPULATION AT 1990 (PERSONS)
PPD-PERSONS PER DWELLING (PERSONS/UNIT)
PPF-PROPOSALS PER FACULTY (PROPOSALS/PERSON)
Q12-VOLUME ON LINK 12(VEH/HR)
Q12T-THRU TRAFFIC ON LINK 12 (VEH/HR)
Q13-VOLUME ON LINK 13(VEH/HR)
Q13T-THRU TRAFFIC ON LINK 13 (VEH/HR)
Q21-VOLUME ON LINK 21(VEH/HR)
Q21T-THRU TRAFFIC ON LINK 21 (VEH/HR)
Q23-VOLUME ON LINK 23(VEH/HR)
Q23T-THRU TRAFFIC ON LINK 23 (VEH/HR)
Q31-VOLUME ON LINK 31(VEH/HR)
Q31T-THRU TRAFFIC ON LINK 31 (VEH/HR)
Q32-VOLUME ON LINK 32(VEH/HR)
Q32T-THRU TRAFFIC ON LINK 32 (VEH/HR)
RFP-RESEARCH FACULTY POSITIONS (PERSONS)
RGATS-RATIO GRAD ASSISTANTS TO STUDENTS (DIM)
RLAM-RESIDENTIAL LAND AVAILABILITY MULT (DIM)
RLFO-RESIDENTIAL LAND FRACTION OCCUPIED (DIM)
RO-RESEARCH OVERHEAD (\$/YR)
ROB-RESEARCH OVERHD TO BUDGET (\$/YR)
RUGSTS-RATIO UNSUPPORTED GRAD TO STUDENTS (DIM)

S-STUDENTS (PERSONS)
 SA-STUDENT ADMISSIONS (PERSONS/YR)
 SAN-STUDENT ADMISSIONS NORMAL (FRACT/YR)
 SEN-SENIORS (PERSONS)
 SG-STUDENTS GRADUATING (PERSONS/YR)
 SOPH-SOPHOMORES (PERSONS)
 SP-STUDENT POSITIONS (PERSONS)
 SPF-SPACE PER FACULTY (SQ FT/PERSON)
 SPG-SPACE PER GRAD STUDENT (SQ FT/PERSON)
 SPS-SPACE PER STUDENT (SQ FT/PERSON)
 SPSF-SPACE PER STAFF (SQFT/PERSON)
 SS-STUDENT SALARIES (\$/PERSON-YR)
 SSI-STUDENT SALARIES INCREASE (\$/PERSON-YR)
 SSN-STUDENT SALARIES NORMAL (\$/PERSON-YR)
 SSPCT-STATE SUPPORT POLICY CHANGE TIME (YRS)
 SSPS-STATE SUPPORT PER STUDENT (\$/PERSON-YR)
 SSPSI-STATE SUPPORT PER STUDENT INCREASE (\$/PERSON-YR)
 SSPSN-STATE SUPPORT PER STUDENT NORMAL (\$/PERSON-YR)
 STFP-STAFF POSITIONS (PERSONS)
 STFS-STAFF SALARIES (\$/PERSON-YR)
 STFSI-STAFF SALARIES INCREASE (\$/PERSON-YR)
 STFSN-STAFF SALARIES NORMAL (\$/PERSON-YR)
 STJP-SOPH TO JUNIOR PASSING (PERSONS/YR)
 TGF-TRIP GENERATION FACTOR (DIM)
 TGS-TOTAL GRADUATE STUDENTS (PERSONS)
 TK-COLLECTION,DISTRIBUTION,TRANSFER TIME AT NODE K (MIN)
 TN12-TRAVEL TIME BETWEEN AREA 1 AND AREA 2 NORMAL(MIN)
 TN13-TRAVEL TIME BETWEEN AREA 1 AND AREA 3 NORMAL (MIN)

TN31-TRAVEL TIME BETWEEN AREA 3 AND AREA 1 NORMAL (MIN)
TOT-TOTAL SPACE (SQ FT)
TS-TEACHING SALARIES (\$/PERSON-YR)
TSI-TEACHING SALARIES INCREASE (\$/PERSON-YR)
TSN-TEACHING SALARIES NORMAL (\$/PERSON-YR)
T12-TRAVEL TIME FROM AREA 1 TO AREA 2 (MIN)
T12E-TRAVEL TIME BETWEEN AREA 1 AND AREA 2 AT EQUILIBRUM (MIN)
T13-TRAVEL TIME FROM AREA 1 TO AREA 3 (MIN)
T13E-TRAVEL TIME BETWEEN AREA 1 AND AREA 3 AT EQUILIBRUM (MIN)
T21-TRAVEL TIME FROM AREA 2 TO AREA 1 (MIN)
T31-TRAVEL TIME FROM AREA 3 TO AREA 1 (MIN)
T31E-TRAVEL TIME BETWEEN AREA 3 AND AREA 1 AT EQUILIBRUM (MIN)
UGS-UNSUPPORTED GRADUATE STUDENTS (PERSONS)
UR-UNEMPLOYMENT RATE
VPP-VALUE PER PROPOSAL (\$/PROPOSAL)
VPPI-VALUE PER PROPOSAL INCREASE (\$/PROPOSAL)
VPPN-VALUE PER PROPOSAL NORMAL (\$/PROPOSAL)
V12-DEMAND FROM AREA 1 TO AREA 2 (PERSONS/DAY)
V13-DEMAND FROM AREA 1 TO AREA 3 (PERSONS/DAY)
V21-DEMAND FROM AREA 2 TO AREA 1 (PERSONS/DAY)
V23-DEMAND FROM AREA 2 TO AREA 3 (PERSONS/DAY)
V31-DEMAND FROM AREA 3 TO AREA 1 (PERSONS/DAY)
V32-DEMAND FROM AREA 3 TO AREA 2 (PERSONS/DAY)
X12-DIST BETWEEN NODES 1 AND 2 (MILES)
X13-DIST BETWEEN NODES 1 AND 3 (MILES)
X21-DIST BETWEEN NODES 2 AND 1 (MILES)
X23-DIST BETWEEN NODES 2 AND 3 (MILES)
X31-DIST BETWEEN NODES 3 AND 1 (MILES)

X32-DIST BETWEEN NODES 3 AND 2 (MILES)

Vita

Abdullah S. Al-Dawood was born in Hurimla, a town 40 miles north of Riyadh capital of Saudi Arabia. He attended public school in Riyadh and completed his high school at Yammamh High School. He received his B.S. in Civil Engineering from King Saud University, Riyadh, Saudi Arabia in 1982. In 1982 he joined the Ministry of Transportation in Saudi Arabia, where he was assigned to a training program conducted for the new engineer for a period of four months mainly in pavement material. Following that he was assigned as one of the supervisor engineer on Riyadh ring road a project which costed about one \$ billion. In 1983, he was assigned, beside his work in Riyadh ring road, to join a committee to establish a Right of Way Engineering department for the whole road network in Saudi Arabia. In 1984 he was awarded a scholarship from Ministry of Transportation through U.S. Department of Transportation to a six months training program in Design Highway and Right of Way Engineering from March to August 1984 in California highway Department (district 11 San Diego) and five weeks of that training was spent in San Diego county. Then, he returned to Ministry of Transportation in Saudi Arabia where he was assigned as a supervisor to the south branch of the Riyadh ring road a project which costed \$ 100 million and following the Right of Way Engineering in Riyadh area. In August 1986 he was granted a scholarship to pursue his higher education in U.S.A. from Ministry of Transportation in Saudi Arabia through International Road Federation

(IRF). In September, 1986 he was enrolled in master program in Transportation Division, Civil Engineering Department at Virginia Tech, Blacksburg, Virginia. In September, 1987 he received Master of science degree in Civil Engineering. Then he was enrolled in a PH.D. program in the same department. While he was pursuing for PH.D degree he worked from September 1987 to February 1988 in Anderson Assoc.(consulting firm in Blacksburg Virginia). His doctoral work was completed in November, 1990. He is married and has three children; Saad, Nora and Iyah.

A handwritten signature in black ink, consisting of a series of loops and a long horizontal stroke extending to the right.