PRICING CONTROL AS A STRATEGY
OF URBAN TRANSPORTATION PLANNING

by

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ABSTRACT

For many reasons planners in the past have failed to realize the full potential of the market system as a powerful practical and intellectual tool to be used in urban transportation planning. At a time when there is increasing evidence that past approaches to the urban transportation problem have not yielded the long term solutions that were expected, it is urgent that all alternative strategies be explored. This study addresses itself to one policy course: control of urban transportation through the deliberate use of the market mechanism.

The objective of the pricing of urban transportation would be to promote a more socially desirable pattern of usage of the system through a structuring of the demand characteristics - by mode, route, time of travel, and amount of travel. Pricing may thus be used to make the tripmaker aware of, and accountable for, the social costs he incurs in the form of delays due to congestion, noise, air pollution, and so forth, and his travel behaviour would alter accordingly. Because these so-called externalities are, at present not quantifiable in monetary terms, and because of differences in individual utilities, the use of the pricing mechanism cannot displace the political decision-making, but can supplement it.

This study is an evaluation of the tool of pricing control in urban transportation planning. The theoretical relationships and the rationale for use of the price mechanism are discussed, and the technical and administrative problems of implementation of a pricing scheme are evaluated. The potential impacts are examined. The practical application of the tool is explored in the context of a case study of traffic in the Lions' Gate Bridge Corridor in Vancouver.
There are several compelling advantages to the use of the pricing system for achieving both short-run and long-run objectives. It is extremely flexible, adaptable, incremental, reversible, and most schemes can be implemented at very low capital cost. It can be a strategy for restraint or containment of traffic, or more generally a strategy for directing the patterns of use of the transportation system. But there are serious unanswered questions concerning the limitations of the tool—specifically the income redistribution effects and the overall effectiveness of the pricing mechanism in an increasingly affluent society. There are potential long-term impacts which will remain speculative until we have working urban simulation models.

Although the direct application of pricing would be practicable in Canada in only a limited number of clearly defined situations, an understanding of the theoretical concepts will assist in the formulation of specific objectives which may then be pursued using alternate tools more suited to each set of circumstances.
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INTRODUCTION

The object of this thesis is to evaluate feasibility of deliberate use of the market mechanism in the control of urban transportation. The intent of such control is to achieve certain social objectives through a structuring of the patterns of demand for urban transportation (by mode, route, time of travel and so forth). The pricing of urban transportation is thus seen as an instrument for restraint and containment rather than for accommodation of urban traffic demands.

The object of transportation pricing policies that have been proposed has been to internalize the externalities (congestion costs, air pollution, noise, etc.) and achieving that insofar as the external costs are quantifiable, to rely on "consumer sovereignty" to produce the optimum pattern of transportation in both the short-run and the long-run. However, there are still imperfections in the market mechanism, relative to nonquantifiable benefits and costs, particularly in the context of social goals, and there are the factors relating to the distribution of income. If the present distribution of income is not optimum in some social sense the market will not produce the optimum transportation system.

In seeking solutions to the problems of urban transportation it is unfortunately only too easy to regard one strategy as the panacea. But the urban transportation system is an extremely complex entity within an even more complex urban system - and any panacea is an illusion. By the very nature of the problem the solution cannot be found in one remedial, action or in one policy course. We cannot rely entirely on the "invisible hand" approach to produce a transportation system completely in accordance
with the goals of society. Pricing should be viewed as complementary to other approaches rather than a substitute. On this basis the study does not attempt to compare the strategy of pricing control to other planning alternatives.

This does not deny that there are worthy reasons for exploring this alternative. At a time when there is increasing evidence that past approaches have not always yielded either the desired or the expected long-term solutions to urban transportation problems, there are several compelling reasons for studying the strategies relating to pricing.

The first relates to the concept of incrementalism in transportation planning. Pricing policies could reduce the risks arising from uncertainty by seeking solution in which investment costs are low or can be taken step-by-step. Decisions with respect to urban transportation must be predicated upon a strategy of coping with uncertainty - the uncertainty in planning that stems from three fundamental bases; first, ignorance of the present system relationships, second, changing human values and perceptions, and third, changing technology, particularly relating to housing, transportation and communications. If we invest in heavy hardware that may radically change the city we may be foreclosing other options to accommodate the changing needs and desires of the urban residents in the future. Policies relating to pricing control would permit us to step back and try another direction if the first was not the best, or if any of the elements of uncertainty change. Such policies, if they could be implemented with sufficient sensitivity could be applied generally throughout the transportation network or they could be applied to remedy specific problems or situations.
A second reason for exploring this alternative relates to the philosophical questions concerning the various approaches to transportation planning. The concept of restraint on consumption may be alien to the growth enthusiasts, but there are those, of the Club of Rome or the Jay Forrester persuasion, who regard restraint on growth as inevitable in a world of limited resources. The pricing of urban transportation albeit only a portion of the whole of our consumptive capacity, would be a direct application of the philosophy of constraint—a brake on consumption of the resources that are now devoted to urban travel. Since direct reduction of urban travel would appear to contravene other social goals, this writer sees pricing policies as tools to ensure that the resources that are consumed in urban travel are put to the most efficient, the most socially desirable, use. Pricing is therefore a mechanism to promote the most "socially efficient" use of the existing transportation system and, in the long-run, to avoid investments in transportation infrastructure that do not satisfy the efficiency criterion.

This introduces the third reason. There is no doubt that direct application of pricing would be practicable in Canada in only a limited number of clearly defined situations, but the principles discussed in this thesis need not, for that reason, be discarded. Indeed the intellectual exercise may well assist in formulating the specific objectives which may then be pursued using alternative tools more suited to each set of circumstances.
Organization of the Study

The evaluation of pricing as a tool of transportation planning is carried out loosely within the framework of the conventional planning process model depicted on the next page. Although the model is by no means complete, it does illustrate the parameters. The three important questions that this thesis seeks to answer are:

1. Is the control of urban transportation by pricing a feasible strategy, i.e., will it achieve the stated objectives?
2. If not, what are the limitations and where would it fail?
3. If pricing control were adopted as a planning tool, what would be the probable environmental, social and urban morphological impacts?
### PLANNING PROCESS MODEL

| GOALS | A "liveable" Environment  
|       | Freedom of Choice  
|       | Equitable Distribution of Income  
|       | Maximize Access to Opportunities  
|       | Efficient Allocation of Resources in the long-run |
| OBJECTIVES | Accommodate Forecast Demands  
|            | or Contain Demands  
|            | More Efficient Use of Existing Transportation System |
| ALTERNATIVES | New Capacity to Meet Projected Demand  
|              | Traffic Engineering  
|              | Persuasion - eg. car pooling  
|              | staggering hours  
|              | "marketing" transit  
|              | Price Control  
|              | Restriction by Fiat |
| IMPACT | Absolute Demand for Travel  
|        | Mode Split  
|        | Environmental Quality  
|        | Urban Morphology  
|        | Social Impact |
| EVALUATION | Evaluation vis-a-vis Goals  
|           | Administrative Feasibility  
|           | Social and Political Acceptability |
| PLAN FORMULATION |
In Chapter I the functions of prices are examined both in relation to present policies - or non-policies - and to the potential functions (i.e., the objectives) of deliberate pricing control.

In order to understand the function of the price mechanism it is necessary to establish the fundamental theoretical relationships of price to short-run and long-run supply of and demand for transport. This is done in Chapter II. This chapter further seeks to explain the reasons for the apparent failings and limitations of past and present planning approaches.

The concept of divergence between private and social cost is introduced in Chapter III in order to demonstrate that until the transport user is made aware of and accountable for all the social costs he incurs, the present approaches to the transportation problem can only achieve non-optimal solutions.

The pricing of transportation, while virtually ignored by planners, has been the object of considerable investigation by transport economists. A study of pricing as a planning tool would not be complete without a look at the economic rationale for the frequently suggested policy of pricing at marginal cost. (Chapter III) The concepts are sound, subject to certain qualifications, and it is on these fundamental welfare economic principles that the Case Study in Chapter IV is based. But where the traditional economics of road pricing has dealt with only one social cost - that due to congestion - this must be extended to embrace all social costs. Some can perhaps be evaluated in monetary terms but others must be expressed politically. The social costs are considered descriptively in Chapter III and, where possible, analytically in the case study in Chapter IV.
Chapter V is an investigation of the various specific schemes for practical application of road pricing. These are evaluated (rather subjec-tively) on the basis of their technical and administrative feasibility.

Chapter VI draws the components of the various chapters together, again within the framework of the planning process model for final con-clusions and recommendations for further study.
1.1 A Mechanism for Rationing Limited Capacity (Short Run)

The function of prices in the conventional economic definition is to allocate scarce resources efficiently by two general mechanisms: first by ensuring that the commodity goes to the consumer who values it most highly under a given distribution of income, and second, by signalling that more production capability is needed. In the context of a transportation facility the primary purpose of prices would be to ensure that the existing facilities are put to the "best" (ie. the most valued) use and that with increasing demand for the service the price (or more correctly the quasi-rent) for the roadspace would serve as an indicator that investment in expansion of existing or in building new facilities is economically justified.

The pricing mechanism is of course, not the only method by which scarce resources (ie. limited capacity) may be rationed.\(^1\)

(1) Where it is impossible to supply an unlimited quantity of a commodity, administrative exclusion may be employed (Walters refers to this as "the uglier twin sister of the pricing system").\(^2\) Although it may be acceptable under certain conditions (ie. wartime), it is generally a distasteful exercise. In Galbraith's words "an onerous form of control, ill adapted to differences in personality...Even the formally planned economies regard

\(^1\) In the discussion in the following chapters it is necessary to recognize the distinction between short-run resource allocation, meaning the rationing of the existing facilities of limited capacity, and long-run resource allocation, meaning the application of generalized factors of expansion or the creation of new facility. The relationship between the short-run and long-run allocation will be clarified in later sections.

\(^2\) Walters (1968) p 15
rationing as a manifestation of failure."

(2) The second alternative to allocation by pricing is by congestion, which it may be argued is indeed a pricing mechanism by which the consumer is required to pay, not in monetary terms, but in time expended. As will be seen later this is an extremely inefficient mechanism which fails to achieve an optimum allocation in both the short-run and long-run sense.

The three methods whereby allocation of resources may be achieved are, therefore market pricing system, rationing by administrative fiat, and rationing by congestion. Under our current system the mechanism for allocating roadspace is partly by pricing (vehicle license, gasoline taxes) and partly by congestion. However the value of the former insofar as automobile usage goes is questionable. The weaknesses of this pricing system will be formally examined later in the study.

1.2 A Mechanism for Allocating Scarce Resources (Long-Run)

The long-run allocation of resources means the relative amount of resources devoted to constructing transportation facilities, purchasing rolling stock, and so forth, vis-a-vis other uses. It is very closely related to the pricing mechanism. The question of whether the price system leading to short-run efficiency would also yield a long-run optimum has been much debated in the literature, but it appears, subject to certain qualifications, that one pricing policy would serve both.

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3 Galbraith (1967) p 213
4 See discussion by Mishan (1960)
1.3 A Definition of Social Efficiency

Worthy as the goal of efficient allocation of resources might be, we as planners have a larger responsibility than the pursuit of economic efficiency. Efficiency, in the economic sense is a component of, but not synonymous with, social wellbeing. The question we must ask is therefore whether pricing policies can be used as tools to achieve certain goals which will produce a net social benefit. This is quite different from one that asks how to increase the National Product.

We need not discard the notion of efficiency. Indeed, in this thesis the concept forms the very basis of the argument. But what do we mean by the term efficiency? Wilson et al.\(^5\) have emphasized that there are two aspects to efficiency: allocational and distributional. Traditional economics has concerned itself almost exclusively with the first in the manner outlined above, ie, putting scarce resources to the most valued use. The value placed on a good or service is expected to be at least equal to the price the consumer is willing to pay for it. Thus the economic rationale for promoting allocational efficiency assumes that money is a cardinal measure of satisfaction. This is quite obviously a gross simplification. It is necessary to consider first, who the beneficiaries are and whom the costs fall upon (the distributional aspect), and second, the satisfactions or dissatisfactions associated with factors for which there is no market, eg. clean air, and quiet (externalities). Therefore it is necessary to dispel the notion that efficiency has only one dimension - monetary. Instead we should consider social efficiency in the wider welfare context.

\(^5\) Wilson et. al. (1971)
1.4 The Social Objectives of Transportation Pricing

The essence of the argument for adopting a pricing system will be demonstrated in the following paragraphs. Later the concepts will be developed in a more formal logic. The argument runs thus: If the trip-maker (the consumer of roadspace) is not aware of the true costs that he imposes on to others he will not use the transportation system in the most efficient or socially desirable manner. For example, if a motorist has a choice of routes A and B to reach his destination he will choose the one that costs him the least in time, cost, discomfort, etc. He chooses B, say. Suppose route A passes through a heavy industrial area where noise and pollution emissions are of little consequence, while route B runs through a residential area close to dwellings, playgrounds, etc. Because there is no mechanism for making the motorist aware of the annoyance and health and safety hazards that he causes in driving along route B, he will, unless he is unusually socially conscientious, continue to use route B. Route B is in this context less socially efficient than route A.\(^6\) The same reasoning can be extended to the selection of modes: unless the motorist is made aware of the true costs he incurs in driving his private car he will continue to use it in preference to the transit vehicle which may be more efficient socially.

Thus the short range objective of transportation pricing is to promote a more desirable usage of the existing transportation system. But there is an even more persuasive reason for investigating the present patterns of usage of the existing system: Consider the criteria that we accept for expanding or improving the present network, or for building

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\(^6\) Formally: Route B less socially efficient than route A if:

\[ \sum \text{Costs route } B > \sum \text{Costs route } A \]
new links such as urban freeways. The fundamental basis for investment is present or estimated future demand for travel by a given mode over a given route. Consider again the example of route A and route B above. The transportation planner gathers data from his Origin-Destination survey and together with his best estimates of urban growth for each zone he feeds it into his computerized distribution, mode split and assignment models. The result is irrefutable: in year X route B will no longer be capable of carrying the projected volumes of cars. Traffic congestion on B will be intolerable; noise levels will be excessive; accident rates at grade intersections will be disastrous. With this unhappy outlook the planner engages in a cost-benefit analysis of a grade-separated freeway. The benefits are overwhelming, expropriation proceeds....

The scenario may be excessive but the concept is valid. What may today be a minor distortion in the socially efficient use of substituting modes and routes might in time be magnified manyfold through our transportation planning process.

The argument is taken one step further. As with most goods and services, if the price of one is too low relative to other goods and services people will tend to consume more of that one than they normally would.\(7\) The motorist, again if he is not assessed the full costs he incurs, will tend to "consume" too much travel, ie. drive too often or too far or at the wrong times. To meet this demand in the long run there will be a tendency to overinvest in roads relative to other social goods and services, eg. schools, hospitals, parks, etc., or to private goods, eg. cars, factories.

\[7\] Although transportation per se is generally not the final consumed good the principle still applies.
This brings us to the final point. If we accept the arguments that some roads are underpriced relative to others, and that private road use is underpriced relative to transit usage, then it follows that if a "rational" system of making the tripmaker aware of the costs were implemented then changes would take place in the tripmaking behaviour of individuals and businesses. If fewer or shorter trips were made we would expect that in time a locational change would take place in the activities that require travel to get to - be it work, shopping, or recreation. Using the pricing system to influence the demand for travel therefore would effect changes in the spatial relationships of activities in urban areas. Stated more positively, if it were deemed desirable to pursue a policy for "decentralization", pricing might be potentially a very powerful tool. One writer, Vickrey, has observed that a "rationalization of the pattern of business activity might be stimulated". Activities generating relatively large amounts of traffic, such as warehouses, could be induced to move to less congested areas, leaving room for activities better suited to metropolitan cores. He concludes that, "it is hard to think of such changes as being on balance baneful, except on the basis of an overpowering enchantment with the status quo". However, others contend that a road pricing system would have serious adverse effects in producing "a far flung and loosely knit conurbation". At the present time, it is far from clear exactly what long run effects a change in the pricing system would have on the urban morphology, and even if we would predict with reasonable accuracy what the effects might be,

8 Vickrey (1968) p 115
9 ibid, p 115
10 Comments to Quinet (1970) p 57
there is some doubt whether one pricing scheme or another would be entirely consonant with other social goals.

These then are the three uses of transportation pricing policy of special interest to the planner: (1) to influence the short-run demand in order to promote the most desirable use of available routes and modes; (2) to influence the amount of investment in transportation and the type and location of the infrastructure; (3) to influence the direction of urban growth and the location of residential areas and of economic activities. Although all these have been urged by economists in terms of conventional economic efficiency they are inextricably bound to the notions of social efficiency expressed earlier. The three uses described are by no means mutually exclusive; it would require very sensitive policies to influence each component in exactly the desired amount and direction.

1.5 The Revenue Generating Function

Aside from those uses of the price mechanism stated above there are other more mundane but important functions of prices. The first is to raise revenue to cover interest on the investment expenditures, overhead costs and possibly to make a profit. While profit is obviously the objective of private industry, the argument for pricing as a revenue producing device is not so clear-cut for publicly owned transportation facilities. Indeed, as has been argued in classic papers by Dupuit¹¹ and by Hotelling¹² that the price charged to the user, if the net social benefit is to be maximized, should bear no relation to the financing requirements of public utilities.

¹¹ Dupuit (1844) reprinted in Munby (1968)
¹² Hotelling (1938)
Using the example of a newly built bridge, Hotelling shows that the maximum satisfaction will accrue to society if the bridge is financed exclusively out of general taxation (as distinct from bridge tolls)

"A free bridge costs no more to construct than a toll bridge, and costs less to operate; but society, which must pay the costs in some way or other gets far more benefit from the bridge if it is free, since in this case it will be more used. Charging a toll, however small, causes some people to waste time and money in going around by longer but cheaper ways, and prevents others from crossing". 13

This principle, he explains, is only valid so long as there are no other external social costs involved, such as delays or accidents due to congestion.

Hotelling's "Fundamental Theorem" and the theory of Marginal Cost pricing will be examined in a later section, but in the present discussion, if we accept his argument, it demonstrates that the function of prices in raising revenue for financing purposes should not be considered a necessary, or even desirable function.

1.6 Income Distribution

A second use of pricing policy is as a deliberate device to redistribute income. Price discrimination to this objective is generally not a very popular device, nor in all cases a very efficient redistribution device, but we do see some uses of it. It is, for example, used in free or reduced fares to the elderly people, or in subsidized housing where the rent varies in direct proportion to the income level of the tenant. However the redistribution of income is probably not a significant objective of transportation pricing; there are generally more effective means.

13 Hotelling (1938) pp 260-261
But while it may not be a specific objective, it is of utmost importance to recognize the redistributive side effects that are likely to occur when pricing changes are effected. On this matter Ruggles' warning is worthy of special mention.

"Every pricing system results in some sort of income distribution, and no substantial redistribution of income is possible without changing the pricing system. For this reason it is imperative that interpersonal valuations be taken specifically into account. It thus appears that, since the distribution of income must be taken into account there is no one general pricing system which can be more efficient (in the sense of being both allocative and distributionally efficient) than all others."\(^{14}\)

A later part of this paper will be devoted to an examination of the distributional effects of a rational pricing scheme.

1.7 Present Policies of User Charges

This second half of Chapter I examines the present user charges for urban transportation - private road use and public transportation. The discussion later focuses on how the present user charges perform as a pricing system with respect to those functions of prices described earlier.

For the purpose of this discussion we consider only the "administered" price, that is the money the consumer must pay for the use of the transportation facilities. This is not sufficient to describe the elements that enter into the travel decision, and accordingly will be expanded upon in a later section.

\(^{14}\) Ruggles (1949-1950) pp 123, 125
Basically the motorist is charged for road use by three mechanisms:

1. gasoline taxes
2. annual licence taxes
3. tolls

These taxes except for the last, tolls, cannot be considered prices in the full sense and effect of the word, since their size and impact are not related to the act of road use and its specific costs. As Reynolds points out, "just as the man who walks becomes aware of the costs of walking only when he repairs his shoes or buys new ones (and sometimes not even them), the road user becomes aware of these charges only when he pays his licence duties or fills his tank".15 Gasoline taxes, although related to the amount of road use, does not differentiate among different roads and different traffic conditions; licence charges relate only to ownership and are completely unrelated to road use. Tolls, on the other hand, which possess the qualities of being visible and directly related to the act of driving on a specific road, are generally not intended as a rationing mechanism but as a scheme for generating revenue.

Table 1.1 on the following page indicates the relative taxation revenue derived through the three taxation schemes in seven Canadian cities.

---

15 Reynolds (1971) p 69
### Per capita annual revenue through user charges*

<table>
<thead>
<tr>
<th>City</th>
<th>Registration</th>
<th>Gasoline</th>
<th>Tolls</th>
<th>Total (A)</th>
<th>Ratio A/B</th>
<th>Population** (000)</th>
<th>Vehicle Registration** (000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montreal</td>
<td>$11.</td>
<td>$22.</td>
<td>$1.</td>
<td>$34.</td>
<td>$144.</td>
<td>.24</td>
<td>2321</td>
</tr>
<tr>
<td>Vancouver</td>
<td>14.</td>
<td>20.</td>
<td>-</td>
<td>34.</td>
<td>219.</td>
<td>.16</td>
<td>850</td>
</tr>
<tr>
<td>Winnipeg</td>
<td>10.</td>
<td>23.</td>
<td>-</td>
<td>33.</td>
<td>192.</td>
<td>.17</td>
<td>490</td>
</tr>
<tr>
<td>Hamilton</td>
<td>12.</td>
<td>15.</td>
<td>2.</td>
<td>39.</td>
<td>216.</td>
<td>.13</td>
<td>431</td>
</tr>
<tr>
<td>Edmonton</td>
<td>11.</td>
<td>21.</td>
<td>-</td>
<td>32.</td>
<td>247.</td>
<td>.13</td>
<td>385</td>
</tr>
</tbody>
</table>

* average for the years 1963, 1964 and 1965

** 1965

Source: N.D. Lea and Associates (1966)

---

Table 1.1

TAXATION REVENUE FROM ROAD USER CHARGES IN SEVEN CANADIAN CITIES

18.
In the context of this discussion, the most interesting and revealing column is the computed ratio $\frac{A}{B}$ (per captia revenue through user charges/total annual auto expenditures per capita). The charges connected with the actual use of the vehicle are very small (between 12 and 24 percent) relative to the total expenditures on automobiles. Furthermore, tolls, which are the only charges that serve as a price in the rationing function, are used in only two cities—bridge crossings in Montreal and Hamilton—and in those cities the toll charges account for less than one percent of the total private expenditure.

1.8 Limitations of Present Pricing Policies

Several observations arise out of the above discussion which suggest reasons for the apparent failure of present pricing policies to perform the functions described earlier. The first comment: vehicle purchase tax and annual licence tax do not serve as pricing mechanisms at all, once the vehicle has been purchased. It is true that these taxes may deter an individual from acquiring a vehicle, and in that sense they do tend to limit the total number of vehicles in private ownership and use.

It is conceivable that many automobile owners have an intuitive grasp of marginal and average costs of owning and operating a vehicle. Having invested $3,000 to $4,000 in a car, an individual may well perceive the principles of economics in the form of "getting as much use as possible out of the car" before it ages and depreciates naturally. If this is the case, and there is some research evidence to substantiate it,

16 It has been argued that these two methods of taxation are inequitable in that they discriminate against the low-income individual—thereby reducing his satisfaction in not being able to afford a private auto.

17 Lansing and Hendricks (1969) p 49
it means that the usual models which assume economic rationality with respect to operating cost only, could not explain or predict the choice of mode on the basis of cost, all other factors being equal.18

The second comment relates to the invisibility of gasoline taxes. There is increasing evidence that the road user is neither aware of (nor greatly concerned with) the cost of operating his automobile.19,20,21 Lansing and Hendrick's report on the results of two U.S. surveys indicate that only about 25% of all automobile commuters have ever estimated the cost of their journey to work. "When asked to guess, they can do so. When they guess, they seem to guess high..."22 When asked how much it would cost to drive to work one way, including only gasoline and oil and any tolls he might have to pay, the responses were distributed as in the following table.

Table 1.2
THE PERCEIVED COST OF AUTOMOBILE USE

<table>
<thead>
<tr>
<th>Cost per Mile</th>
<th>Percent of Auto Journeys</th>
</tr>
</thead>
<tbody>
<tr>
<td>1€</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>8 or more</td>
<td>27</td>
</tr>
<tr>
<td>not ascertained</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

18 There are of course the usual arguments, advanced by psychologists, that the ownership and use of an automobile serves as a vehicle for expression and gratification of many subconscious needs (Freudian and otherwise) unrelated to travel. It appears, however, if recent trends in advertising are any indication, that the image of the car is changing. (See The Financial Post December 4, 1971 p 29 "The Car as a Status Symbol: Dying or Not? -- All you Really Need is a Datsun --")

19 Brown (1971) p 86
20 Hille and Martin (1969) p 36
21 Lansing and Hendricks (1967)
22 ibid, p 47
The median estimated cost per mile calculated from the above is 5.1 cents. As only a very few did actually pay tolls the estimate seems quite high when compared to the cost of 3 to 4¢/mile for operating a vehicle calculated by Oglesby and Hewes and by Soberman and Clark.

The responses are especially high when we consider the large number who indicated an estimated cost of 8¢ and over.

Lansing and Hendricks conclude their findings thus:

"Generally, people who go to work by car are not concerned enough about the cost to make an effort to calculate it carefully. To understand this, consider the way in which people actually pay the cost of automobile transportation. They pay for a car when they buy it (or when they pay installments). They then use the car for all sorts of trips over a period of several years. They pay insurance and registration fees annually. Some maintenance and repair expenditures may be made at more or less regular intervals, whereas others occur sporadically. In any event, there is usually no direct connection. Even when a person fills his gasoline tank he usually uses the fuel for a variety of trips."  

One would be hard put to attempt to fit the price mechanism for road use into the economists' taxonomy of pricing systems - if indeed, all things considered, it can be considered a price mechanism at all. With all the cross-subsidizations (peak - non peak, urban - rural etc.) that exist, it is almost impossible to assess the relative contribution of the individual user in the total picture. On the whole it appears that the private automobile driver is contributing a relatively constant annual percentage of around 65 - 70% of the total operating and investment expenditures as summarized in Table 1.3 on the following page.

23 Oglesby and Hewes (1963) p 65  
24 Soberman and Clark (1970)  
25 Lansing and Hendricks (1967) p 49
<table>
<thead>
<tr>
<th>Year</th>
<th>Gross Capital Stock</th>
<th>Net Capital Stock</th>
<th>Depreciation</th>
<th>Interest at 6%</th>
<th>Maintenance &amp; general</th>
<th>Administration &amp; general</th>
<th>Total Cost</th>
<th>Total Revenue</th>
<th>Total as percent of col. 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>6085</td>
<td>4147</td>
<td>83</td>
<td>249</td>
<td>185</td>
<td>27</td>
<td>544</td>
<td>389</td>
<td>140 %</td>
</tr>
<tr>
<td>1962</td>
<td>6479</td>
<td>4431</td>
<td>89</td>
<td>266</td>
<td>198</td>
<td>26</td>
<td>579</td>
<td>402</td>
<td>143</td>
</tr>
<tr>
<td>1963</td>
<td>6867</td>
<td>4708</td>
<td>94</td>
<td>282</td>
<td>206</td>
<td>42</td>
<td>625</td>
<td>483</td>
<td>144</td>
</tr>
<tr>
<td>1964</td>
<td>7320</td>
<td>5040</td>
<td>101</td>
<td>302</td>
<td>212</td>
<td>49</td>
<td>664</td>
<td>471</td>
<td>141</td>
</tr>
<tr>
<td>1965</td>
<td>7679</td>
<td>5439</td>
<td>109</td>
<td>326</td>
<td>225</td>
<td>45</td>
<td>705</td>
<td>492</td>
<td>143</td>
</tr>
</tbody>
</table>

All figures in million dollars in 1949 prices.

(Source: M.Q. Dalvi, 1969)

REVENUE-COST COMPARISON FOR ALL ROADS COMBINED - CANADA AS A WHOLE

Table 1.3
1.9 Parking Charges

A fourth system of charging the road user, the parking tax, might be considered here. Although it relates only indirectly to the use of roads, the parking charge comprises a very significant component of the monetary cost of driving in the city. Although the charge is very visible, it does not relate to either the distance travelled or to the routes taken. Parking charges are, and rightly so, a rental fee paid for the use of a space to store a vehicle for a certain length of time. In essence, therefore, it should not be considered a levy for the use of roads and indeed it would be difficult to rationalize a parking tax as a road user charge.

Having said that, it is equally clear that if the parking rates do not represent an economic rent on the space occupied, i.e., if parkers are subsidized or if the charge is hidden to the parker, then the demand function for urban travel might be drastically altered. In Vancouver, the results of a 1967 study of commuters in the Lions' Gate corridor showed that approximately 30% of the motorists interviewed were provided with free parking in the Central Business District (CBD) and the remainder paid an average of $20. per month or about one dollar per day. It appears, in calculations made by Roer that, at that rate, the provision of parking in Downtown Vancouver is an uneconomic undertaking, producing at best an annual rate of return of 3%. The Downtown Parking Corporation (D.P.C.) which controls about 10% of all downtown parking spaces was, between 1948 and 1969 supported by an annual subsidy of $72,000 from the merchants.

26 Such would be the case where parking is provided at below cost by a department store and the parkers, in effect pay through the purchases. Another case would be in the situation where an employee's parking space comes as part of wage "package".
27 Lea (1967)
28 Paul O. Roer, correspondence to G.F. Farry, Senior Associate, Greater Vancouver Regional District, September 12, 1971
29 ibid.
Thus it appears from this brief sketch, that the downtown parker is, on the whole being subsidized, and furthermore, since for many motorists the parking charge represents the only visible cost of the trip, the subsidies thus granted will distort the demand for travel to the central area. The parking rates should, it is therefore argued, at least reflect the true opportunity cost of the space occupied.

1.10 The Pricing Functions of Present User Charges

In concluding this section we pose the question: How do present policies for user charges of private transportation serve the functions of prices described at the outset?

(a) Allocation of Resources (Short-Run) - The existing method of taxation of road users does not (and does not appear to be intended to) serve the function of efficient rationing of limited capacity. The rationing is conducted on the basis of a policy of total laissez-faire. Rationing by congestion will be discussed in the next section.

Signal for Investment (Long-Run) - The existing system does not serve this purpose.

(b) Revenue Producing - Approximately 65 - 70% of the total costs of providing roads in Canada as a whole are borne by the road user, although in urban areas the user probably contributes more than his share of the total costs.30

(c) Income Distribution - While there does not appear to be any conscious or deliberate effort to redistribute income through

30 See Fitch (1964)
the price mechanism, there are undoubtedly very definite effects that occur simply as a byproduct of present policies. Rationing of roadspace by congestion places an equal drain on all user's time. Thus those that place a high opportunity cost on time would be paying more for the use of the road. We would expect the value of time is closely corelated to the income level; therefore rationing by congestion would appear to be a progressive form of rationing, ie., the higher the income the higher the price paid for the trip. But, several factors detract from this, supposedly desirable state of affairs. First, providing roads as public goods, that is, free to all wishing to use it, presupposes one thing: that all have both the availability of a car and the ability to use it. Second, the most expensive facilities - urban freeways and rail rapid transit - are most often radially oriented to serve the commuters who reside in the suburbs and are employed in the Central Business District. These are by no means the poorest members of society. So the effect of present pricing and financing policies on the distribution of income is very difficult to determine ever approximately. About the only thing we can say is that society apparently finds it acceptable so it must be reasonably equitable.

(d) Other social Goals - Pricing policies on roads are historically based on the concept of "the Kings Highway", free to all users. From the present policies we might therefore extract the intended purpose that it is to serve the goal of freedom of movement to all. Hutchinson in a report to the Department of Highways of Ontario specified a goal of Provincial highways "to maximize aggregate consumption of the community." 31

31 Hutchinson (1969) p 9
This he decomposed into three sub-goals as follows (in that order): 32

"1. to maximize the aggregate accessibility provided by the Provincial highway system

2. to minimize the undesirable impacts of the Provincial highway system on the natural and human environments

3. to maximize the achievement of desirable patterns of Provincial development."

These may change in the future, and may indeed be changing now, but they have up to the present apparently been explicit goals.

1.11 A Note on the Pricing of Public Transit

The price of public urban transportation is somewhat easier to ascertain, i.e. the fare. The pricing principle in transit operation is simply to minimize the loss to the operating authority, while at the same time maintaining a "politically acceptable" level of service. The object is therefore to achieve an average cost pricing although, as reported by N.D. Lea, in 1966, only two transit authorities in Canada - Ottawa and Hamilton - have managed to achieve the breakeven point. 33 Although two important studies on the subject of transit pricing indicate a very low price elasticity of demand 34, 35 - and therefore considerable potential for price increases without significant loss of patronage - operating authorities have, probably for political reasons, refrained from setting prices to maximize revenue. 36

32 Hutchinson (1969) p 10
33 N.D. Lea and Associates (1966)
34 Charles River Associates (1968) The meaning of elasticity will be clarified later (page 31)
35 Moses and Williamson (1963)
36 Canadian Federation of Mayors and Municipalities (1966)
The public transit "industry" is characterized by a downward sloping average cost curve, i.e., comparable to a firm which has the potential for increasing economies of scale. The cost of one more unit of production is below the average cost of the operation. Without more complete data than are available it would be difficult to estimate the marginal cost of serving an additional passenger. During the off-peak hours the marginal cost is very low—possibly the cost of time and added fuel consumption expended in making one or two extra stops and starts. In the peak periods the marginal cost might be very high, especially if, to accommodate one additional passenger, it requires the purchase and operation of an added vehicle. However even this situation is not quite that simple, as the existing passenger volume would tend to redistribute itself so that the present users would also benefit from a reduction in waiting time, reduced crowding, and so forth.

The present pricing policies for public transit do serve, in a small way to ration the available resources, but here again it is primarily a revenue generating device. There does appear to be an attempt to provide service at minimum cost to the public. The basic social goal that is evident is the provision of transportation to as many people as possible, as inexpensively as possible.

It should be noted that public transit vehicles as well as private automobiles incur social costs for which they are not made accountable. The bus is probably responsible for considerably higher contributions to both congestion costs and environmental costs than the individual private car, but, because of the generally higher load factor in buses than cars, especially during peak hours, the social cost per bus passenger is likely quite low relative to the per automobile passenger.
In concluding this section it is important to recognize that the costs perceived by the urban traveller extend far beyond the purely monetary price. Time, comfort, convenience, safety - these are all important factors that enter into the individual trip-makers calculus when making the travel decisions. Only if these elements can be converted to monetary terms or built into the economic model can the price mechanism be made to perform the desired functions of a pricing system described at the outset.
CHAPTER II  THE DEMAND FOR URBAN TRANSPORTATION

In order to understand the way in which a price system would function, it is necessary to examine the basic determinants of demand for urban travel. There is a very close mutually dependency between demand and supply both in the short-run and long-run. The short-run relationship is discussed first; later sections examine the long-run implications in order to suggest reasons for the limited success of past planning strategies which have ignored all reference to pricing.

2.1 Defining the Demand Function

The demand function for transportation is, in its simplest terms a dependent relationship between the quantity purchased or consumed and the cost of trip-making to the traveller. The "generalized cost" is a composite of many cost components, which, in their summation add up to a total disutility of travel. The components of the cost of travel (although not necessarily ranked in order of importance) are:

(1) money cost
(2) time - line-haul
(3) time - waiting, walking etc. - usually termed "excess travel time"
(4) discomfort (crowding, exposure to undesirable behaviour of others)
(5) inconvenience

In terms of the individual's decision-making process, it is the perceived cost that determines behaviour patterns, not the objective cost. And there may be considerable divergence between the two.

The demand for travel at any time between two spatially segregated
locations i and j is also a function of other elements which have been the object of considerable discussion by Meyer, et. al.\(^1\) and by Oi and Shuldiner\(^2\). Among the major elements influencing demand are:

1. activities in Zones i and j at time t
2. trip purpose
3. socio-economic characteristics of the tripmaker

It would be desirable to have detailed and accurate information concerning the effects of these elements; however for the present discussion concerning the relation of demand to the supply factors, these will be assumed to be constant.\(^3\) The demand function may be described by the following relationship:

\[ q = f(p, t_l, t_e, \theta) \]

Where

- \( q \) = the flow volume of vehicles or persons
- \( p \) = perceived out-of-pocket money cost
- \( t_l \) = line-haul trip time
- \( t_e \) = excess time cost (perceived)
- \( \theta \) = qualitative characteristics of the trip

In a simpler, combined form the above can be expressed thus:

\[ q = f(z) \]

where \( z \) = the "generalized cost"

The relationship is demonstrated in Figure 2.1. The demand curve DD\(^*\) represents the number of person-trips that would be generated at each level of disutility. As the fundamental elements change, eg. change in number of individuals, change in activities in i and j, etc., and at different times, new demand curves are generated, such as \( D_1D_1' \), but as the system characteristics, (time, cost, etc.) change we move along one demand

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1 Meyer, Kain and Wohl (1965) pp 83–107 "Trip Patterns and Demand"
2 See Oi and Shuldiner (1962) for a detailed discussion of these components of demand for urban transportation.
3 These elements would not remain constant in the long run, and as will be shown later transportation pricing policies may in fact be causative of long run changes, particularly in the spatial relationships of activities.
As will appear there is no special significance to the exact shape of the two curves.

![Diagram of demand curve]

**Figure 21. THE DEMAND CURVE - AN ILLUSTRATION**

We do not know very much about the demand curve. The demand curve is not a simple line on the page but a complex map changing continuously - the only point we know about is the one we are at now. Even the elasticity at the present point is very difficult to determine. The only thing we can be reasonably certain about is the general shape - downward sloping to the right. This means that at lower costs of travel more and longer trips will be made. Wohl's illustration, reproduced in Figure 2.2 representing the changing demand curve at different hours of the day is instructive.

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4 The elasticity of demand can be defined as the percentage change in the amount demanded that would result from a 1% change in the price. For example: when the elasticity of demand is 1.5, a rise in price of 10% would bring about a decrease in purchases of 15 percent.
2.2 Relation of System Characteristics to Demand

The above discussion has considered how the number of person trips change with a change in any of the components of disutility of travel. These components are functions of the "service level" of the transportation network. Service level - sometimes referred to as accessibility - is an abstract measure of the physical characteristics of a given trip, and is determined in the first place by the physical characteristics of the route, ie, the design and operation. This includes such factors as the design of the carriageway or track, the design of the vehicle itself with respect to speed, comfort and safety, the operation of traffic controls such as legal speed limits, signal lights, and the operation of the transit vehicle as to frequency and duration of stops, layovers, etc. Over fairly short
periods of time the physical characteristics will not be altered; those factors therefore define the short-run fixed supply. Over a longer period the fixed supply can, and does of course, change to define the long-run supply.

In the short-run the cost of making the trip is determined by the physical properties of the system and the institutional constraints and is independent of the volume of traffic. The cost is therefore determined by the time to cover a fixed distance, the vehicle operating cost and tolls, and a qualitative disutility. All these are fairly constant up to the point where congestion commences and the perceived private cost of an additional trip (the private marginal cost) is given by:

\[ C_1 = p_1 + t_{11} + t_{e1} + \phi_1 \]

Technically \( t_{11}, t_{e1}, \) and \( \phi_1 \) are all multiplied by a parameter to convert them to equivalent dollars. If the demand curve intersects the marginal private cost curve between zero and \( Q_1 \), the equilibrium flow level will be \( q_1 \) as indicated.

![Figure 2.3](image)

THE SUPPLY CURVE - AN ILLUSTRATION
In the second place the service level includes, in addition to the factors described above, the effects of congestion. A useful definition of congestion is: "when the costs of two vehicles using a given facility are more than the addition of the costs of each using it alone then there exists congestion". At traffic flows above the practical capacity of the facility, vehicles increasingly interfere with the free movement of one another, and the result is an increasingly slower stream of traffic. The time to cover a given distance therefore increases, and the vehicle operating costs increase, there is a higher probability of accidents, there may be longer waiting periods for transit vehicles, and we would imagine that the discomfort, \( \phi \), would increase. Therefore, in addition to the cost being a function of the fixed supply, it is also functionally related to the traffic volume. Thus the cost at any traffic level \( q \) is defined by:

\[
z = p + t_1 + t_e + \phi
\]

where \( z, p, t_1, t_e, \) and \( \phi \) are as defined earlier. But \( p \) and \( t_1 \) are both functions of speed, thus:

\[
p = f_1(v)
\]
\[
t_1 = f_2(v)
\]

where \( v = \text{speed} \), which is in turn functionally related to the traffic volume \( q \), (ie. \( v = g(q) \))

The short run supply function can be expressed thus:

\[
z = f\left[g(q)\right] + t_e + \phi
\]

---

5 Beesley and Roth (1962) p 184

6 Several assumptions are necessary in devising this relatively simple model, but the concept remains valid under most conditions, subject to the following considerations: Traffic rarely reaches a completely steady-flow condition; as vehicles enter or leave the system they create wave-like disturbances which may travel for considerable distances (very similar to the water-hammer effect in compressible fluids). Erratic behaviour of one or a few drivers may cause the same effect. However, for the present purpose - to illustrate the supply of roadspace under congestion-rationing conditions - the assumptions of steady and uniform flow do not invalidate the illustration.
Of the elements in the expressions above, the most significant is probably the line-haul time, i.e., the time delay that the individual experiences due to congestion. As it happens, time delay is also most easily measured in theoretical investigations.

The cost function, under conditions of increasing congestion is represented in Figure 2.3 as the upward curving portion of the private marginal cost (MPC) curve between $Q_1$ and $Q_{\text{max}}$. If the demand curve $D_2$ intersects the MPC curve between $Q_1$ and $Q_{\text{max}}$, the equilibrium flow will be $q_2$.\footnote{The condition for equilibrium is the solution to the two equations: Demand curve: $q = f_1(z)$
Supply curve: $z = f_2\left[g(q)\right] + t_e + \varnothing$}

It should be noted that the MPC curve defines only the costs that the individual traveller experiences. It is not an objective measure of his true private costs, and more important does not include the costs that his presence, or the presence of his vehicle imposes on others. The latter, termed the marginal social cost, will be examined in detail in Chapter III.

The flow volume indicated by $Q_{\text{max}}$ is the absolute maximum flow volume of vehicles, or individuals that the given system can accommodate. If demand for the facility rises above the maximum capability of the system the result is a decrease in the total carrying capacity, accompanied by a considerable increase in the trip cost. The visible indication of this is an extremely slow traffic stream together with an increasing queue at the entrance points. In Figure 2.3 the flow level $q_3$ results when demand rises to $D_2$. Ultimately, if demand were to continue to increase, the traffic would eventually come to a standstill, although this rarely occurs.
Once the traffic volume approaches the maximum capacity of the system, the costs (mostly in time delay) increase rapidly with the arrival of more users. This increase in costs is the mechanism whereby rationing of roadspace takes place. An individual will continue to use the facility so long as he values the trip higher than the cost of the trip to himself. If, for example, he perceives the satisfaction to be gained as an outcome of the trip to possess a valuation equal to $C_2$ (in Figure 2.3), then he will continue to make the trip until the congestion conditions are such that he consistently expects the time delays, etc. to cost him more than $C_2$. At that point he will seek another mode of transportation or another route or will take other measures to avoid the congested area. Congestion is, therefore, largely but not entirely, a rationing by time delay. It is a mechanism whereby those that place the highest value on time (the "time-preferrer") will be the first to be rationed off, while the individuals that place a relatively lower value on time will continue to use the facility.

2.3 The Long-Run Supply as a Function of Demand

The process by which additional transportation is supplied is dependent on many factors, one of which is the existing pricing mechanism. The long-run supply might be considered to be related to three elements, all of which are indirectly related to the price mechanism. They are:

1. present visible needs for new facilities
2. projected future needs
3. financing and the availability of funds

These three elements will be discussed below in terms of their dependence
Figure 2.4

THE RELATIONSHIP OF PRICING TO THE LONG-RUN SUPPLY OF URBAN TRANSPORTATION
on the pricing system in supplying the "correct" amount of roadspace at some future date, ie. to achieve the desired equilibrium level between quantity supplied and the number of person-trips demanded. A Schematic representation of the relationship of the elements is given in Figure 2.4.

(1) Visible Needs - the bottleneck approach

It would be a very rare situation if traffic were to build up at a constant rate throughout the network, and at the same time, all parts of the network possessed a constant capacity. The more usual situation is an observed build-up of congestion at certain bottlenecks in the system, or at least a higher than average density of traffic.\(^8\)

To place the bottleneck situation in the context of the previous discussion, the situation occurs when the demand curve representing the desire for movement through the congested areas intersects the marginal private cost curve at a point which represents a cost higher than the average cost in the system. Figure 2.5 on the next page demonstrates.

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Figure 2.5
AN ILLUSTRATION OF THE BOTTLENECK CONDITION

The curve $MPC_b$ represents the supply curve in the constricted area, and the curve $MPC_a$ represents the "ambient" supply over the rest of the road system. As indicated in the figure, traffic would be severely constricted through the bottleneck, and the visible result would be a backup of the traffic wishing to enter the section - the queuing effect. Thus, rationing by congestion at one point in the system (a bridge, or an intersection) is a most eloquent expression of need for improvement and such measures as are warranted can usually be implemented using the various traffic engineering techniques without disrupting the entire system and often without necessitating large-scale investment. Burns observes,
"Allowing physical pressure on existing facilities to indicate when an expansion is in order is one way to be certain that the improvement is 'needed' and will be utilized." Thus, funds are readily allocated to abolish the constriction - until the next bottleneck appears in some other location.

The mechanics of bottleneck situation will be examined in some detail in the case study in Chapter IV.

(2) Projected Future Needs

In long range planning we place, of necessity, a great deal of confidence in the forecasts made by some method of extrapolation of past trends by means of models that we hope will simulate the future. The following discussion concerns the importance of the pricing mechanism with respect to forecasting models. It is not intended as a critique of urban transportation models but rather an attempt to demonstrate the relationship between present pricing mechanisms, the models that we use to predict future traffic volumes and modal splits, and long range investment. If the present system is inherently "unbalanced", then it is extremely difficult if not impossible to build correction factors into the models. Alain Bieber in an address to a 1971 O.E.C.D. conference stated the problem thus:

"The most striking characteristic of this simulation process based on reproduction of existing individual behavioral mechanisms (traffic generation, modal split, network assignment) is its tendency to merely perpetuate the existing situation."

9 Burns (1969) p 307
10 Bieber (1971) p 35
Even the most complex and sophisticated transportation models in use today are conceptually very simple and most are in fact based upon analogies to the physical laws of dynamics and thermonodynamics.¹¹ But the main failing of the models lies not in the conceptual simplicity, but in the constants of calibration. The model for example allows us to project the traffic volumes by modes at some future date, given that the structural elements of the model, derived empirically today hold true in the future.

The model may be perfectly valid in short run forecasting when the structural elements, hence the constants of model calibration, do not change significantly. But in the long run the human societal relationships do not necessarily remain constant - changing human values and changing perception of the urban system will, almost certainly cause urban residents to acquire different activity patterns in the future. Thus we find the recent interest in a "behavioral approach" to modelling.¹² Model designers, says Hurst, have a tendency to "make the facts fit the formula, further obscuring the possibility of gaining much insight into the true conditions governing transportation demands".¹³ But, for the discussion of this paper, more important than the "facts to fit the formula" complaint, it is implicit in the model that the existing transportation system in general, and the mode split in particular is "correct" - according to some unstated principle of "correctness", that is, some socially desirable allocation and distribution of resources.

As discussed earlier, one of the primary purposes of a pricing system is the allocation of resources to the user who values the service most

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¹¹ For a brief overview of forecasting models see Meyer and Straszheim (1971), Chapter VIII, "Forecasting Urban Passenger Travel".
¹² See for example Horton, F.E.; Reynolds, D.R.; "Action Space Formation: A Behavioural Approach to Predicting Urban Travel" HRR 322 1970
¹³ Hurst, M.E, "The Structure of Movement and Household Travel Behaviour" Larry S. Bourne, ed. Internal Structure of the City (Toronto: Oxford University Press 1971) pp 248-255
highly. The existing system of pricing urban transportation is far from being the ideal mechanism for efficient allocation, or for efficient distribution of resources. More important, the perceived price on which the consumer choice is based may show considerable divergence from the measured price thus magnifying any objective imbalance that exists.

A second important fact is that factors that cannot be expressed in, or somehow converted to monetary value, are not explicitly included in the model. The following provides an illustrative example of the models' propensity to project the status quo. It has been shown that virtually no drivers are aware of, or concerned with, the true cost of operating an automobile.\textsuperscript{14,15} It has been shown that excess travel time (walking, and especially waiting) are highly onerous to the traveller.\textsuperscript{16,17} It has been shown that comfort is an important factor in mode choice.\textsuperscript{18} And yet models have been developed and are used which include automobile operating costs and total travel time (instead of times of individual components of the trip) with no reference to comfort.

Finally there exist very close interrelationships between transportation and land use (which we are only now making the first groping attempts to simulate in dynamic models). The phenomenon, often referred to by the maxim "traffic expands to fill the available highway capacity", is a visible result of the complex functional relationship. Thus conventional transportation models have a capacity for "self-validation",\textsuperscript{19} and so long as we continue to measure the success of a plan in terms of its

\textsuperscript{14} Brown (1971)  
\textsuperscript{15} Lansing, Hendricks (1967)  
\textsuperscript{16} Brown \textit{op.cit.}  
\textsuperscript{17} Charles River Associates (1968)  
\textsuperscript{18} Department of Housing and Urban Development: Urban Transportation Administration (1968)  
\textsuperscript{19} Fitch (1971) p 196
ability to accommodate projected traffic using transportation models in isolation, the planner and traffic engineer will almost always be vindicated.

The limitations of models described above lead to a very serious implication, which will be mentioned only briefly here. This concerns the financial justification to the decision makers (the politicians and public administrators) of a given project. Rightly or wrongly, there is a certain "black-box" mystique about the output data of a computer model. If the model projections are then accepted without questioning the fallability of the input data or the model structure, it is all too easy to demonstrate, through project evaluation techniques (such as cost-benefit analysis), the economic superiority of one project or policy over another. It would be difficult for the public decision makers to ignore such persuasive evidence.

Referring again to the discussion at the outset of this chapter we can illustrate the mechanism by which transportation facilities are supplied in response to forecast demand. Given the present supply curve MPC\_p and a demand function d\_p, the present traffic volume is shown as q\_p (Figure 2.6). It is forecast that in some future year the traffic volume (i.e., the number of person-trips demanded) will be q\_f; then, if we are to maintain the same level of service in year f as at present, new capacity, characterized by MPC\_f must be provided.
If, on the other hand the new capacity is not provided, or its construction is delayed, the traffic will adjust within the constraints of the existing supply, and rationing by congestion will take effect and the traffic volume will be $q_\text{fo}$.

Figure 2.6
AN ILLUSTRATION OF THE LONG-RUN SUPPLY OF TRANSPORTATION CAPACITY
(3) Financing

We turn now to the question of financing and fund availability, (Figure 2.4, page 37). In the Canadian context there are many elements, unrelated to demand forecasts (hence to pricing), that enter into the decision to allocate funds for a given project. There are of course budget constraints, so priorities for investment must be established. The determination of investment priorities will not be dealt with here except to say that the political decision in Canada at the Federal and Provincial level is often based on many considerations other than simple demand (examples: concern for regional disparities, national unity, and access to natural resources). Although these may only indirectly influence the urban transportation network there are other factors that do very much affect urban investment decisions. For example, at the Federal level, funds are often granted, or withheld because they provide an easy and effective way to administer national fiscal policy.

In Canada investment in transportation facilities is generally financed from general revenue. There is little direct relation between the revenue collected from users and the amount invested, ie, no earmarking. The important exception is in public transit where, in the past the transit authority has been required, as far as possible, to finance its own investment in rolling stock and ancillary equipment.

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20 Canadian Federation of Mayors and Municipalities (1966) pp 41-42
(To quote C. Foster: "Keynesian economics indicates that public works expenditures is one way to lift the economy out of a slump. Road building is particularly suitable." Foster 1963, p 13)
2.4 Summary Chapter II

In this chapter it was first demonstrated that there exists a mutual relationship between the amount of trips demanded and the "generalized cost", of which the user charge (or price) is one important element. The short-run supply function is thus largely determined by actual traffic volume (demand), and conversely the demand is dependent upon supply.

In the long-run the supply is indirectly related to the price since the price is a determinant of present demand, and the criteria for investment depend very much on demand trends. Thus if the short-run traffic volume is non-optimum the long-run investment will also be non-optimum.

The paradigms in Chapter I demonstrated that today's user charges are not optimal in a "social efficiency" sense. The following chapter furthers that discussion in a more rigorous theoretical manner.
3.1 A Theoretical Investigation

It was argued in the previous Chapter that the private disutility of travel is composed of elements of the out of pocket cost, line-haul time, excess time, and an "intangible" factor, $\theta$. Those are the factors that are considered by the individual contemplating making a trip. Furthermore, it was emphasized that the perceived cost, on which the private decision is based is not necessarily the same as the objective cost - that is his true private cost.

Now we introduce the question of social costs - the costs that the trip-maker - motorist or transit user does, unconsciously impose on others. North and Miller provide a clear explanation of the Problem:

"When there is a divergence between social costs and private costs we say that an externality exists. Costs external to the private decision-maker are not included in his calculations. In many cases an externality occurs because of the inability of all concerned to arrange a contractural agreement that would eliminate the problem."¹

Thus, the divergence occurs because the motorist cannot directly make an agreement with the person who must breathe the fumes from the car, or hear the noise, or suffers delays because of the presence of the motorist. The technical and administrative reasons are self-evident. Also, the costs the the $i^{th}$ individual incur to the $j^{th}$ individual is very small but, when multiplied by hundreds of thousands, or millions the result becomes significant. The most obvious examples of these externalities are, of course, air and noise pollution, and the "visual intrusion" of vehicles, roadways and parking lots.

¹ North and Miller (1971) pp 70-71
Less obvious perhaps are the costs due to congestion, i.e., the costs in time delay and increased vehicle operating costs, that the marginal vehicle imposes on the entire stream of traffic. It is to this problem that virtually all proposals for a "rational" road pricing scheme have addressed themselves; not because it is necessarily the greatest social cost but because it can be measured with reasonable accuracy whereas the others cannot readily be ascertained.² In the literature this is most often referred to as "road pricing" but congestion pricing seems more appropriate.

The fact remains, that none of these factors are at present taken into consideration in the pricing mechanism and it might therefore be argued that something is better than nothing. Congestion pricing would probably be a move in the right direction.

We refer again to Figure 2,³ (page 33) of the previous chapter which demonstrated the marginal private cost as a function of traffic volume. The figure is reproduced here with the addition of two curves, (see next page) a marginal social cost curve (MSC) and another which we shall term the marginal congestion cost curve (MCC). The objective marginal private cost curve can, at least with respect to time and out of pocket cost, be determined with reasonable accuracy; so with the marginal congestion cost curve.³ The marginal social cost curve is for the present simply sketched in as a conceptual cost.

² Mishan in The Costs of Economic Growth has this to say, "At a guess, I should put the measurable congestion costs at not more than one twentieth of the total social costs generated by motorized traffic, the remaining nineteen twentieths being accounted for by the so-called intangibles", page 133 and "Under an institutional framework which, among other effects, has that of saddling the motorists with defraying to the full, all social costs, including compensatory payment for reducing the amenity of others, the traffic problem would disappear of itself". page 131. Vickrey disagrees: "While (the intangibles) are extremely hard to evaluate in monetary terms, they are not likely to loom large in the total" Vickrey (1965) p 282

³ See Summary of the theory in Appendix II, pages 139-40.
Figure 3.1

A REPRESENTATION OF THE DEMAND CURVE AND THE COST CURVES OF URBAN TRANSPORTATION
Time loss due to congestion appears rather elusive at first glance. It has been argued that congestion costs should be considered entirely internal to the traffic system, i.e. that the $i^{th}$ and $j^{th}$ vehicles or individuals impose mutual costs on one another. Therefore it is contended that time loss cannot rightly be considered an externality at all. The fallacy of that argument can best be demonstrated by an analogy. If three men sit comfortably on a seat in a bus and a fourth gets on and has the option either to remain standing or to squeeze in beside the other three, he chooses the latter as the least uncomfortable to himself, but in the process causes discomfort to the other three already in the seat. Therefore, of the total discomfort from crowding, the fourth man pays only $\frac{1}{4}$, the others must bear the other three quarters of the "social cost".

The same principle applies to traffic congestion. But in the traffic situation it is physically impossible to point to the $i^{th}$ - the marginal - motorist entering the road system and charge him the costs he incurs. Each road user is equally "guilty"; therefore each must bear an equal portion of the total social cost. Congestion pricing is therefore a rationing mechanism that restricts the use of the road to those that place a value on the trip by private car, at least equal to the costs of delay which he would have caused the other road users. The authors of Better Use of Town Roads explain the objective of congestion pricing this way: "...in congested conditions some road users impose more cost on traffic than they themselves gain from using the road. More would be gained than lost if they did not use the road system. The best use of roadspace is achieved when all these less valuable road users have been restrained, leaving only those road uses which are of sufficiently high value to cover the costs imposed on others."

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4 See for example St. Clair (1965) Wohl (1966)
5 Mishan (1968) p 108
6 Better Use of Town Roads, HMSO (1967) p 5
3.2 The Costs

It is useful to consider the various components of social and private costs to gain some insight into the real divergence between the two.\footnote{Most writings on the subject of congestion pricing regard the relationship between the private cost curve and the marginal cost curve to be purely mechanical. But this cannot be so as long as there are social costs which remain "unquantifiable". See Technical Note in Appendix II.} We need to consider separately the variable costs (ie. variable in short-run) and the fixed costs (ie. fixed in the short-run) for both the private and social components. In Table 3.1 on the next page, the various costs are listed in such a classification.

The variable costs are those that are related to the location, time and amount of usage while the fixed costs are, in the short run, completely independent of the usage. It should be noted that the private variable costs are not coincident with the costs that the individual user perceives. Indeed, as stated in Chapter I, it would be a rare individual who is sensitive enough to even perceive the costs of gasoline consumed for each short urban trip. A third category, private perceived cost, is therefore included in the table.

Of the social costs there exist certain costs which may possess elements of both fixed and variable qualities; the contribution to each is difficult to determine. These indeterminate costs are categorized under fixed/variable social costs.

In the short-run we are only concerned with the costs that result directly from the motorist's presence on, and use of, the road, not the fixed costs that can only be varied in the long run. The private costs we are interested in are the variable costs and those which the user perceives and upon which he bases his travel decision. The private costs will be discussed at some length in the case study in the following chapter.
| PRIVATE COSTS | Fixed                          | Annual Licence Tax |
|              |                               | Annual Insurance Premium |
| Variable     | Gasoline                       | Maintenance          |
|              | Tolls                          | Parking Charges      |
|              | Travel Time                    | ComFor, Convenienc (Ø) |
| Perceived    | Tolls                          | Parking Charges      |
|              | Travel Time                    | Comfort, Convenience (Ø) |

| SOCIAL COSTS | Fixed                          | Land Acquisition    |
|             |                               | Infrastructure       |
|             |                               | Aesthetic Aspects of Fixed Structures |
|             |                               | Sociological Costs  |
| Fixed/Variable | Road Maintenance           |                           |
|              | Snow Removal                  |                           |
|              | Lighting                      |                           |
|              | Administration                |                           |
|              | Policing                      |                           |
| Variable     | Congestion Costs             |                           |
|              | Accident Costs (ie. costs not covered directly by privately purchased insurance) |
|              | Air Pollution                 |                           |
|              | Noise                         |                           |
|              | Visual Intrusion              |                           |

Table 3.1
THE COSTS OF URBAN TRANSPORTATION
Of the social costs, the only costs that we can estimate even approximately are those arising as a result of congestion. They are time delay, and increases in the operating and accident risk costs. These also will be discussed in the numerical study. The social costs on which we cannot place a monetary value are those due to air and noise pollution, visual intrusion, and the accident costs that are not covered by purchased insurance (e.g., accident investigation, suffering, etc.).

Despite the voluminous literature on both air pollution and environmental noise, we still cannot place even a crude estimate of cost on either. We could, perhaps estimate the pollution-inflicted damage to crops, or the accelerated corrosion rates in areas of heavy pollution, but how do we place a value on the life of a potential "excess death" during a temperature inversion? Or what is the social cost of any of the ailments that have been linked to the products of combustion or the particulate matter from rubber and asbestos? What is the social cost of restraining children from physical activity during "smog-days"? The list goes on...

The exhaust emission rate is not constant but varies inversely with speed. The authors of Cars for Cities found that there is approximately a four-fold increase in exhaust emissions when the speed is halved (from 15 to $7\frac{1}{2}$ mph). The rate of emission also depends very much on the frequency of acceleration and deceleration; therefore, under highly congested conditions the emission volume might increase many-fold. The absolute amount would of course depend on many factors - size of engine, number of cylinders, weight of car, state of engine tune, etc.

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8 See for example the massive report of the U.S. Senate Subcommittee on Air and Water Pollution (1968) or the report by the U.S. Surgeon General to the U.S. Congress (1962): Motor Vehicles, Air Pollution and Health
9 For a review of the literature see J.H. Hansen, R.R. Stussi, Noise and the Urban Environment, University of British Columbia, Centre for Transportation Studies, 1971
10 Cars for Cities, HMSO 1967
While the air pollution factors are directly correlated to the amount of congestion, noise on the other hand, shows a declining marginal contribution as traffic density increases. This is because noise emission is not additive and once a background noise has been established by a relatively small number of cars, the noise produced by the added vehicle in the stream is almost entirely "masked" by the background noise.\footnote{11}

The factor we refer to as 'visual intrusion' is probably the most elusive of all. ("... buildings rising from a plinth of cars."\footnote{12}) This is related to the amount of land area devoted to the storage of motor vehicles, and as we saw in Chapter I, unless an economic rent is charged for the parking of vehicles, the demand for parking space will be inflated, with the resulting proliferation in parking lots - and visual intrusion.

Accident costs: The insurance that the automobile owner buys covers only the property damage and some degree of compensation to the victims of injury, or to the victim's survivors in the case of fatal accidents. It does not cover the social costs of accident investigation or the court costs in settlements, ie. the opportunity costs of the police force and the courts. Nor does it cover the loss of a productive member of society, nor the grief and suffering of the victim and the survivors - especially in accidents involving pedestrians where the pedestrian is "at fault".

Several studies have established the relationship between traffic volume and the rate and cost of accidents (property damage and injury, convertible to monetary terms).\footnote{13} These will be discussed in the case study in the following chapter.

\footnotesize

\footnote{11} See specific discussion in Chapter VI page 112
\footnote{12} Traffic in Towns, HMSO 1963 p29
\footnote{13} See for example Gwynn (1967) and Haikalos and Joseph (1961)
Finally, there are the social costs of time delay due to congestion. These too will be examined at some length in the numerical study in Chapter IV. The following Table 3.2 indicates the magnitude of the social cost of time loss under different traffic conditions. (from studies by Smeed and by Johnson)

Table 3.2

<table>
<thead>
<tr>
<th>Traffic Speed</th>
<th>Marginal Social Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>212 ($/mile)*</td>
</tr>
<tr>
<td>6</td>
<td>140</td>
</tr>
<tr>
<td>8</td>
<td>72</td>
</tr>
<tr>
<td>10</td>
<td>41</td>
</tr>
<tr>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>14</td>
<td>16.4 31.8 ($/mile)**</td>
</tr>
<tr>
<td>15</td>
<td>13.3 16.2</td>
</tr>
<tr>
<td>16</td>
<td>10.8 11.1</td>
</tr>
<tr>
<td>17</td>
<td>8 8.4</td>
</tr>
<tr>
<td>18</td>
<td>7.1 6.8</td>
</tr>
<tr>
<td>19</td>
<td>5.7 5.7</td>
</tr>
<tr>
<td>20</td>
<td>4.6 4.8</td>
</tr>
</tbody>
</table>

Sources: * the Smeed Committee (1964)
** M.B. Johnson (1964) p 149

At a traffic flow \( q_0 \), the above estimates are shown as BC in Figure 3.1 on page 49. If the other social costs were included the estimated values would be represented by AC. This is a non optimum traffic flow in the Pareto sense and in order to move to an optimum flow, a tax equal to \( B_1 C_1 \) must be applied to lower the demand to the optimum \( q_1 \) if we consider only the congestion costs. If all costs can be calculated the tax applied must be equal to \( A_2 C_2 \) for a flow of \( q_2 \). (Figure 3.1)
There are many problems in estimating the social costs, even for the relatively straightforward congestion pricing.\textsuperscript{14} To include the other social costs, magnifies the problem many-fold. Some of the problems in bringing these into the analysis will be discussed in the last Chapter. The problem of ascertaining the exact social cost, it is argued, is not critical since the new price level can be approached incrementally, gradually increased until the socially desirable level of traffic is attained.

3.3 The Rationale for Marginal Cost Pricing

A discourse on transportation pricing would not be complete without a brief glimpse of the arguments that have sustained the "marginalist" school of welfare economic thought for several decades. Many economists have long urged the adoption of the marginal cost pricing principle in the public utilities sector of the economy.\textsuperscript{15} Although not yet adopted in the transportation sector there has been much interest and much has been written on the subject. The diagram on the following page (Figure 3.2) attempts to set the road pricing scheme in both a historical and a theoretical economic context. The "rationale for marginal cost pricing" is the concern of the top half of the diagram as far as "Buchanan". The remainder of the components will fall into place in the remainder of the study.

\textsuperscript{14} For instance the question of value of time is paramount; it still has not been answered to complete satisfaction. See Harrison and Quarmby (1968); Lansing and Hendricks (1970)

\textsuperscript{15} Marginal cost pricing is practiced successfully in the electrical power industry in several European countries - notably Electricité de France.
Figure 3.2

SCHEMATIC REPRESENTATION OF THE STATE OF ROAD PRICING IN A HISTORICAL AND THEORETICAL CONTEXT
The five elements (represented in the hatched boxes in the lower part of the figure) in essence represent the frontier of our knowledge concerning road pricing. The three boxes on the right hand side, distributional efficiency, externalities, and townplanning objectives are viewed as potentially useful, and perhaps necessary inputs into the road pricing mechanism; and long-run investment and comprehensive social impact are viewed as outputs of road pricing. Each of these elements, very interesting and very complex, will be discussed in a later chapter.

In its essence the principle of pricing at marginal cost states that when all goods and services are produced in a quantity such that the cost of producing the marginal unit of output is exactly equal to the benefit received from it, then scarce resources are allocated in the most efficient manner. In the market system the benefit received from the consumption of any good or service is at least equal to the price the consumer is willing to pay for it. Hence, if production is everywhere expanded to the point where the cost of production at the margin is exactly equal to the market price, the allocation efficiency rule is met, if this condition is met in all markets and no externalities exist.

It would be hoped that, having identified the principle in economic terminology, it does not obscure the intuitive concept that the user should pay the full costs he incurs insofar as allocation efficiency is paramount. If he is not prepared to do so he should be restrained from using the facility.
If roads are underpriced under certain conditions (due to the costs of congestion and external costs) resources are drawn from other sectors where they could have been used to greater social benefit. In order to move to a position of higher welfare, it is necessary to reduce the divergence between real or perceived prices relative to costs between roads and the remaining economy. Any increase in road prices (under specified conditions) will therefore transfer resources from that sector to others with a higher value on the marginal unit of resource.

The same reasoning can be extended to different modes of travel within the transportation sector.

3.4 Fundamental Questions Concerning Pricing at Marginal Cost

The main object of controversy of pricing at marginal cost concerns the possible income redistribution effects. Moving from the existing system of user charges to marginal cost pricing will not necessarily contribute to an "equitable" distribution of income.\(^\text{16}\) Any change in the pricing system will affect the distribution of social benefits and it is of utmost importance that in any scheme the redistribution be examined with great care to ascertain whether it is consistent with social goals. This is one area where the economist can give the planner or politician relatively little guidance. While it is the explicit function of the planner to assess the human values of diverse groups in the community, the economist, in his professional capacity must exclude any inter-personal value assessment.

\(^{16}\) In the context of road pricing Hedges defines the equity criterion thus: "Any alternative which imposes a burden on some commuters in the form of higher tolls (or less freedom) so as to make them worse off than before in terms of real income will be judged to violate the equity criterion". Hedges (1966) p 92
from his evaluation of alternatives. If the two, the objective and subjective, elements are combined, only then can we accept Little's statement that "welfare economics is a branch of ethics".\textsuperscript{17} The implications of this become clear when we consider the income distribution of various proposals for the pricing of urban transportation.

A second object of concern is the apparent all-or-nothing character of the applicability of the allocation rule of pricing at marginal cost. It is argued that unless all sectors of the market operate at price equal to marginal cost, a move to MC pricing in one sector may in total result in less efficient allocation of resources.\textsuperscript{18} If we consider a two sector economy say, transportation and "all other services and commodities" - then if the "all other" sector is operating at a price other than at marginal cost, by altering the pricing structure in the transportation sector we are\textit{not necessarily} moving toward a condition of higher welfare. However, as a general guideline we may adopt the rule that any change in one sector which minimizes the divergence of the ratios of prices relative to marginal cost, will serve to cause a transfer of resources to the sector where their value is higher.\textsuperscript{19}

On the question of the pricing in other sectors of the economy, Meyer\textit{et al.} point out that "it is not at all clear that the other sectors of the American economy, when closely scrutinized, depart markedly from competitive (ie. marginal cost) pricing conditions". If that is the case the objections against transport pricing reform on this basis are of questionable validity.

\textsuperscript{17} I.M.D. Little (1958)
\textsuperscript{18} Lipsey and Lancaster (1956-1957)
\textsuperscript{19} Farrell (1968) pp 112-115
Figure 3.5

PRICING AT MARGINAL COST: THE REVENUE PRODUCING FUNCTION
The adverse effects attributable to divergences among the pricing systems can therefore, in Meyer's words, "easily be exaggerated".\textsuperscript{20}

Finally, on the question of pricing as an agent for producing revenue to cover operation costs and to permit reinvestment, marginal-cost pricing may or may not function to completely finance the operation, or be as Kuhn terms it, "self-liquidating".\textsuperscript{21} If a perfect marginal-cost pricing can be achieved in the supply of transportation the profit (and loss) will be determined by the price relative to the average cost of production - ie. cost per vehicle mile. Thus if production is characterized by increasing returns to scale (declining average cost curve\textsuperscript{22}) the revenues to the operating authority will fall short of the costs and the transportation system must be subsidized by a per unit subsidy of (AD) or, by a total amount shown in the shaded area ABCD in Figure 3.5a on the next page. Figure 3.5b demonstrates the alternate situation where the system is subject to diminishing returns to scale (rising average cost curve). In that case the authority will make a perunit profit of $ (EH) or a net profit shown as area EFCH.

In a pure short-run marginal-cost pricing scheme the signal for investment in additional capacity would be at the point where the road in question starts to make a profit, ie. at the point where the short-run marginal cost rises above the average cost. In a situation of perfect competition and perfect divisibility of production capability, this would be the situation, but since road capacity can generally not be added incrementally the problem is greatly complicated. Therefore, given all the imperfections and indivisibilities in the transportation "market" the above criterion for reinvestment

\begin{itemize}
\item \textsuperscript{20} Meyer, Kain and Wohl (1965) pp 336-337
\item \textsuperscript{21} Kuhn (1962)
\item \textsuperscript{22} The average cost curve is identical to the marginal private cost curve discussed earlier
\end{itemize}
can only serve as a theoretical guide. But this would seem to be an appreciable improvement over the present system which provides no general guide for reinvestment.

3.5 Summary - Chapter III

This brief examination of the theory has demonstrated that short-run marginal cost pricing if applied, would serve to guide the allocation of resources between the transportation sector and others, and among different modes within the transportation sector. The principle would indicate whether we are moving toward an increase in net social welfare but would offer no guide to the problem of income distribution. Finally, marginal-cost pricing would not assure that the road system or the transit system be self-liquidating in the short-run, but in the long-run some guidance might be received from the pricing system to signal the need for expanded capacity.

It is very doubtful that a road pricing system could be calibrated to that sensitivity, and it will be formally argued in Chapter VI that because of the many limitations on practical road pricing, the above criterion could not replace the conventional project analysis in establishing investment priorities.

The concepts developed in this chapter will be employed in the case study to evaluate private costs and marginal social costs as described in the first part of the chapter. Then the rule of pricing at marginal social cost will be applied to define the objectives for socially efficient allocation of resources.
4.1 Purpose of the Case Study

The purpose of the case study is two-fold. The first is to demonstrate how a price system might be applied to a specific corridor, and to determine what the potential effects might be if such a pricing system were implemented. The corridor under study is not a microcosm of the entire urban area but it does serve as a "laboratory" at least to suggest the relevant parameters to be considered if pricing policies were adopted for universal planning objectives.

Data from the case study corridor are more complete than one would generally expect, but not sufficiently comprehensive to form definite conclusions and recommendations. The study thus raises more questions than it is possible to answer and the second purpose is to determine the type of additional data, the quantity and accuracy of data required to build a reliable model for setting prices and predicting the consequences.

4.2 Description of the Study Area

The Lions' Gate Bridge spanning the western end of Burrard Inlet, is a major connecting link between the dormitory communities north of the Inlet and the Vancouver Central Business District. The corridor, which includes the bridge and the Causeway through Stanley Park is subject to very high unidirectional peak-hour loads, southbound in the morning and northbound in the afternoon. A map of the region of the study is shown in Figure A-1 of the Appendix and a detail drawing of the corridor is given in Figure A-2 of the Appendix.
4.3 General Framework for the Study

The organizational diagram on the following page demonstrates a generalized framework for carrying out the numerical study. It is proposed that the study be divided into four separate parts as described in the following sections.

Section I

The first objective is to determine the supply function, i.e., the private cost curve. This defines the resources that the individual trip-maker consumes. The calculation of the marginal social costs follow directly from the determination of the private costs. As both the private and social costs were examined extensively in the previous chapter they will not be discussed further here. In order to convert all costs to equivalent units of measurement it is necessary to estimate the average value that commuters place on time and ultimately, and much more difficult, to assign a monetary value to the "unquantifiables".

Section II

As stated in Chapter II not much is known about the demand function except for the present equilibrium point. Practically nothing is known about the elasticity of demand with respect to time, cost and comfort and convenience changes, nor about the cross-elasticity between two modes, or between peak and off-peak travel. This section will postulate a demand function using the small amount of data that is available from other studies. In this section the analysis of the supply functions and the demand function are combined to predict the shifts (mode 1 to mode 2; peak to off-peak) that would occur if various taxation rates were applied. A very significant refinement of the analysis would be the disaggregation of the commuting
Figure 4.1

GENERAL FRAMEWORK FOR THE CASE STUDY

Traffic Flow Characteristics

Capacity Constraints

Queueing

Waiting Time

Congestion Costs

Value of Time

Accident and Operating Costs

Private Cost Function

\[ z = f_1(g) \]

Marginal Cost Function

\[ M.C. = \frac{\partial z}{\partial q} \]

Demand Function

\[ q = f_2(z) \]

Optimum Tax

Effects: Tolled-off, Tolled-off
Estimation of the Costs and Benefits.
population into groups displaying similar utility functions, specifically
groups with similar valuation of time and comparable marginal utility of
money. Such groups, if they could be properly defined would probably
display like cost curves and common demand elasticities; therefore the
effects of changes to the system would vary among the different groups.
A given price change, for example, would cause many poor people to change
their travel patterns while the same change would cause little shift
among the rich.

Section III

If a pricing system were implemented, some commuters would gain,
some lose, and some lose more than others. This section seeks to trace
the losses and gains for two purposes: first, to assess the potential
income redistribution, and second, to estimate the net benefits that
would accrue to society on the whole.

Section IV

The final objective in the analysis is the assessment of the long-
term impact of road pricing policies. In the long run we should be aware
of the two related elements of transportation economics; the price itself
and the investment policies. Both the cost of travel itself and the
policies for investment in urban transportation facilities will effect
changes in the urban land use pattern and the location of economic activit­
ies. Because little is actually known about the determinants of land use
with respect to transportation changes this section will conclude in a
fairly broad conjectural context. The long-run implications will depend
very much on the allocation of the collected revenues. Recommendations
by various researchers range from reinvesting all in road construction, to
financing rapid transit construction or subsidizing transit operations, to absorbing all the "profits" in general revenue. Each of these could have vastly differing consequences on the urban area. Thus it follows that if road pricing were to be used as a tool of planning it must, as a first order of necessity be complemented with appropriate financing arrangements. The general discussion on the long-term implications will be left until the final chapter.

4.4 A Note on the Numerical Study

Because of the weaknesses in the data and limitation on resources, this study will not fulfill the comprehensive outline above. There will be certain gaps, assumptions and simplifications and should on the whole be viewed largely as a blueprint for further study. Deficiencies in the data and in the numerical analysis will be acknowledged and possible improvements and realignments suggested. Thus the numerical evidence in the following pages should be considered as suggesting the order of magnitude to be expected rather than determining a precise estimate. No attempt will be made here to place a monetary value on the environmental factors; it is simply a numerical study of one type of social costs, those related to congestion. The estimates therefore, if anything, err very much on the low side.

The technical problems of administering a pricing scheme will be examined subsequently. For the present discussion it is assumed that a reasonably sensitive and flexible pricing system could be implemented,
4.5 Section I - The Supply Function

The Lions' Gate Bridge corridor is an example of a pure bottleneck but it exhibits one peculiarity: that the equilibrium traffic flow does not move into the backward bending portion of the supply curve. The speed generally does not fall below 26 miles per hour and the volume does not fall below 3400 vehicles per hour.¹

In order to simplify the discussion from here on we will consider only the morning peak traffic period, (ie. southbound traffic). The afternoon 'rush hour' is similar in most respects, and since only the concepts are presented here, consideration of the two directions would unnecessarily complicate the exposition.

A simple representation of the supply curve (cost vs. traffic volume) can be derived from a knowledge of the speed - volume relationship. As traffic volume increases there is a slight decrease in the average speed from about 35 miles per hour when \( q \) is near zero to 26 miles per hour at the maximum capacity when \( q = 3400 \) vehicles per hour. An approximate linear relationship of the speed - volume relationship can be derived and expressed thus:

\[
V = 35 - 9 \times \frac{Q}{S}
\]

where \( V \) = speed in mph
\( Q \) = actual traffic volume in veh/hour
\( S \) = corridor capacity = 3400 vph

The time - volume relationship is therefore:

\[
T = \frac{(D/V) \times 60}{35 - 9 \times \frac{Q}{S}}
\]

where \( T \) = time elapsed from entry to exit in minutes
\( D \) = corridor length in miles = 2.4

¹ The most recent data available (July - August 1971) indicate an average of 3,423 vehicles per hour southbound between 8 and 9 A.M. (Personal correspondence with J.H. Harding of B.C. Department of Highways) At this hourly volume (two lanes, peak direction) the traffic flow is very close to the maximum physical capacity of the road as defined by the Highway Capacity Manual (Highway Research Board Special Report No. 87, 1965)
Hence the equivalent time cost (in dollars) can be calculated:

$$C_{\text{time}} = \frac{2.4}{35 - 9 \times \frac{Q}{S}} \times T_v$$

where $T_v$ is a parameter equivalent to the mean value of time of commuting motorists.

The three curves defined by the above equations are sketched in Figure 4.2 on the next page. (Figures 4.2 (a), (b) and (c) respectively)

A second cost curve may be calculated which, in addition to time costs include estimates for operating costs and accident costs as functions of traffic volume. The estimates below are drawn from the Chicago Area Transportation Study (CATS).

Table 4.1 (Source: Haikalis and Joseph, 1961, Table 5)

<table>
<thead>
<tr>
<th>Speed (MPH)</th>
<th>Operating</th>
<th>Accident</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4.80</td>
<td>6.75</td>
<td>11.55</td>
</tr>
<tr>
<td>10</td>
<td>3.69</td>
<td>4.25</td>
<td>7.94</td>
</tr>
<tr>
<td>15</td>
<td>3.10</td>
<td>2.70</td>
<td>5.80</td>
</tr>
<tr>
<td>20</td>
<td>2.78</td>
<td>1.80</td>
<td>4.58</td>
</tr>
<tr>
<td>25</td>
<td>2.57</td>
<td>1.15</td>
<td>3.72</td>
</tr>
<tr>
<td>30</td>
<td>2.41</td>
<td>0.80</td>
<td>3.21</td>
</tr>
<tr>
<td>35</td>
<td>2.36</td>
<td>0.55</td>
<td>2.91</td>
</tr>
</tbody>
</table>

From the table the approximate regression equations can be derived:

$\text{OPCOST} = (3.30 - 0.021 \times V) \times D$  where V and D are defined above.

$\text{ACCOST} = (5.75 - 0.081 \times V) \times D$  $\text{OPCOST}$ and $\text{ACCOST}$ are in units of cents/mile.

The above is sketched combined with $C_{\text{time}}$ in Figure 4.2 (d).
Figure 4.2

RELATIONSHIP OF TRAFFIC FLOW TO SPEED, TIME & COST IN THE LIONS’ GATE BRIDGE CORRIDOR.
There are no data available from which to estimate accurately the costs of accidents in the case study area as a function of traffic volume or speed. Most accidents (65%) have been of the rear-end type and there are peaks in the hourly distribution of accident rates during the two peak traffic periods so the CATS estimates are at least in part substantiated.\(^2\)

If, as is the case in the Lions' Gate Corridor, the instantaneous demand (the arrival rate) exceeds the capacity of the bottleneck (the service rate), a queue will form at the entrance. The length of the queue will continue to grow so long as the arrival rate exceeds the service rate.\(^3\) The traffic behaviour in a bottleneck situation characterizes a cost curve quite different from that discussed in Chapter II. The following section seeks to estimate this curve. This will later be combined with the cost curves (Figure 4.2 (c) and (d)) calculated above.

The characteristics of the queue buildup during the morning peak have been recorded in N.D. Lea's 1967 study,\(^4\) and the relevant arrival and service rate parameters are reproduced in Figure 4.3 on the next page. The diagram indicates that the queue starts to form at about 7:20 A.M., grows to a maximum length at 8:00 and then gradually dissipates and the system resumes free flow at about 8:25. The maximum waiting time, it was found, was about 12 minutes and the average about 6\(\frac{1}{2}\) minutes.

\(^2\) Lea (1967) drawing 7116-807
\(^3\) This is a very much simplified description of queue formation. The standard model of queuing is a probabilistic model which assumes a Poisson distribution of arrivals and an average arrival rate \(A\), a service rate \(S\), where \(A\) is always less than \(S\). For each \(A/S\) ratio the model predicts the equilibrium state, i.e. mean queue length and mean waiting time. But it tells us nothing about the transient states when \(A/S\) is changing or when \(A > S\). The simple model described in the text will, if anything err on the low side when estimating queue lengths and waiting times.
\(^4\) Lea (1967) p 40
The above diagram however provides little information from which to generate the cost curves as a function of arrival rate. This can be done by constructing a simple model to simulate the growth of arrival rates up to and beyond the capacity (service rate). The object is to generate two sets of data points to define the marginal private cost curve and the marginal social cost curve. The algorithm and the program that was developed to achieve this as well as the complete printout are included in the Appendix on page 141. The two curves are plotted on page 77. Again it is emphasized that the calculated values should be considered indications of magnitude, not precise estimates.
The model described here makes several assumptions and simplifications:

1. That the arrival rate is uniform over the period of queue formation. This rate is \( A_1 \) where \( A_1 > S \).

2. That the service rate \( S \) is constant at 3400 vehicles per hour.

3. No distinction is made among different types of vehicles. This is not a serious limitation since there are very few commercial vehicles using the bridge during the peak periods and buses from the north are permitted to bypass the queue. At the time of the study buses and commercial vehicles comprised less than 2% of the total flow.

4. After the period of constant arrival rate (\( A_1 > S \)) the arrival rate falls abruptly to \( A_2 (< S) \).

These simplifications of the true situation are shown superimposed on Lea's representation of the traffic flow characteristics in Figure 4.4(a) on the next page.

5. An average value of time of $1.50 per individual per hour is assumed. At an average occupancy of private cars of 1.3, the value of time per vehicle is estimated at $1.95.\(^5\)

6. It is assumed that growth of demand is accommodated by two mechanisms simultaneously: First, by a broadening of the time of excess arrivals (\( t_{ex} \) in Figure 4.4 (b)), and second, by an increase in the absolute rate of arrivals (\( A_1 \)). Thus the assumed manner of growth of demand is as demonstrated.

---

\(^4\) This model is similar in some respects to one described by Vickrey (1970). However he is wrong in stating that an efficient solution can only be achieved in the complete elimination of the queue. (page 256)

\(^5\) Vickrey's suggestion that the different values of time be assigned to different portions of the trip is correct but leads to an uncontrollably complicated model. (ibid. p 254)
Figure 4.4 (a)

APPROXIMATION OF TRAFFIC FLOW FOR PURPOSES OF SIMULATING THE GROWTH OF A QUEUE

Figure 4.4 (b)

REPRESENTATION OF ASSUMED MANNER OF GROWTH OF A QUEUE
The algorithm generates two sets of cost curves (Figure 4.5). The first accounts the time costs only. PCI describes the average time cost of the trip from the time of entering the queue til arrival at the Coal Harbour end of the causeway. MC1 is the corresponding marginal cost curve. SCI is the social cost that the average motorist incurs but which he himself does not experience. It should be noted that SCI = MC1 - PCI.

The second curve, PC2 describes the average private cost including time, operating costs, and accident costs (estimated from Table 4.1). MC2 is the corresponding marginal cost. No attempt has been made to include any other social costs in this demonstration exercise.

4.6 Section II - The Demand Function

Having approximated the supply functions above of the form $z = f_1(q)$, it is now necessary to postulate the demand curve $q = f_2(z)$. The estimated present equilibrium point is at $q = 4400$ and from Figure 4.5, we see that the corresponding $z$ is 61%. Given a demand curve downward sloping to the right, what is the "optimum" traffic flow? That is, where does the demand curve intersect the marginal cost curve? Three demand curves of different elasticities have been sketched on the diagram. Elasticities of 0.5, 0.75 and 1.0 are tested and the intersecting points are respectively 3680, 3660 and 3640 vehicles per hour. It is clear, therefore that the optimum traffic volume is not sensitive to demand elasticity. Nor is the optimum tax very sensitive, ranging from $38\%$ to $46\%$ for the range of elasticities considered.

The literature is unfortunately rather scant on the estimates of a realistic demand elasticity. However, there are several studies from which we can at least attempt to impute an elasticity. These are summarized in Table 4.2 on the next page.
Figure 4.5
PRIVATE AND SOCIAL COSTS AS FUNCTIONS OF ARRIVAL RATE IN A QUEUEING SITUATION

EQUIVALENT COST ($)

ARIVAL RATE (V.P.H.)

MSC 2
MSC 1
PC 2
PC 1
Table 4.2

<table>
<thead>
<tr>
<th>City and Year</th>
<th>Elasticity with respect to price (or time converted to money)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Moses and Williamson</td>
<td>Chicago 1963</td>
</tr>
<tr>
<td>Comment: calculated the percent of commuters diverted to transit for each increment of change in price.</td>
<td></td>
</tr>
<tr>
<td>(2) Wilbur S. Smith</td>
<td>(general) 1968</td>
</tr>
<tr>
<td>Comment: standard diversion curve for general application.</td>
<td></td>
</tr>
<tr>
<td>(3) Charles River Associates</td>
<td>Boston 1968</td>
</tr>
<tr>
<td>(4) R.L. Pratt</td>
<td>Washington, D.C. 1970</td>
</tr>
<tr>
<td>Comment: results show some variation with income level as would be expected</td>
<td></td>
</tr>
<tr>
<td>(5) J.M. Thomson</td>
<td>London 1965</td>
</tr>
<tr>
<td>Comment: short run elasticity would be somewhat lower</td>
<td></td>
</tr>
<tr>
<td>(6) M.E. Beesley</td>
<td>London 1965</td>
</tr>
<tr>
<td>(7) G.R. Brown</td>
<td>Vancouver 1967</td>
</tr>
<tr>
<td>Comment: based on the response to the question: What is the minimum quality of service you would desire for your journey if you were to use normal bus service? There is some doubt as to the possible interpretation of this question since the respondent is offered six different possibilities for improved service: Are they mutually exclusive or are they all effective simultaneously?</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion: It would appear from the above that a mean elasticity of 0.5 reasonable. This means that a 33% increase in price (from the equivalent of 61¢ to the equivalent of 81¢ in Figure 4.5 would cause a 16.5% decrease in the instantaneous demand, reducing the arrival rate from 4400 to 3680 vph. Thus 720 vph would be "toll ed off" to one of five alternatives: 1. divert to transit 2. select another route (across the Second Narrows) 3. car pooling 4. put of the trip to a different time of day 5. choose not to make the trip at all
4.7 The Effect of a Price Change

It would indeed be difficult to estimate the proportion of the commuters who would select each of the above alternatives, but since almost all the peak-hour trips across Burrard Inlet are trips to work it is likely that in the short-run there would be little change in the absolute number of trips. Also, because of general institutional inflexibility in the hours of work it is unlikely that a significant number of trips would be put off until another time. That leaves the mode shift, the route diversion, and car pooling effects.

(1) Route diversion: It would be reasonable to assume that of those crossing the Lions' Gate Bridge destined for the Central Business District and other points in the region, those whose origins or destinations fall closest to the Second Narrows Bridge would be most likely to select the alternate route.

<table>
<thead>
<tr>
<th>ORIGINS</th>
<th>DESTINATIONS</th>
<th>AVG. AUTO TRIPS/ HOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>East of Lonsdale Ave.</td>
<td>CBD</td>
<td>110</td>
</tr>
<tr>
<td>Entire North Shore</td>
<td>Vancouver East, Burnaby</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>240</td>
</tr>
</tbody>
</table>

Therefore 240 or about 1/3 of the tolled off automobiles would probably select the Second Narrows Bridge.

(2) Mode Shift and Car Pooling Effects: The question of mode split is much more complicated than the route assignment. The standard type of mode split model is usually in the form of a regressed correlation between the percent transit in a zone and the socio-economic and

6 Lea (1967) drawings 7116-820 and 7116-821
demographic characteristics of the population. Thus it is of little use in attempting to predict the effects of changes to the transportation system. The diversion curve mode split model holds somewhat more promise but it too is a very simplistic tool which uses the measured time as a surrogate variable for a large number of the qualitative characteristics of the transportation system. Road pricing would have an effect on the quality of service in addition to changing the relative prices of private and public transport. For example, with more people using the transit system more vehicles would be required and the average waiting time would be reduced. Bus transit would be speedier as a result of a general reduction of the level of congestion. Riding would be more comfortable particularly for the standees if there were fewer congestion-enforced stoppages. These factors would all serve to make bus travel more attractive in absolute terms. There is therefore a need to develop more comprehensive models to predict the mode split for the condition where several qualitative variables are changed simultaneously.

Given the current state of modelling all we can say is that some of the "tolled off" will choose to switch to buses and some will form car pools. But in both cases the objective of using the transportation system more efficiently would be achieved. If we assume that all the remaining persons were to switch to buses it would require approximately an additional twelve buses per hour to accommodate the persons from the 480 vehicles.
4.8 Section III - The Costs and the Benefits

It is of interest to note in Figure 4.5 the very abrupt change that takes place in the cost curves at the point where arrival rate exceeds capacity. Especially interesting is the extreme change in slope of the marginal social cost curve. Although the graph does not show it, the printout in the Appendix indicates that at the present magnitude and time duration of excess arrival rates and duration of the marginal arrival is incurring a social cost of $3.09 in addition to his private cost of $0.58.

It should be again emphasized that the curves are based on a mean value of time of $1.50 per hour per individual. Despite many studies on the value of time we do not know whether $1.50 is realistic for the particular socio-economic group of the case study area. Whatever mean value of time is selected it must be recognized that it is a mean of a distribution - some lower, some higher. To demonstrate the sensitivity of the example to the value of time another set of average cost and marginal cost curves have been generated and plotted in Figure 4.6. The three mean values that have been considered are $1.00, $1.50 and $2.00 per individual per hour. The operating and accident costs remain as before. The demand curves for each set of private cost and marginal cost curves are maintained at \( e = 0.5 \).

---

7 The opportunity value of the vehicle is assumed to be zero.
8 Harrison and Quarmby in a review of eleven studies report estimates varying from $.25 per hour to $4.00 per hour (Harrison, Quarmby 1969)
9 $1.55 per hour has been used in economic feasibility studies for many years by AASHO (American Association of State Highway Officials, Road User Benefit Analysis for Highway Improvements, Washington, D.C. 1960, p 126)
Figure 4.6

SENSITIVITY OF OPTIMUM TAXATION RATE AND TRAFFIC FLOW
WITH RESPECT TO VALUE OF TIME
It is evident from Figure 4.6 that the "optimum" arrival rate is virtually insensitive to the assumed value of time, but the tax to be applied is very sensitive as summarized in the following:

<table>
<thead>
<tr>
<th>Assumed Mean Value of Time</th>
<th>Optimum Arrival Rate</th>
<th>Optimum Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.00</td>
<td>3640 vph</td>
<td>$0.36</td>
</tr>
<tr>
<td>1.50</td>
<td>3660</td>
<td>0.45</td>
</tr>
<tr>
<td>2.00</td>
<td>3680</td>
<td>0.63</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equivalent Time Saving</th>
<th>Net Increase in Cost of Trip</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.23</td>
<td>0.36 - 0.23 = $0.13</td>
</tr>
<tr>
<td>0.24</td>
<td>0.21</td>
</tr>
<tr>
<td>0.35</td>
<td>0.28</td>
</tr>
</tbody>
</table>

The net economic benefit would also vary in proportion to the value of time. In traditional economic calculations the net benefit is equal to the net time saving per user, times the number of users, minus the loss to those that were tolled off. Because the toll is not a social loss, as is time (i.e., the toll is available for others to use), economists refer to the toll as a "costless transfer payment". The theoretical benefits may be calculated for each mean value of time:

<table>
<thead>
<tr>
<th>Mean Value of Time</th>
<th>Gross Benefit* (Area ABDE)</th>
<th>Gross Loss (Area CDF)</th>
<th>Net Social Benefit (Area ABDE - CDF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.00</td>
<td>0.23x3650 = $840./hr.</td>
<td>1/13 x750 = $49./hr.</td>
<td>$791./hr.</td>
</tr>
<tr>
<td>1.50</td>
<td>880./hr.</td>
<td>79./hr.</td>
<td>801./hr.</td>
</tr>
<tr>
<td>2.00</td>
<td>1,280./hr.</td>
<td>103./hr.</td>
<td>1,177./hr.</td>
</tr>
</tbody>
</table>

* Refer to adjacent figure.
This obviously does not tell us anything about who the gainer of the gross benefit are, or who the losers of the gross loss might be. It simply states that if, for example, time is indeed valued at $1.50 per hour, and if a toll of $.45 per trip were applied the time normally lost in queuing, which has an equivalent total value of $880 per hour would not be lost because money is transferable where time is not. The total benefit lost for \( T_v = 1.50 \) is equal to \( \frac{1}{2} \times 0.21 \times 750 = 79 \). The net social benefit is thus the difference between $880 and $79, equal to $801 per hour.

If we could include other social costs such as pollution, noise etc., the analysis would be exactly the same but the marginal social cost curve would be higher, the optimum tax higher and the traffic volume (i.e., arrival rate) somewhat lower.

Finally, the collection of the tolls is not "costless". The net benefits calculated above would be reduced by exactly the hourly cost of collecting the tax. The authors of *Better Use of Town Roads* in their analysis of the possibilities of road pricing in London estimate that the collection costs would amount to between 25% and 45% of the collected revenues,\(^{10}\) variation depending on the specific collection mechanism used.\(^{11}\) Accepting the worst case (45%), the net benefits under various values of time would be as follows:

<table>
<thead>
<tr>
<th>Value of Time</th>
<th>Gross Benefits</th>
<th>Gross Losses</th>
<th>Administration</th>
<th>Net Benefit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.00</td>
<td>$840/hour</td>
<td>$49/hour</td>
<td>.45 x 840=$378</td>
<td>$414/hour</td>
</tr>
<tr>
<td>1.50</td>
<td>880</td>
<td>79</td>
<td>396</td>
<td>405</td>
</tr>
<tr>
<td>2.00</td>
<td>1,280</td>
<td>103</td>
<td>577</td>
<td>600</td>
</tr>
</tbody>
</table>

---

\(^{10}\) *Better Use of Urban Roads* HMSO 1967 p 46

\(^{11}\) The alternative schemes for collection will be discussed in Chapter V.
4.9 Summary - Chapter IV

The case study has demonstrated several things. Foremost, it has shown that it is possible to generate supply functions that do account for at least some of private and social costs, and in that sense the demonstration was successful. But it was also evident that the numerical study hinges on some rather large assumptions such as the value of time, the elasticity of demand, and so forth. And certain unquantifiable elements, such as environmental factors, had to be left out entirely for lack of estimates of equivalent money valuation. Finally the analysis has left completely unanswered the questions concerning the potential income redistribution effects.

Despite these obvious shortcomings of the case study, it does demonstrate very clearly the direction and magnitude of an optimum taxation rate and the optimum traffic flow. The analysis may therefore be used for direct application of the specified tax rates, or it may be used to specify the objective. The study has demonstrated that the objective optimum traffic flow for efficient allocation should be between 3600 and 3700 vph. How the objective of limiting the traffic flow is achieved is not very important. The mechanisms for applying direct pricing that will be discussed in the next chapter represent only one method of restraint. Others, more familiar and perhaps more applicable in this specific case are, for example, outright prohibition to all but the journey-to-work trips during the rush hours; provision of park-and-ride services to attract the motorist out of his car, queue priority to cars carrying four or more people, and so on.
CHAPTER V  EVALUATION OF ALTERNATIVE PRICING SCHEMES

Many proposals and suggestions have been put forth for implementation of a practical road pricing scheme. Many of the schemes for administering a pricing system are highly developed in technical detail. As these have been ably described by others, the details will not be repeated here. For further discussion concerning the details of the schemes the reader is referred to the authors footnoted below.¹

This discussion will address itself to an evaluation of the schemes - the criteria that, in this writer's opinion, the proposals must, or should meet in order to be successfully implemented, and to be effective instruments for achieving the stated objectives.

The scheme must be considered with respect to performing the functions of prices discussed earlier, ie. (1) allocation of resources (2) generation of revenue and (3) promotion of equity.

To these may be added a fourth, which must be examined separately, that is the question of whether a scheme conflicts with, concurs with or is complementary to other goals of the urban residents. Finally two important criteria are included, administrative feasibility and technical feasibility. Taking the view of the planner as designer, no attempt will be made to suggest the political acceptability, except where the issues are clearly defined.²

¹ See Vickrey (1959); Smeed (1964); Roth (1967); Beesley (1967); Hedges (1966)
² John F. Kain warns the planner to beware of making a "premature imposition of constraints", ie. prematurely deciding that a project or a policy course is, or is not, politically feasible. Kain urges: "This I regard as both improbable and illegal seizure of power by technicians that is inimical to the principles of our democratic process". Quoted in Hedges (1969)
The evaluation is presented in the form of a binary response. When reading through tables 5.1 and 5.2 it is obvious that an indicated response may be conditional on other things, for example how the plan is implemented with respect to sensitivity to public relations, or what technology is applied. The evaluation is quite subjective and it may well be that the reader finds himself in disagreement with some of the responses.

5.1 Criteria for Economic Efficiency

The objective of the mechanism should be such as to permit inclusion of all the short run marginal social costs incurred by the user. It is therefore paramount that each proposed scheme be evaluated with respect to operational criteria as a necessary input into the more general non-operational evaluation. The operational requirements may further be classified in the two groups of high order requirements - those that are considered to be necessary for the system to achieve allocational efficiency - and low order requirements - those that are desirable to make the system function more effectively, but are not absolutely necessary. The following requirements are adopted from seventeen basic specifications suggested by Smeed, and are evaluated in Table 5.1.

---

3 Smeed (1964) p 7
High - Order Requirements

(1) In order to satisfy the economic resource allocation criterion, it is necessary that prices equal marginal cost under all conditions. This means that the pricing system must be variable in both space and time, and for different types of vehicles. According to Smeed, "It should be possible to vary prices to some extent for different roads (or areas), at different times of day, week or year, and for different classes of vehicles." Table 5.1 shows this in four columns: Time Variable, Space Variable by locality, Space Variable by street, and Vehicle Type Variable.

(2) Charges should be ascertainable in advance. If the price is not known at the time when the individual makes his travel decisions, it cannot possibly enter his decision-making calculus. Roth contends that there is no point in devising automatic systems that relate the price charged to the actual congestion in the area. The price should rather relate to the expected conditions.

(3) The price should be visible, i.e., the perceived cost should coincide with the objective price. If this is not so the mechanism will be distorted and fail in its allocative function. This suggests that payment should be frequent and should be accompanied by some physical action by the paying individual. Quinet observes "A price which is accurately computed but is ignored by the public which is only aware of it a posterior at time of payment would lose its incentive."

---

4 Smeed (1964) p 7
5 Roth (1967) p 45
6 This also relates to the stability of the pricing system. If there is no "damping" built into the mechanism it will be far too sensitive. See Quinet (1970) p 22; Welsby (1971)
7 The analogy to Pavlov's dogs is perhaps not inappropriate.
8 Quinet (1970) p 21
<table>
<thead>
<tr>
<th>INDIRECT</th>
<th></th>
<th>DIRECT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Related to Vehicle Ownership</strong></td>
<td><strong>B. Related to Vehicle Usage</strong></td>
<td><strong>A. Charges Registered off-vehicle</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>9. &quot;PULSE&quot; locating</strong></td>
</tr>
<tr>
<td><strong>1. Annual Licences</strong></td>
<td><strong>(a) amount of usage</strong></td>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td><strong>2. Purchase tax</strong></td>
<td><strong>(b) place of usage</strong></td>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td><strong>B. Related to Vehicle Usage</strong></td>
<td><strong>(c) amount and place of usage</strong></td>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td><strong>A. Charges Registered on-vehicle</strong></td>
<td><strong>8. Differential fuel tax</strong></td>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td><strong>11. Fixed charge to enter zone</strong></td>
<td><strong>Yes</strong></td>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td><strong>12. Continuous Charging within zone</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(a) time-related</strong></td>
<td><strong>Yes</strong></td>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td><strong>(b) distance-related</strong></td>
<td><strong>Yes</strong></td>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td><strong>13. Automatic sensing device</strong></td>
<td><strong>Yes</strong></td>
<td><strong>Yes</strong></td>
</tr>
</tbody>
</table>

**Table 5.1**

<table>
<thead>
<tr>
<th>EVALUATION OF OPERATIONAL REQUIREMENTS OF VARIOUS ROAD PRICING SCHEMES</th>
</tr>
</thead>
</table>

* Subject to expectation

Yes - probable affirmative

No - probable negative

? uncertain

- not applicable
Low - Order Requirements

(4) The method should be simple to understand and should not distract the driver's attention from his other responsibilities.

(5) The equipment used should possess a high degree of reliability.

(6) It should be reasonably free from the possibility of fraud and evasion.

(7) Enforcement measures should impose as little extra work on the police forces as possible.

(8) The pricing mechanism should be applicable to motorists from other countries or other areas where no pricing scheme is in effect.

(9) It would be preferable if the method could also be applied to a charge for street parking.

(10) The method should be amenable to gradual introduction commencing with an experimental phase.

The various schemes proposed are examined with respect to these operational requirements in Table 5.2. Elaboration on the elements of the matrix follows in the general discussion of the alternatives.

5.2 Revenue Generation

Although this is not a requirement for efficiency from a welfare economic standpoint it is very important with regard to other aspects. In accordance with the National Transportation Policy the user should pay the full costs of infrastructure. As observed earlier, this does not

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9 National Transportation Act (1967) Chapter 69 Canadian Revised Statutes
necessarily violate the efficiency criterion in the long run. It does require, because of indivisibility, that the facility be operated at a profit (marginal cost above average cost) at certain periods to generate the revenue to finance an expansion or the new facility. Although in principle it would be very neat to say that facilities should only be expanded or new infrastructure built when the signal is received at $MC > AC$, there are obviously many political considerations. Though it would involve cross-subsidizations, (possibly impossible to trace) the Act does suggest that these should occur internally to the mode in question.

Also for reasons of social acceptance, it would be justifiable to support that approach for re-investment. As Sharp observes: "Both the value judgement that the people paying the tax ought, if possible, to benefit from it and the need to make the tax politically acceptable point to investment in new roads, or in road improvements, as the best means of using tax revenue".  

5.3 Distribution of Income

The problem of income distribution will be discussed in Chapter VI and does not need elaboration here. It is unlikely that any of the proposed pricing schemes are totally equitable according to the Paretian principle. Although compensation is theoretically possible, it is extremely difficult to apply. One reason is that the identity of the "tolled-off" is simply not known. It may therefore be concluded that only the status quo - rationing by congestion - completely satisfies the equity criterion in terms of Pareto-optimality.

10 Sharp (1966) p 815
11 The Pareto-optimality principle is satisfied when none is made worse off and at least one individual is made better off.
5.4 Administrative and Technical Feasibility

In column five of Table 5.2 is indicated the feasibility evaluation of various schemes. It includes such elements as:

1. technological capability
2. cost of implementation
3. administrative difficulties
4. enforcement, problems of evasion
5. administrative costs

5.5 Other Societal Goals

It is beyond the scope of this paper to attempt to elucidate all the goals of society. Being cognizant of the fact that the analysis is far from complete, this exposition limits itself to those five described at the outset, of which the first two are dealt with above:

1. efficient allocation of resources
2. equitable distribution of income
3. freedom of choice
4. a "livable" environment
5. maximize accessibility to opportunities

This study will not attempt to assess the potential goal achievement (this is closely related to the political acceptance criteria) but rather it will identify some of the impacts that are directly related - positively or adversely - to the stated goals. Many of these factors will emerge in the following discussion.
<table>
<thead>
<tr>
<th></th>
<th>Economic Efficiency</th>
<th>Distributional Efficiency &quot;Equity&quot;</th>
<th>Revenue Generation</th>
<th>Administrative Feasibility</th>
<th>Technical Feasibility</th>
<th>Political Feasibility</th>
<th>Other Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>INDIRECT</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>A. Related to vehicle ownership</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>1. Annual Licences</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Purchase tax</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>B. Related to vehicle usage</td>
<td></td>
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<td>(a) Amount of usage</td>
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<td></td>
</tr>
<tr>
<td>3. Fuel tax</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>4. Tyre tax</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>?</td>
<td>No</td>
<td>Yes</td>
<td>?</td>
</tr>
<tr>
<td>(b) Place of usage</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>5. Poll tax</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>?</td>
</tr>
<tr>
<td>6. Daily Licences</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>?</td>
</tr>
<tr>
<td>7. Parking tax</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>?</td>
<td>Yes</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>(c) Amount and Place of usage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Differential fuel tax</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>?</td>
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<tr>
<td>DIRECT</td>
<td></td>
<td></td>
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<tr>
<td>A. Charges registered off-vehicle</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. &quot;PULSE&quot; locating</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>?</td>
<td>No</td>
<td>No</td>
<td>?</td>
</tr>
<tr>
<td>10. Toll gates</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>?</td>
</tr>
<tr>
<td>B. Charges registered on-vehicle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(a) Zone system</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>11. Fixed charge to enter a zone</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>12. Continuous charging within a zone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) time-related</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>(b) distance-related</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>(b) Point system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Automatic sensing device</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>?</td>
</tr>
</tbody>
</table>
5.6 Alternative Schemes

The pricing mechanisms can be classified in many ways. The method of classification chosen here is as indicated in Tables 5.1 and 5.2. It should be self-explanatory.

(1,2,3,) The first three, annual licences, purchase tax, and fuel tax have already been discussed in Chapter II, and the deficiencies pointed out. As indicated in the table, these methods satisfy the low order operational requirements but not the more important high order requirements for efficiency of resource allocation. These are, as has been shown excellent tools for raising revenue, and are clearly administratively and politically feasible. They also satisfy the criterion for equity, since there would be no change.

(4) A tyre tax is analogous to a fuel tax in many respects, except that it lends itself admirable to evasion by purchase outside the jurisdiction, therefore need not be examined further.

Taxes related to the place of usage would vary in different parts of the city according to the level of congestion in a given area. As Roth describes the general concept, there would be different zones, possibly concentric to the Central Business District, which would be identified by different colours. "Thus there would be high-priced 'red' zones in the most congested areas and lower priced 'blue' zones in the less congested ones" ...etc. "It might also be desirable to vary the charges in accordance with the time of day; for example, a zone could be 'red' during the peak traffic hours, 'blue' during the rest of the day, and completely free at night". 11

11 Roth (1967) p 48
(5) One suggested way of administering a zonal charge would be through a "poll tax" on all employees in a zone. It has two positive characteristics; that it would be relatively easy to administer, and that revenue would be generated. Aside from that it is entirely unrelated to road use by time, distance or route. Being thus, it would not serve as a pricing mechanism at all. It is inequitable and altogether rather distasteful.

(6) An improvement over the poll tax is the daily licence to enter a zone. Such a licence would be purchased by the day, or in "books", and daily affixed to the windshield when the intent is to enter a congested zone. Different classes of vehicles would require different permits. The system of licences would, it seems, satisfy most of the high and low-order efficiency criteria; it is administratively feasible and would generate revenue. The Smeed Committee concluded that if and when a pricing system is implemented, the licencing system would probably be the first to be attempted.

The system does exhibit two distinct drawbacks. A problem would arise in the determination of boundaries, and the concern arising from very short trips which cross the boundary. In some cities the boundary problem might be very great, but in Vancouver, which already has some natural boundaries the system might work very well. The second problem concerns enforcement, particularly for through travellers not intending to stop in the zone where the tag authenticity could not be established at a glance. Evasion, as Beesley points out, would be dependent on the severity of the penalties for breach and on the degree to which the system is

---

12 Such a system is used effectively to pay for use of ski lifts and tows. The tags are colour-coded for each day and for the type of lift they are issued for.
regarded as "fair", i.e., is self-enforcing.\textsuperscript{13} The licencing system has one distinct advantage over most others in that it applies to all traffic, not only commuting, but also through traffic, occasional visitors and tourists.

(7) Whereas off-street parking charges, as discussed in Chapter II, do not readily lend themselves to road pricing, on-street parking charges should very definitely be considered in a road pricing scheme. One parked vehicle, for example, can for 10 or 20 cents an hour effectively reduce the capacity of a three lane street by one third, or conversely raise the congestion level by 50 percent. Also it has been found that where street parking is permitted, there is a marked increase in accidents.\textsuperscript{14}

In Thomson's "Evaluation of Two Proposals for Traffic Restraint in Central London" he considers the relative effectiveness of the daily licence and a parking charge. He estimates the optimum charge in both cases to be 9d. (\(=\frac{9}{10}\)) per hour or 6s. (\(=\frac{72}{10}\)) per day but his conclusions show that the net benefit from a daily licence - "at least £ 6-7 million a year" - is twice that arising from a parking tax.\textsuperscript{15} Table 5.3 on the next page, reproduced from Thomson's paper, shows the effects that each of the two proposals would have, compared to the present situation.

Thus it appears that, of these two systems, the daily licencing offers a far greater chance of success than parking taxes would unless, as Welsby observes, the latter were raised "to a punitive level, and this is a proposition which the majority of economists reject".\textsuperscript{16}

\textsuperscript{13} Beesley (1967) p 423
\textsuperscript{14} Selburn (1967)
\textsuperscript{15} Thomson (1967)
\textsuperscript{16} J.K. Welsby, Comments to Thomson's (1967) paper
Table 5.3 (source: Thomson 1967)

Comparative effects of daily licence and parking tax
(Average effects on main survey roads of Central London.)

<table>
<thead>
<tr>
<th></th>
<th>Peak hours</th>
<th>Off-peak hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without restraint</td>
<td>With 6s. daily licence</td>
</tr>
<tr>
<td>Flow (veh/hr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars</td>
<td>1,201</td>
<td>633</td>
</tr>
<tr>
<td>Taxis</td>
<td>208</td>
<td>298</td>
</tr>
<tr>
<td>Cycles</td>
<td>432</td>
<td>261</td>
</tr>
<tr>
<td>Commercial vehicles</td>
<td>369</td>
<td>418</td>
</tr>
<tr>
<td>Buses</td>
<td>139</td>
<td>193</td>
</tr>
<tr>
<td>Total</td>
<td>2,349</td>
<td>1,803</td>
</tr>
<tr>
<td>Total p.c.u.'s/hr</td>
<td>2,522</td>
<td>2,225</td>
</tr>
<tr>
<td>Average speed (miles/hr)</td>
<td>9-1</td>
<td>11-4</td>
</tr>
<tr>
<td>Net benefits per mile-hr (d.)</td>
<td></td>
<td>11,434</td>
</tr>
</tbody>
</table>

(8) A differential fuel tax functions similarly to a straight fuel tax (ie. it is not an allocative mechanism at all) except that there would be a difference in rates between urban and rural users. The system would be ineffective because it would promote "fuel-fetching" trips to low-priced areas.¹⁷ Thus this alternative is dismissed.

Several direct systems of charging have been proposed. These usually involve rather sophisticated sensing and transmitting equipment. The principle is this: that a transducer senses the passing or presence of a vehicle and the charges are recorded either on a vehicle mounted meter or a centralized computer. The Smeed committee, rather unnecessarily it seems, got caught up in all sorts of various gadgets of this type.

¹⁷ see Hedges (1969) p 23
(9,10) Charges registered off-vehicle requires some sort of vehicle identification which is picked up and recorded by some master sensing or tracing system, and the motorist is billed on a regular basis. The simplest would be a toll-type sensing point, which would double as a normal toll gate for motorists who are not "tuned in". It suffers from the same problem of zoned boundary determination as the daily licence system, plus the costs of operating the tolls, plus the congestion causing propensity of toll-gates. The second, which has been suggested by Hedges, is the PULSE (Public Urban Locator System) which works on a triangulation principle to follow the movement of vehicles wherever they go in the urban area. The objection to PULSE is self-evident.

The question of visibility arises in most of these proposals. As theorized earlier, there must be some personal involvement in paying if the system is to function. However, large fluorescent signs and flashing lights screaming, "YOU ARE NOW ENTERING RED ZONE" might well distract the driver from his other responsibilities. The same may be true for a taxi-type meter ticking away in the car.

(11,12) The fixed charge to enter a zone registered on a vehicle meter has the same advantages and disadvantages of a daily licence, and it could not be implemented gradually - thus would require a massive initial investment. The method most often proposed consists of electrical coils imbedded in the pavement or mounted at roadside. The magnetic field actuates a transducer in the vehicle which, much like a taxi meter ticks

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18 Hedges (1969) p 20
19 The benefits through crime abatement however might be enormous.
off the charge to enter the zone. The same principle works for meters that are connected to a clock, which was actuated upon entry and stopped upon exit from a zone. However, should the motorist depart from a zone undetected the meter would keep ticking. The advantage to a time-related metering system would be that charging for parking is possible, thus it would deter long-term parkers from entering. The time-related system might encourage excessive speeds in the "red" zones...etc.

These are all long-term proposals that could be investigated after a small scale licencing system has been employed experimentally and found administratively feasible and socially acceptable. It would certainly be unrealistic at the present time to consider a system that would require millions of dollars to implement when there are so many factors relating to human (and political) behaviour about which we know very little.

(13) The final method, point pricing, is one that could be made to approximate most closely pricing at marginal cost. It would have characteristics of time variability (by the number of coils actuated), space variability to the micro-level of differences between streets and blocks, and vehicle variability. This method could, in other words be a very sensitive and powerful instrument if road pricing were adopted. It would satisfy both the high and low-order operational requirements; it would generate revenue; it appears to be both technically and administratively feasible. It would not lead to what was defined earlier as an "equitable" distribution.

20 Charge made as the vehicle passes a specific point.
The Strategy of "Second Best"

Finally, one more strategy should be mentioned. If, instead of increasing the price of roadspace to private motorists to the marginal social cost, an alternative would be to grant equal subsidy to transit users. In this way a person trip by automobile would ideally incur the same social cost as a person trip by transit. By such a second-best approach there would exist a balance between the resources expended in the two modes of travel, but the transportation industry, if it were still as a whole priced below marginal cost, would tend to draw more than the optimum of resources. That is, there would still be an imbalance between the resources devoted to transportation, and that devoted to other social goods and services.

The second best approach would therefore not produce the optimum allocation of resources but it would probably lead to more efficient utilization of existing roadways so in the long run there might be a net social benefit.

And indeed other mechanisms (such as exclusion in certain areas of the city) could be applied to achieve a close approximation to the optimum social efficiency. Such an approach would rank high in distributional efficiency in the sense suggested by Wilson et al. since the lower income group would form a major portion of the beneficiaries. The "subsidy" would not necessarily have to be in the form of reduced fares; indeed it could take the form of increased frequency, better areal coverage, etc. The authors of Latent Demand for Urban Transportation indicate four identifiable groups to which such a subsidy would serve especially well in

21 Wilson, Bayliss, Blackburn and Huchinson (1971)
22 Transportation Research Institute (1968)
achieving distributional efficiency. They are (1) the poor, (2) the elderly, (3) the handicapped, and (4) the young. The net benefit to those groups (in terms of utility) would be very important.

The second best solution could well complement any of the other pricing schemes discussed above. It need not be exclusive. The recent proposals of the Greater Vancouver Regional District for improved transit service represents a very real move in this direction and indicates that this direction is probably politically acceptable at the present. 23,24

This strategy, of all those discussed is the only one which appears to meet the social goal of unimpeded accessibility to opportunities in the urban area. The question of meeting any or all of the social goals have not been included in this section for reasons stated earlier. Some of these considerations will be taken up in the final chapter. For the sake of the discussion it will be assumed that a viable system could be implemented. Point pricing probably comes closest to the ideal marginal cost pricing of any discussed so far, and the second best approach probably comes closest to the optimum in satisfying the goal of equity.

23 G.V.R.D. (1971)
24 The political feasibility is also evidenced in a recent proposal by the U.S. Transportation Secretary, John Volpe, to make 20% of the $5 billion/year Highway Trust Fund available for subsidizing rapid transit. (Time, March 3, 1972 p 49)
While worthy arguments have been advanced by many writers expressing favour for road pricing proposals, there have also been raised some very fundamental objections and reservations. Both the positive and the negative aspects have been touched upon from time to time throughout the paper, but the final assessment has been left to this chapter. The following is therefore both the summary and conjunction of the components of the preceding chapters.

The question of paramount importance in this thesis, is, of course, whether adoption of deliberate pricing policies will achieve the objectives described at the outset in Chapter I.\(^1\) The second question is: If pricing does not achieve the stated objectives, what are the limitations and the compromises? And finally, as with any change, pricing policies would likely produce both anticipated and unexpected side effects - some desirable, some otherwise. What are these effects likely to be?

Objective Achievement

To reiterate, the three aspects of "social efficiency" to which road pricing is addressed are:

(1) to achieve a more socially desirable pattern of usage of the existing transportation system

(2) to promote long-run economic efficiency by restraining potential overconsumption (and possible overinvestment) in transportation vis-a-vis other private and public goods and services

(3) to influence the direction of urban growth and the location of urban activities

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\(^1\) See Chapter I, pages 8 to 16.
To those we added three of the more conventional "goals", which might more appropriately be viewed as constraints in the pursuit of social efficiency. These are:

1. to seek to minimize the income redistributive effects.
2. to generate sufficient revenues to cover all operating, maintenance, administrative, and investment costs.
3. to maintain the highest possible level of accessibility for all urban residents.

6.1 The Theoretical Problem

Despite objections to the contrary, the general concept of pricing at marginal cost to achieve efficient resource allocation is sound. The principle is, however, subject to the qualification described in Chapter III: that all sectors of the economy price their goods and services at marginal cost (perfect competition) or in a constant proportion of price/MC (second best). Extending the principle of M.C. pricing to include the non-quantifiables is conceptually above reproach, albeit it difficult to apply in practice.

The next order of objections concern the assumptions involved in relating M.C. pricing specifically to transportation. Here the excessive concentration on "congestion pricing" has obscured the generality of the concept, and has invited criticism on the basis of some very tenuous assumptions (eg. the value of time, the shape of the demand curve, etc.). Because of these and other simplifying assumptions the numerical analysis, at our present stage of knowledge, loses even its illusion of exactitude. Hence, better that we place too little faith in the numbers than too much, and view the analysis as indicative of magnitude (possibly a minimum) rather than an exact estimate.
6.2 Object Achievement

(1) Feasibility

No objectives can be achieved if the operation of the instrument is patently infeasible. Thus the problems of technical and administrative feasibility were explored at some length in the previous chapter; it was concluded that practical road user pricing is within the realm of feasibility. But one question still remains: In an increasingly affluent society will the price mechanism continue to function as a rationing device? Already we observe the traditional tenets of Keynesian economics apparently failing to achieve the desired objectives. Is the price system becoming obsolete as a rationing device? To that there is really only one answer: try it!

If the demand elasticities imputed in Chapter IV are realistic, then the answer would be negative: pricing would be effective in restraining usage. Furthermore, if the "second-best" approach were adopted, the manipulation of demand may in part be exercised by changing variables other than price - such as the transit comfort, frequency, door-to-door service, etc. It might be that in the long-run these qualitative variables can be used to exert more influence than the price mechanism by itself.

(2) Political Acceptability

Turning to the question of political acceptability, it has been the strategy in this paper to refrain from prejudging the political feasibility. Having said that, it is apparent that the political acceptability is in no small measure dependent on the methods by which the proponents promote their ideas, and how the ideas are received by other professionals.
There is for example one class of argument that recurs over and over in the literature. This is the argument that the "motorists pay more than their share, therefore... etc.". One suspects that much of that kind of argument is motivated by interests other than the social welfare.\(^1\) While it is most unlikely that the so-called Highway Lobby in the U.S. will ever embrace the strategy of deliberate road pricing, it is nevertheless important to realize that the "political feasibility" will in no small way depend on the degree of hostility with which the Lobby greets the proposals.

The assertion by some writers that congestion is not a social cost at all is in error, but, for the very reasons that this type of cost is external to the private experience, the urgings of those writers are likely to gain acceptance by the layman. Thus many of the arguments put forth appeal rather to emotion than reason.\(^2\)

"Externalities", being what they by definition are, are outside the range of personal experience. Being so, road pricing would most likely be found implausible and on the whole unacceptable to the public, if the arguments are not put forth in more pragmatic and human terms. The proponents must come down from their dogmatic platforms, even if it means compromising the logical purity of their arguments. In these terms there can be only one rationale for pricing: to restrain the movement of private cars in order to improve the urban living environment - to "rehumanize"

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1 For example: "As of today (1962), highway users are paying, in special motorvehicle taxes, a great deal more than is required to meet the outlays not only for construction but for administration, policing, debt retirement and the like... This matter of transportation - and particularly highway transportation - is far too important a matter to be decided by politics, by uninformed opinions, by intellectual shenanigans, or by anything else except the cold light of fact..." Kermit Rykken, director A.M.A.

2 One might refer to *Traffic in Towns* (1963) p 13: "What (politically acceptable) licencing system could be devised, in a democratic society, which would turn away 75 or 90% of the applicants?" Or St. Clair (1964) p 75: "It seems adding insult to injury first to recognize that time delay is a cost to him, and then to say that he must pay in order to maximize his own benefits..." Or Sharp (1966) p 813: "Imagining the reaction to a change designed to reduce waiting time in doctors' surgeries by removing those who are not prepared to pay as much..."
our central cities. With that as the operational issue, certain moves
toward restraint have already become evident in some Canadian and U.S.
cities. Restraint by increasing CBD parking fees, by making transit
relatively more attractive, or restraint simply by-not providing the
capacity to meet projected demand (eg. Spadina Expressway) are all political
expressions of acceptability of the concept, if not yet of the mechanics of
road pricing.

6.3 Limitations on Objective Achievement

While it thus appears that the conceptual basis of road pricing is
firm, and that it is within the realm of the feasible, we must examine the
more specific issues of contention of road pricing. The first of several
is the question of the distribution of income.

(1) Income Redistribution

In Chapter I it was urged that the distributional aspect be accorded
more emphasis than at present in economic analysis when assessing the
incidence of costs and benefits of transportation infrastructure or policy
changes. Similarly it is important that we consider the redistribution of
income that would take place if road pricing were adopted. Who are the
losers and if we can identify them, can they be compensated?

The pure economic considerations for road pricing as an allocative
mechanism does not require assumptions concerning the distribution of bene­
fits and losses. The efficiency argument makes no pretense to lead to any
sort of "equitable" distribution of income. Thus, as Oort has pointed out,
the question of distribution constitutes the great dilemma of welfare
economics and the main reason for its failure to provide any clear rules
for economic policy. The compensation principle could be applied but unless compensation is actually made, the argument is likely to remain academic. Also the question arises as to the determination of the rate of compensation for a trip not made. Furthermore we simply would not know who to compensate when, almost by definition we do not know who was restrained from making a trip.

Having said that it is equally clear that in order to evaluate the social costs and benefits of a rational pricing system it is not enough to say: Look, we are discriminating against Chevolet owners to the benefit of Cadillac owners! — and reject the proposal a priori.

It is necessary that the entire package of the proposed scheme, including any changes it brings to demand forecasting, revenue generation, mode split and investment criteria, be considered as one alternative with its flow of benefits and costs from year to year, be evaluated vis-a-vis the entire package of today's trends. In other words we need to simulate the impacts of the alternatives, and year by year perform weightings according to marginal utilities of individuals. We must explicitly make interpersonal comparisons of utility in project analysis.

When road prices are increased it has been said that the "tolled-off" will be those that place a higher utility on money than on time. But it is a mistake to analyse the problem only in terms of time and money. We earlier entertained the idea that the disutility of travel is a function of many things of which time and money may be among the least. The correct statement would therefore be "when a marginal cost pricing scheme is implemented, those that place a higher utility on A, B and C than on D, E and F

3 Oort (1967) p 25
4 Zettel and Carll (1968)
will be diverted to another mode". It is clear therefore that a great deal of work in the area of utility theory needs to be done before we can with reasonable accuracy predict the distributional effects.

What positive statements can we make about the distribution of income? There are several items that appear to weaken the charge that transportation pricing would lead to "inequity". The first is perhaps trivial, but should be mentioned. If the present operating equilibrium is in the backward-bending portion of the cost curve, all would gain since the forced-flow portion of the curve represents a higher order inefficiency that should be eliminated. The recent interest in metering traffic onto freeways is designed to achieve exactly that purpose, but instead of paying with money the metered traveller pays with time spent queueing at the entrances. (Indeed the queueing at the Lions' Gate Bridge entrance, without conscious design, achieves the same purpose). As demonstrated in the case study, this metering could be accomplished more efficiently through an appropriate price mechanism, with a minimum of income redistributive effects.

The second item is probably more significant. Generally the most expensive urban transportation facilities in our cities are radially oriented to serve the commuter traffic from the suburbs to the CBD. These commuters on the whole are not exactly poverty stricken. Thus the most expensive, and most highly subsidized facilities, are being built to serve the already affluent. A.G. Wilson in a recent paper to the O.E.C.D. asks us to consider the "fairness" of a system that funnels vast social resources into the construction of freeways and bridges designed to carry the upper-

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5 Discussed by Johnson (1964) p 142-143
6 Nowlan estimates that the user charges on the now dormant Allen (nee Spadina) Expressway would have had to be $4.76 per peak-hour trip to cover all operating, maintenance and financing costs. (D. Nowlan and N. Nowlan, The Bad Trip, Toronto 1970 p 18)
7 Wilson, et.al. 1971
middle class commuter from his office in the downtown through, or over the poor neighbourhoods, to his desirable place in suburbia.

If therefore the income distribution that would result from road pricing policies is considered vis-a-vis that resulting from other long-term policies, especially the status quo, the "inequity argument" may be more imagined than real. The true distribution would, of course, depend heavily on the disposal of the revenue derived from pricing. Some of the alternative proposals for use of the revenue will be mentioned later in this chapter and the distribution effects will become evident.

One group that would unquestionably benefit are the current users of public transit. With less congestion in the streets transit travel would be faster and with fewer congestion-enforced stops. More buses would be required to accommodate the newly "persuaded" users; thus more frequent schedule and possibly with better area coverage would likely result. Perhaps, as Altshuler has suggested, with improved surface transportation, it would no longer be necessary to invest in vastly expensive underground rail rapid transit systems.8

(2) Revenue Generation

Because the revenue generation function has always been the primary objective of road user taxation, it is difficult to avoid the question of financing if the emphasis were switched from the revenue function to the rationing function. Whether this switch amounts to "fiscal irresponsibility" as Zettel and Carll9 have charged is not clear. This charge is based on the claim that the 'production' of highway transportation is

8 Altshuler (1969)
9 Zettel, Carll (1965)
characterized by a declining average cost curve; therefore pricing at marginal cost would result in a net loss. (See Chapter III, Figure 3.5)

It was demonstrated in that chapter that in a situation of continuously growing demand, the loss situation is a short run phenomenon; in the long run the loss or profit would depend entirely on the policies for reinvestment.

But, aside from the theoretical economic considerations the charges of financial ignorance seem ill advised. Several transport economists have made estimates of the potential revenue generation from road pricing. Roth, for example, estimates that an average annual surplus of £500 million over present road expenditures would be generated if congestion pricing were universally adopted in the U.K. If such estimates are indicative of the magnitude to be expected, then the concern over revenue generation for financing purposes appears unfounded. Indeed, concern might better be directed toward the potential use (or misuse) of the "excess" revenue.

(3) Use of the Revenue

The economic criterion for efficiency tells nothing about the "best" use of the revenue. But, obviously if the revenue were put to some low social use the benefits from road pricing would be illusory. On the other hand, the problem of achieving the maximum possible benefit would, it seems, be constrained only by the effort to compensate the losers in the scheme.

10 Roth (1967) p 87
Thus, assuming that the moneys are kept within the transportation sector, some of the alternatives are as follows:  

a) The "economic purist" approach - return all directly to the facility - each street, bridge, intersection - which generated the revenue in a one-to-one revenue-to-expenditure ratio. (Possible impact discussed in the next section)

b) A general Highway Fund with no special guiding rule for location and type of investment except as indicated in conventional planning procedures. Thus, for example, high revenue producing urban streets might be made to subsidize rural roads.

c) A general Transportation Fund in which the private and public transportation facilities are treated as a system and conventional planning principles are maintained.

The above possibilities are mutually exclusive, but any one could be combined with the two following proposals:

d) Adjusting the present user taxes (gasoline taxes, licence fees, etc.) since they do not serve the purpose of rationing at all, and are in fact regressive forms of taxation. The extent to which these non-pricing taxes were kept would be entirely a political decision.

e) Divert part of the revenue to research into, and operational efforts toward, the abatement of noise and air pollution from motor vehicle sources and traffic safety. There would also be great possibilities for experimenting with different technologies of moving people.

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11 There is no economic reason why the revenue should be kept in the transportation sector. In many European countries the revenue from present gasoline taxes is a lucrative source of income for the state,
6.4 The Impact of Road Pricing

Throughout this study the author has urged that road pricing if adopted, should include externalities beyond those of congestion costs alone. It has been emphasized that these are very important inputs into road pricing. But, we must also consider the outputs: the potential impact that road pricing would have - environmental, social and morphological. These are considered briefly in the following.

(1) Environmental Impact

On Noise: A pricing scheme probably would not produce any beneficial reduction in noise level for two reasons. First, overall noise level is related to the noisiest vehicle in the traffic stream, not to the number of noise sources. A reduction in traffic flow would have negligible effect on noise level. (See Figure 6.1)

![Figure 6.1: Relationship of Noise and Traffic Composition on Urban Roads](image)
However, with a pricing scheme there is a premium on finding uncongested streets, traffic would tend to find every residential side street and alley unless precautions were taken. Areas that had previously suffered little noise on their residential streets would find themselves worse off.

On Air Pollution: The benefits that would accrue due to a reduction in exhaust emissions appear to be considerable. There are two reasons for this: First, there would be a decline (or at least a slowdown in the growth) of total traffic volume, hence in the total potential emission. But the second is probably much more significant. With roughly an inverse quadratic relationship between vehicle speed and harmful exhaust emission, there would be a significant decrease in air pollution from motor vehicles if traffic were to move at even slightly higher speeds and if stop-and-go congestion situations were eliminated.

As with noise it is most important that the distributional aspect be considered, to avoid merely spreading the problem over a wider area, especially into residential areas.

A pricing system that would take air pollution costs into account as an input in determining the tax would have to consider the polluting potential of the various vehicles and engine sizes. Hence such a mechanism would provide an incentive to drive smaller, less polluting cars.

Thus it is fairly clear that the potential benefits from the reduction in pollution are large if the pricing mechanism were used with sensitivity.

12 See discussion in Chapter III
13 Since smaller cars also possess the obvious characteristic of contributing less to congestion, the advantages of such tax differentials are difficult to ignore.
On Visual Intrusion: With an effective pricing system there would be fewer automobiles moving and being stored. Hence there might in the future be a significant relative reduction in the land area appropriated for automobile uses; more land could be made available for other, more socially desirable purposes.

(2) Social Impact

The direct social impact is not likely to be of great consequence. But, if the restraint of urban traffic were to act as a catalyst to promote the formation of more street shopping malls, more neighbourhood pubs, and the like, it is not improbable that pricing might have a contributory effect. This, of course, is highly speculative.

Of a less speculative nature are the long-run social effects. These are likely to be very significant. By seeking to contain traffic instead of accommodating it we may avoid some of the disastrous effects that freeway construction in the past has wrought in slicing up urban neighbourhoods, dislocating residents and promoting the growth of slums. These effects are well documented, yet we have proceeded blindly, placidly maintaining the status quo with its built-in biases and social imbalances. If road pricing can contribute to avoiding these social costs much would be gained.

The final social effect: If pricing policies were to effect a decline in accident rates, there might be a few more of us around in future years.

(3) Impact on the Urban Structure

As stated in Chapter IV the possible long-term consequences of road pricing depend not only on the pricing policies themselves but also on the specific investment policies. This in turn relates very much to the uses
and disposal of the funds collected through pricing and other means of taxation.

The following will discuss the potential long-run impact under only one pricing and investment combination - one which this writer considers the most suitable for achieving most of the objectives. This might be termed the "planning" approach (in contrast to the laissez-faire approach). This simply implies that we cannot completely rely on the concept of consumer sovereignty, which, as others have demonstrated does not always produce the most socially desirable results. The "planning" approach furthermore implies that pricing and investment policies are not fixed in an inflexible pattern of dogmatism, but remains adaptable to meet changing goals and objectives.

One could, of course, examine any number of combinations of taxation and investment policies but since the potential impact can be examined here only in broad generalities, the proposed alternative will serve as an illustrative example. This writer does not believe that the adoption of the pure economic rules for pricing and investment would lead to a socially desirable solution. The rule implies that the short run optimal pricing (ie. price = marginal cost) will also produce the optimum solution in the long-run, if all revenue is reinvested where it was generated. The cost-benefit criterion would therefore be replaced by a revenue-cost criterion. There are three objections to this.

a) The revenue-cost approach would, even more than present policies, tend to compartmentalize the transportation system at a time when there is every indication of need to integrate, not segregate the components.
b) Until and unless the price were made to accurately reflect the full social cost, the demand, the revenue, and the investment would a priori be distorted. It seems highly unlikely that, at least in the next few years, we will be able to accurately evaluate all the elements of social cost.

c) One further comment about the revenue-cost criterion: If the estimates of the revenue generating potential are realistic, then there would be very powerful forces in play to ensure that these are invested where they are generated. The result would be gross over-investment in urban areas and under-investment in rural areas. Large amounts of money channelled directly into road-building where the congestion is greatest (ie, the central cities) would lead to massive construction of urban freeways in and around the CBD, until the CBD finally disappears in a Los Angeles type of amorphous urban area.

It is this writer's conclusion that reinvestment must be tempered with more moderate, and certainly more deliberate policies in a planning sense. What then would be the morphological impact under such a system? The fundamental purpose of road pricing is to make the motorist aware of and accountable for the social costs he incurs. There would no doubt be an increase in the cost of private travel in the city, and this would result in an alteration in both the absolute demand for travel and the relative demand is the basis for all projections of future demand and hence the supply of transportation. We could, with a workable pricing system, expect a different pattern in both kind and quantity of transportation facilities to be built in the future. This change in pattern of investment would have

14 See discussion of Roth's estimates page 110.
a far greater impact on the urban spatial structure than the pricing itself. Thus for example, if a rail rapid transit system were built in various corridors throughout the urvan region, the impact is likely to be vastly different from the building of freeways.

But the question most often asked is whether road pricing, on the whole, would be a centralizing, decentralizing, or a preservative force. The answer is that without the aid of sophisticated urban simulations, we simply do not know. We can apply such relatively broad generalizing models as those of Wingo\textsuperscript{15} and Alonso,\textsuperscript{16} (Figure 6.2) and these would suggest a levelling of the density gradient from the city centre outward.

\textbf{Figure 6.2}

\textit{THEORETICAL RELATIONSHIP BETWEEN TRANSPORTATION COSTS AND LAND USE}

\textsuperscript{15} Wingo (1961)
\textsuperscript{16} Alonso (1964)
There might, according to the model be a higher intensity of land use on the whole. We could predict a relocation of some types of activities. Warehouses, for example, which generate much truck traffic would probably find it advantageous to relocate in less expensive transport areas.

But until operating simulation models are in use, we simply cannot predict the long-term effects. But, as emphasized at the outset of this study, we really don't know the long-term effects of any other alternatives, and the pricing approach is one that does not foreclose any options. If we find through experimentation that we are not heading in the right direction, or if our values and needs change, it is not impossible to take a step back and try another approach. This, when all else is said is the most compelling argument for adoption of a road pricing scheme.

6.5 General Conclusions

It has been the stated purpose of this thesis to examine the potential for use of transportation pricing control as a practical tool of planning. The intent of such policies would be to effect change in the patterns of urban transportation demand in the pursuit of certain social objectives. The study in the foregoing chapters has therefore examined the tool of pricing control from various angles such as the theoretical basis for pricing policies, the practical problems in determining price levels, the technical and administrative problems in implementation, and the potential impacts - loosely fitted in the framework of the planning process model described in the Introduction.

In retrospect there appears to be two major conclusions of the study. The first relates directly to the stated purpose of the thesis: evaluation of a tool. It is concluded that the control of urban transportation pricing
does indicate potential for effective application to achieve the objective of more "socially efficient" utilization of resources in both the short-run and long-run. There are, however, drawbacks and limitations to the practical application and it is unlikely to be successful in any but the clearly defined circumstances. But even in situations when direct application is not feasible (politically, technically or administratively) the theory can still serve as a guide to policy-making.

This leads to the second conclusion. In circumstances where direct pricing control is not practicable, the principles embodied in the theory of marginal cost pricing may be used as tools to define specific objectives. In this way the intellectual exercise of the theoretical discussion will contribute to a better understanding of the relevant parameters of urban travel and will assist in the formulation of specific policies.

6.6 Recommendations for Further Research

It is true, as several observers have noted, that the state of transportation pricing in theory and practice is a relatively unsatisfactory partial analysis. But the real question we should be asking is whether it is any more or less partial than present analyses. As stated at the outset to this thesis it is easy to become enraptured with one promising tool that appears to offer distinct advantages. I believe many of the proponents of road pricing have failed to be cognizant of all, or perhaps even most of the ramifications. But, even as I have attempted to examine all aspects of pricing as a tool in transportation planning, the analysis is still partial, simply because of a lack of knowledge of many of the relationships. Thus

17 In the Lions' Gate Corridor case study the specific objective would be to reduce the peak-hour arrival rate by about 740 vehicles per hour by whatever practical means are available. See Chapter IV.
in conclusion I offer several suggestions for further research in areas where the need appears to be the greatest.

First, the utility-theory based mode shift analysis by Quarmby\textsuperscript{18} and by Brown\textsuperscript{19} appears to offer a wealth of contributions. This approach will permit completely unaggregated analysis - i.e., at the individual level. This means that, for each individual, it would be possible to answer (in a probabilistic sense) the questions relating to (1) the value of time, (2) mode shift potential, and (3) the distribution of benefits and costs if a road pricing scheme were implemented.

Second, there is a need to continue research into the effects of the "unquantifiables" and although we may never be able to assign an absolute cost to noise, or air pollution, or visual intrusion, whatever we learn of the effects, the methods of transmission, methods of control, and costs of control will be of great use as a necessary input, not to displace, but to supplement the political input into a transportation pricing scheme.

Third, at the risk of exposing myself to charges of élitism, I suggest that there is a need to research the means of "selling" the concepts of restraint of traffic to society. Most Canadian cities have not reached the stage where they are committed entirely to automobile transportation (as Los Angeles) and other alternatives are not yet closed. If, however steps are not taken in the direction of restraint (by one means or another and pricing offers a very attractive means), we will be "over-consuming" transportation both absolutely and relatively, and the patterns for the future will be set. There is, I believe, a need to explore the social and political feasibility of alternatives and "market" those that appear most likely to be endorsed.

\textsuperscript{18} Quarmby (1966)
\textsuperscript{19} Brown (1971)
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Figure A-1

MAP OF THE CASE STUDY REGION
Figure A-2

PLAN OF THE CASE STUDY CORRIDOR
APPENDIX II  THE THEORY OF ROAD PRICING

The Supply Curve

It is postulated that speed varies inversely with the traffic volume:

\[ v = a - bq \]

where \( v \) = the speed

\( q \) = traffic volume on a specific road or street

\( a \) and \( b \) are constants (determined empirically)

The time cost is inversely proportional to the speed:

\[ t = \frac{d}{v} \]

where \( t \) = time to cover distance \( d \)

The cost due to time loss is:

\[ z = f(v) = f(g(q)) \]

\[ = \frac{k}{a - bq} \]

where \( k \) is a constant

The total cost at any traffic flow \( q \) is:

\[ Z = zq \]

Marginal social cost:\n
\[ MSC = \frac{\partial z}{\partial q} = \frac{\partial (zq)}{\partial q} \]

\[ = z + q \frac{dz}{dq} \]

\[ = z(1 + \frac{q}{z} \frac{dz}{dq}) \]

Or, in Walters' formulation:\n
\[ Marginal \ Social \ Cost = Average \ Cost \ (1 + elasticity \ of \ A.C. \ curve) \]

Thus, if the Average Cost curve is adequately defined, the determination of the Marginal Social Cost Curve is a purely mechanical procedure.

\[ 1 \] Walters (1961)
The Demand Curve

Postulate a demand relationship:

\[ q = h(z) \]

The inverse of the demand curve defines the "marginal valuation curve":

\[ z = h^{-1}(q) \]

The condition for equilibrium of supply and demand is the solution to the two equations:

Supply: \[ z = f[g(q)] = g'(q) \]

Demand: \[ q = h(z) \]

At a traffic flow \( Q \), the net benefit is the total area under the demand curve between zero and \( Q \), minus the total cost:

\[
\text{Net Benefit} = \int_0^Q h^{-1}(q) \, dq - Qg'(Q) \tag{1}
\]

(This assumes the "consumer surplus" criterion)

The Net Benefit is maximized when:

\[
\frac{d(NB)}{dq} = 0 \tag{2}
\]

Differentiating equation (1) with respect to \( q \), it may be demonstrated that the Net Benefit is maximized when, at a new equilibrium level, \( Q' \)

\[
h^{-1}(Q') = g(Q') = Q' \frac{dg'(q)}{dq}
\]

In words, this means that the benefits are maximized when the price is raised above the Average Cost curve by an amount exactly equal to the difference between the Average Cost and the Marginal Cost at \( Q' \).

The optimum tax is therefore:

\[
\text{Tax} = Q' \frac{dg}{dq} = [MC - AC] \text{ at } Q'
\]
APPENDIX III

COMPUTER PROGRAM FOR SIMULATION OF QUEUE FORMATION

$SIGNON JHHH
$RUN *WATFIV 5=*SOURCE* 6=*SINK*
DIMENSION A(60),WPC(60),WSC(60),VPC(60),VSC(60)
READ(5,1) TO,S,A,B,VOFT,AL,K,COA
STORW=0.0
STORC=0.0
STORN=0.0
XSTOR=0.0
I=1
J=1
WRITE (6,2) S, B,VOFT
Q=0.
XDEL=0.
QI=A

6 Q=Q+QI
V=35.0.0*Q/S
CPCCST=((3.30-0.021*V)/VOFT)*2.40/100.
ACCGST=((4.75-0.081*V)/VOFT)*2.40/100.
TOTCP=OPCCST*Q
TCTAC=ACCGST*C
DELAY=(2.4C/(35.0.0-0.9*Q/S))
XPT=DELAY*60.0
XPC=DELAY*VOFT
DEL TOT=DELAY*Q
DEL MARG=(CELTOT-XCEL)/QI
XST=DEL MARG*60.0
XSC=DEL MARG*VOFT
XTAX=XSC-XPC
COST=DEL TOT+TCTCP+TCTAC
XM=(COST-XSTOR)/QI
ZPC=(DELAY+ACCGST*OPCCST)*VOFT
ZSC=XPC*VOFT
ZTAX=XSC-ZPC
XSTOR=COST
TOTVEH=Q*TC
XDEL=DEL TOT
WRITE(6,7)Q,
VPC(J)=ZPC
VSC(J)=ZSC
AR(J)=Q
J=J+1
IF (Q.LT.5) GO TO 6
TIM=0.0

5 A=A+AI
DELT=0.075
TIM=TIM+CELT
XN=(A-S)*TIM
TT=XN/(S-B)
TTCT=TIM+TT
TOTN=S*TTCT
DELN=XN-STORN
WMAX=XN/S
XWAVG=WMAX*60.0
WAVG=WMAX/2.0
XWAVG=WAVG*60.0

CONT'D
Figure A.3 (CONT'D)

WTCT=TCTA*WAVG
WMARG=(WTOT-STCRW)/DE LN
PT=(WAVG*60.0)+XPT
PC=(WAVG*VQFT)+XPC
ST=(WMARG*60.0)+XST
SC=(WMARG*VQFT)+XSC
TAX=SC-PC
C=WAVG*COA
CAVG=(WAVG*COA/VQFT+WAVG)
CTOT=CAVG*TOTN
CMARG=(CTOT-STORC)/CELN
YPC=CAVG*VQFT+ZPC
YSC=CMARG*VQFT+ZSC
YTA =YSC-YPC
STORC=CTOT
STORN=XN
STCRW=WTOT
WRITE (6,3)A,TCT,CTN,XWMAX,XWAVG,WTOT,WMARG,PT,ST,PC,SC,TAX,YP

CC,YSC, YTA 
VPC(J)=YPC
VSC(J)=YSC
AR(J)=A
I=I+1
J=J+1

IF(I.LT.K)GO TO 5
WRITE (6,4) S

4 FORMAT(1H1,F6.0)
1 FORMAT(F4.2/F5.0/F5.0/F5.0/F4.2/F3.0/I3/F4.2)
7 FORMAT(1X,F5.0,'VEH/HOUR',56X,2F5.1,'MIN',F3.6.2,'$',3F6.2)
2 FORMAT(1H1,'ASSUMED CONSTANT ARRIVAL RATE A1 DURING QUEUE FORMATIO'
'N,CN,CONSTANT SERVICE RATE S:',12X,'ARRIVAL RATE DURING QUEUE C DISSIPATION',12X,'SERVICE RATE = ',F5.0,'VPH','ARRIVAL RATE A2 = ',F5.0,'VPH','VALUE OF TIME V = ',F4.2,'$/HOUR',12X,'TIME,OPER,ACCID COSTS','ARRIVAL RATE QU DURATION CTCTAL NUMBER',2X,'WMAX WAVG',5X,'WTOT',5X,'WMARG PT TT',8X,'CPC1 MC1 SC1 PC2 MC2 SC2'/28X,'QUEUED!/
3 FORMAT(1X,F5.0,'VEH/HOUR',2X,F5.3,'HR',F5.0,'VEHICLES',F5.1,F5.1 C,'MIN',F8.3,'HR',F8.3,'HR',2F5.1,'MIN $',3F6.2,'$',3F6.2)
STOP
END
Table A.1

QUEUEING SIMULATION MODEL - PRINTOUT
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<tr>
<th>ARRIVAL RATE</th>
<th>QUEUE DURATION</th>
<th>TOTAL NUMBER QUEUED</th>
<th>MAX VEHICLES</th>
<th>AVG VEHICLES</th>
<th>WTOT VEHICLES</th>
<th>WMARG VEHICLES</th>
<th>PT</th>
<th>TT</th>
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<th>TIME OPER ACCID COSTS</th>
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<tr>
<td>4900 VEH/HOUR</td>
<td>8.9 8.9MIN</td>
<td>$0.14 0.14 0.00</td>
<td>$0.27 0.27 0.00</td>
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<tr>
<td>5000 VEH/HOUR</td>
<td>9.0 9.0MIN</td>
<td>$0.14 0.14 0.00</td>
<td>$0.27 0.27 0.00</td>
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</tbody>
</table>

**SERVICE RATE = 3400 VEH/HOUR**
**ARRIVAL RATE A2 = 2500 VEH/HOUR**
**VALUE OF TIME V = 1.65$/HOUR**

**ASSUMED CONSTANT ARRIVAL RATE A1 DURING QUEUE FORMATION, CONSTANT SERVICE RATE S**
**CONSTANT ARRIVAL RATE DURING QUEUE DISSIPATION**