Modelling the Effects of Transport Policies and Pricing Strategies for Melbourne

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ABSTRACT

A study of Melbourne has been made using the TOPAZ planning model to examine the impacts of various policies for public and private transport. Impacts include resulting pollution levels, average trip times and lengths, establishment and interaction costs, modal split and accessibility. In addition, a consumer-surplus approach based on travel opportunities is applied to give a measure of benefits to be obtained from improved performance of the public transport system. These benefits are compared with estimates of investment costs required to improve public transportation to the levels defined.

INTRODUCTION

The current reaction against the dominance of the motor car in major urban centres around the world focuses attention on alternative modes of transport and possible changes in urban life styles and spatial layout. To predict the eventual outcome of these and other changes is a hazardous business since the path of mankind through history is strewn with false predictions.

However, we must plan for the future in spite of the uncertainties. Since the future cannot be predicted reliably, an alternative approach is to paint a series of different futures based partly on the extrapolation of present trends and partly on conjectured future events. In the case of urban transport, the latter include changes in pricing and investment policies.

Transport decisions are continuously being made in the community at all levels, both in the public and private sectors. At each level, data or opinions or both are collected and analysed. From these, plans are formulated and actions are taken. This process may vary greatly in depth and detail from the level of an individual to that of a government department.

Models are used in decision-making processes to aid in the analysis, formulation and evaluation of plans. Models may be qualitative or quantitative, simple (e.g. mental models) or complex, and evaluated by mental, manual or computer techniques. One major advantage of a model is that it can be made to incorporate a wider body of accumulated knowledge and experience than that of its user and hence it may be possible to explore a wider range of alternatives and evaluate consequences better and faster than otherwise. The speed of evaluation of alternatives may be greatly enhanced if the model is evaluated by computer in cases where complex calculations are involved. A disadvantage of a model, especially in the case of a complex model, is that the user is often remote from the model building process and hence is unfamiliar with many of the assumptions and data built into the model.

Urban planning and transportation models have not fared well in decision-making largely because the theories on which they are based are continuously evolving, and the data used are imperfect. Yet, the demands of our urbanised society require that ever growing volumes of data and information be processed and synthesized into plans of action, which, given constraints on manpower, increasingly require the use of computerized models.

The TOPAZ urban planning model has been developed as one aid for this purpose and is capable, amongst other things, of examining the interaction between land use and transportation. In this paper, the TOPAZ model is used to examine a number of broad strategies for improving the transport system for Melbourne.

TOPAZ PLANNING MODEL

The TOPAZ model is only briefly described here as more detailed accounts are documented elsewhere (Brotchie 1969 Sharpe and Brotchie 1972; and Sharpe, Brotchie, Ahern and Dickey 1974).

TOPAZ (Technique for Optimal Placement of Activities in Zones), optimally allocates land use activities to a prescribed set of spatial zones and time periods on the basis of maximum benefits less costs. Two distinct sets of benefits and costs are considered, namely

(1) (a) the benefits of absolute location of the activity including the suitability of the environment, less

(b) the costs of accommodating the activity in this location including the costs of construction and operation of built facilities, streets, supply of gas, electricity and water, removal of solid and liquid wastes, and provision of schools, hospitals, and so on; and

(2) (a) the benefits of relative location, i.e. of interaction including transport and communication, and opportunities of access thereby to work, schools, shops, recreation and entertainment, one measure of which is accessibility, another being later given by a consumer surplus approach, less

(b) the costs of relative location including communication, transportation and pollution costs.

Sub-models calculate the effects of transportation, network services, air pollution and accessibility and in calculating relevant benefits and costs apply a discount rate to future transactions. A doubly constrained gravity sub-model (Arrowsmith, 1973) is used to distribute journey to work, residential, industrial and commercial trips separately by two modes of transport, public and private. Modal split is based on a weighted sum of the trip cost and the time taken by each mode (Davis, 1974). An air pollution sub-model is used to calculate the diffusion of vehicle emissions over the urban area (Pooler, 1961; and Fisher and Fisher, 1972).

Information input includes:

(i) existing activities, and their locations,
(ii) future activities and their growth with time,
(iii) zone sizes and locations,
(iv) time periods,
(v) travel times between zones, and
(vi) unit benefits and costs.

The information compiled and presented by the model includes:

(i) optimal activity locations and times of development,

(ii) traffic flows, modal split, pollution levels, accessibilities, and land values,
(iii) total benefits and costs of absolute location,
(iv) total costs of interactions,
(v) average travel times and distances,
(vi) the distribution of the above by activity and by zone and time period, and
(vii) plots of these activity distributions, air pollution and accessibility where required.

The information above may be provided for different plans, providing a basis for comparison and choice between them.

STUDY OF TRANSPORT POLICIES FOR MELBOURNE

The aim of this study is to investigate for Melbourne some of the possible consequences of policy changes in public transport fare structures and trip times, fuel costs, vehicle occupancy, density of development and population growth rate. The exercise is similar to an independent one made for Canberra (Rockliffe and Paterson, 1975) except that the interaction between land use distribution and transportation over time is taken into account in each case. In other words, new residential, industrial and commercial activity is permitted to redistribute spatially through time as a result of each policy change, in addition to a redistribution of traffic flows between these activities.

A further aim of the study is to provide information in a form that is conducive to public participation in urban and transport planning processes.

Data Input

The following is a summary of the data and assumptions used in the study.

Planning period:	30 years divided into 3x10 year time periods - 1970-80, 1980-90, 1990-2000.	
Population:	1970	2.4 million
	1980	3.0 million
	1985	3.4 million (42% increase)
	1990	3.7 million
	2000	4.5 million (87% increase)

Average gross density of new residential development = 25 people per ha.
Average gross density increase for residential redevelopment = 75 people per ha.
Average gross density of new industrial and commercial development = 50 workers per ha.
The Melbourne area is divided into 41 zones based largely on Local Government Area (L.G.A.) boundaries.

Trip generation rates, trip distances and times for public and private transport and friction factors have been obtained from the 1964 Melbourne Transportation Study (1969), and are assumed to remain constant except where otherwise noted, and 1970 unit trip costs have been used. The disutility modal split data are similar to data derived from the Sydney Area Transportation Study (Davis, 1974) with adjustments to reproduce the existing modal split for Melbourne at 1964.

Percent using public transport in zone j = $\sum_l (T_{jl} P_{jl}) / \sum T_{jl}$

where: T_{j1} = total number of trips made from jone j to zone 1,

P_{j1} = percent using public transport for trips from zone j to zone 1,

= $100/(1.2 + \exp\{2d_{j1}\})$,

d_{j1} = public less private trip fare + w. (public less private trip time) (all expressed in $), and

w = 20% of average wage rate at 1970

= $0.60 per hour.

Air pollution emission and diffusion data have been taken from Fisher and Fisher (1972).

The unit costs of establishing each activity in each zone include water, sewerage, drainage, electricity, telephone, gas, streets, schools, and are based on 1970 data collected in an earlier project (Sharpe and Brotchie, 1972).

The criterion or objective used was to minimise the total sum (over three time periods) of all interaction costs for journey to work, residential, industrial and commercial trips together with the total sum of all establishment costs. This objective is equivalent to maximising the total sum of negative costs.

Results

A series of 10 model runs was made to test the impact of various strategies against a base solution for 1985 with development following existing trends. The results of these tests are summarized in Table 1 in terms of percentage changes from the 1985 expected trend values for the following consequences or impacts:

Av. estab. cost	=	the average total cost of establishing residential, industrial and commercial activity per resident.
Av. per cap. interac. cost	=	the average total cost of all trips per resident per year.
Av. trip time	=	the average time for all trips per resident per trip.
Av. veh. travel dist. per day	=	the average total vehicle kilometres generated each day for all trips in the urban area.
Total vehicle air pollution emissions	=	the average total vehicle emissions each day (assuming 1970 emission controls) of carbon monoxide (CO) for all trips in the urban area.
Max. av. air pollution at CBD	=	the average annual daily air pollution level in the vicinity of the Central Business District resulting from vehicle carbon monoxide emissions.
Av. % using pub. transport	=	average percentage of journey to work and residential trips made by public transport.
Av. resid. access.	=	average level of residential accessibility by both modes of transport, and calculated by summing for each zone the number of residents divided by the trip time to each other zone, and then averaging:

$$= \sum_{jl} (Pop_j \times Pop_l / t_{jl}) \; / \; \sum_j Pop_j$$

where Pop_j = residential population in zone j, and

t_{jl} = trip time from zone j to zone l.

Accessibility provides a good measure of benefit for social interaction, access to jobs, goods and services, access of industry to markets and other industry. Increases in accessibility can lead to economies of scale, increased specialization and diversity of jobs and culture. The above definition would, of course, have to be given in terms of trip type to compare such benefits.

Comparison of Results (Table 1)

The results give impact parameter values at the mid-point of the second time period, 1980-90, with a long term planning objective that optimizes activity distributions over the three time periods simultaneously with feedback between time periods. The first solution uses the "expected" trends data defined above with little or no redevelopment considered. An alternative to simultaneous optimization over the three time periods is to consider a short term planning objective of sequential optimization over the planning periods without feedback between the periods. This alternative has been treated elsewhere (Sharpe, Brotchie, Ahern and Dickey, 1974). A further alternative would be an evaluation of a prepared 1985 plan without optimization if one were available.

1985 Base Solution - Figure 1 shows the base solution in terms of spatial distribution of activities, and Figure 2 shows air pollution contours for this base solution. Both are plotted using the SYMAP computer graphics package developed at Harvard University.

1970 Situation - This gives a comparison of the existing conditions at the base year with the 1985 solution and shows the following:

1. Establishment costs rise by about 9% between 1970 and 1985, possibly because new development will be forced into areas which are more difficult to service.
2. Slight improvement in interaction cost and trip time at 1985.
3. A significant increase in total travel distance and vehicle emissions at 1985. However, the latter should be reduced by planned vehicle emission controls. Figure 3 shows 1970 air pollution levels for comparison with the 1985 solution (Fig.2).
4. The percent using public transport at 1985 shows a slight decrease over the 1970 figure, if public transport improvements are not made.
5. Residential accessibility levels rise significantly over the 1970-85 period, assuming present trip times can be maintained.

This solution can be also be taken as a no growth solution at 1985.

Increase in Vehicle Occupancy - An increase from the current private vehicle occupancy rate of about 1.45 people per car to 2.0 produces significant benefits in relation to travel costs, trip time, and air pollution, but decreases the use of public transport. Secondary benefits such as the increase in speed of private and some forms of public transport due to decreased congestion on the roads are not taken into account.

Incentives for increasing vehicle occupancy include car pooling, concessions on parking, access to congested areas, priority lanes on freeways, and rising fuel maintenance, vehicle and insurance costs.

Free Public Transport - Making public transport free increases the use of this service and decreases air pollution. Per capita interaction costs are not substantially reduced (assuming that the community must still bear the public transport operating costs). Average journey times increase, which results in a decrease in the average level of residential accessibility. However, reduction in congestion on the roads may allow shorter trip times which are not considered here. Savings in fare collection and economies of scale arising from increased public transport patronage are also not included.

Fixed Public Transport Fare - This assumes a $0.20 fare for all public transport trips and is similar to the previous solution with smaller changes.

Public Transport Trip Times Halved - This is an extreme situation, but it may be approached through improved rolling stock, increased frequency of service, and provision of feeder services from residences to public transport nodes. Allowing congestion to build up on the roads may also make public transport trip times relatively faster. Although significant benefits flow from this solution, the increased capital and operating costs which have not been included would reduce the total level of benefits.

Reduction in Work and Industrial Trips - Improvements in communications technology, automation, and reduction and staggering of work hours may lead to significant reductions in work, industrial and commercial trips. This solution assumes a progressive reduction of trips by 25% at 1985 continuing on to 50% by 2000, with substantial savings in interaction costs and air pollution. Other trips are assumed to remain constant.

Fuel Costs Quadrupled - This solution assumes that a quadrupling of motor fuel prices will raise vehicle operating costs as follows:

	1970	1985	
Journey to work trips	0.10	0.16	$ per km
Residential trips	0.05	0.11	$ per km
Industrial plus commercial trips	0.20	0.30	$ per km

This substantially increases interaction costs and promotes greater use of public transport with benefits of decreased air pollution and fuel consumption, and disbenefits of decreased accessibility and longer trip times.

Double Density of New Outer Development - This assumes that new residential development will be developed at a density of 50 people per ha instead of 25, and produces savings in establishment and interaction costs, and total air pollution. There is also a slight increase in the use of public transport and in residential accessibility.

Inner Area Redevelopment - This assumes that 50% of the population increase will be accommodated in inner area redevelopment, and produces savings in establishment and interaction costs, and total air pollution and trip lengths. However, air pollution at the CBD is increased (although this could be offset by the use of cars using fuels other than petrol) and residential accessibility reduced due to the slower vehicle speeds in inner areas. Modal split is only improved slightly, unless coupled with other public transport improvements.

Population Growth Halved - Halving the growth rate produces benefits all round except in the case of residential accessibility.

Transport Benefits vs Required Investment

In Sharpe, Brotchie, Ahern and Dickey (1974), a consumer surplus economic approach is presented comparing the benefits of transportation alternatives, where, instead of using total trips as a criterion, total opportunities of access within the time radius of a trip are considered. From Figure 4, the benefit of alternative m over alternative n, represented by the shaded area B, is given as

$$B = (C_n - C_m\, O_n/\, O_m)\ (1 + O_m/\, O_n)\ /\ 2,$$

and $C_n = c_n O_n$; $C_m = c_m O_m$

where C_m and C_n denote the total costs, c_m and c_n the unit costs, and O_m and O_n the corresponding number of travel opportunities for plans m and n respectively. From Sharpe, Brotchie, Ahern and Dickey (1974), one may with reasonable accuracy replace O_n by A_nP_n and O_m by A_mP_m, where the A's represent the accessibilities and the P's the populations associated with the two plans. In addition to recognizing the benefits of more or cheaper trips, the measure also gives a premium to faster trips, which imply greater diversity of choice for the community in their work and social activities. In addition, plan alternatives with such high opportunity benefits normally encompass many multi-purpose trips not explicitly handled by current models. Although the approach cannot be strictly included within the framework of normal consumer theory, it seems to make sense intuitively in integrated transportation/land use modelling. The above approach is used to compare the benefits of various alternatives, as well as to relate these benefits to the transport investment required to update the system to the standard defined. This procedure is illustrated by the application to three of the above strategy alternatives. Other results are presented in Table 1.

Increase in Vehicle Occupancy - Using Table 1 and the above formula, we can calculate the benefits of increasing private vehicle occupancy through car pooling to 2.0 compared with the base solution as

$$B = (280 - 280\,\{1 - 0.08\}\{100/101\})\,(1 + 101/100)/2,$$

i.e. $B = \$25$ per cap per year,

noting that $P_m = P_n$ for the two alternatives and C_n = 280 (row 1, column 2, Table 1). The benefits could be greater than those given if the model could take into account the effects of reduced congestion in the private system due to the higher vehicle occupancy rate, but these may be offset by the extra distances travelled at each end of a journey to collect and distribute the car pool members.

Public Transport Trip Times Halved - In the same was as above, the benefits of the corresponding improvements in the public transport system are given as

$$B = (280-280\{1-0.03\}\{100/113\})\ (1 + 113/100)/2,$$

i.e. $B = \$45$ per cap per year.

Thus to equalize net benefit compared with the base case, over $150 million per year could be made available to improve the public transport system such that door to door journey times would be halved (assuming that there is no significant difference in operating costs).

In order to compare this value with the likely required investment, the cost of the new BART system in San Francisco can be examined. The system costs approximately $US20 million per mile. However, if such a system were built on the existing rights of way of the Melbourne electric train network, about $5 million per mile would probably suffice, leading to an investment of close to $1000 million for the 223 mile network. Allowing a further $300 million for special situations and distributing the cost over 20 years, gives $65 million per year investment in 1970 dollars. Allowing a further $15 million per year for developing an efficient feeder bus system (including perhaps dial-a-bus) for outer areas, the total cost comes to $80 million per year, representing about $25 per cap per year, which is only about half of the benefit accrued. Here again, the benefits to private car users of the resulting swing to public transport have not been considered in the benefit figure of \$45 per cap per year. In addition, further benefits such as reduced oil consumption, reduced total energy usage and reduced pollution levels would result from improved public transport.

As an alternative to the above approach, an attempt can be made to evaluate directly the value of the travel time savings. From the TOPAZ results, the total number of daily person trips in 1985 is about 8 million. From Table 1 it is seen that 0.18 (27) = 5 minutes savings per trip on the average could be achieved by the public system improvement. Thus taking the travel over 240 days per year, $8(10^6)(240)(5)/60$ hours travel per year would be saved, i.e. $160(10^6)$ hours per year. The results of several authors seem to confirm that travellers value their travel time at about 20% of their wage rate for in-vehicle time and a considerably higher figure for between mode waiting time. If the average wage rate of travellers is taken as \$3 per hour (in 1970 dollars) and the effect of a reduction in waiting time included in ratio, then the value of time saved is approximately \$1 per hour. Thus the savings per capita per year are $160(10^6)1/(3.5(10^6)) =$ \$45 per capita per year, which coincidentally equals the value obtained by the consumer surplus approach. However, as most of the research performed on the valuation of travel time savings has been confined to the journey to work trip and the above results relate to total daily trips for all purposes, the results should be considered as approximate only. Because of the various assumptions made in the two approaches, results even of the same order of magnitude would have been quite satisfactory.

Reduction in Work and Industrial Trips - Considerable investment in telecommunications could conceivably result in, for example, a 25% proportionate reduction in work and industrial/commercial trips by 1985. From Table 1, the benefits of this reduction are given as

$$B = (280 - 280\{1 - 0.15\}\{100\}/100)\ (1 + 100/100)/2,$$

i.e. $B = \$40$ per cap per year,

implying an annual amount of about $140 million per year (in 1970 dollars) available for telecommunications efforts in Melbourne to equalize the net benefit. Again, this figure should be further increased to allow for the effects of reduced congestion in the private transport system. It remains to approach the telecommunications experts to determine if the annual investment in home-based telecommunications of say between $100-$200 million per year could reduce work and industrial trips by 25% in 1985.

CONCLUSION

The results presented above provide some insight into the complex interactions within an urban system and the impact of certain policy decisions regarding transport and planning. They are just a few examples of studies that can be made using the TOPAZ model at relatively low cost (approximately $20 per run of the CSIRONET Cyber 76 computer). It is not claimed that the predicted results are particularly accurate in absolute form, as growth and behavioural trends, etc., may alter unexpectedly during the forecast period.

However, relative differences between the alternative policies should not change so markedly, and such results could be used by both planners and the public to debate policies to improve urban systems and stimulate discussion of further options for testing before decisions are made.

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Strategy or Assumption	Impact or Consequence								
	Av. Estab.Cost	Av. per cap Interac.Cost	Av. Trip Time	Av. Tot. Veh. Travel Dist. per day	Total vehicle carbon monoxide polln. emission	Max. Av carbon monoxide polln. at CBD	Av. % using Pub.Trans.	Av. Resid. Access	Transport Benefit $/cap/year
1985 base solution a	$8000/cap	$280/cap/year	27 min.	40 x 10^6 km	2070 tonne/day	0.78 ppm	33%	5 x 10^6 people/h	
1985 base solution b	0	0	0	0	0	0	0	0	-
1970 situation	-9	1	1	-35	-34	-19	1	-24	-192
Vehicle Occupancy increased to 2.0	-1	-8	-3	-14	-14	-12	-5	1	25
Free Pub. Transp.	-1	-3	4	-9	-9	-7	7	-5	-5
Fixed $0.20 Pub. Transp. fare	-2	-1	3	-4	-4	-3	3	-2	-3
Pub. Trans. Trip times halved	-1	-3	-18	-10	-10	-9	8	13	45
25% reduction in work and indus. trips by 1985	-2	-15	-3	-13	-14	-16	-1	0	40
Fuel costs quadrupled	-2	60	5	-9	-9	-8	7	-4	-185
Double density of new outer development	-12	-3	1	-3	-2	1	1	2	14
50% Pop. in inner redevelopment at 75 ppha	-8	-2	0	-3	-2	8	1	-13	-35
Population growth rate halved	-11	-3	-1	-17	-16	-11	0	-12	-70

TABLE 1: Changes in key parameters for various planning strategies for Melbourne at 1985

a The first row gives absolute values for the 1985 solution
b Rows 2-12, columns 1-8 give percentage changes on 1985 base values
c The last column gives absolute changes from the 1985 base value.

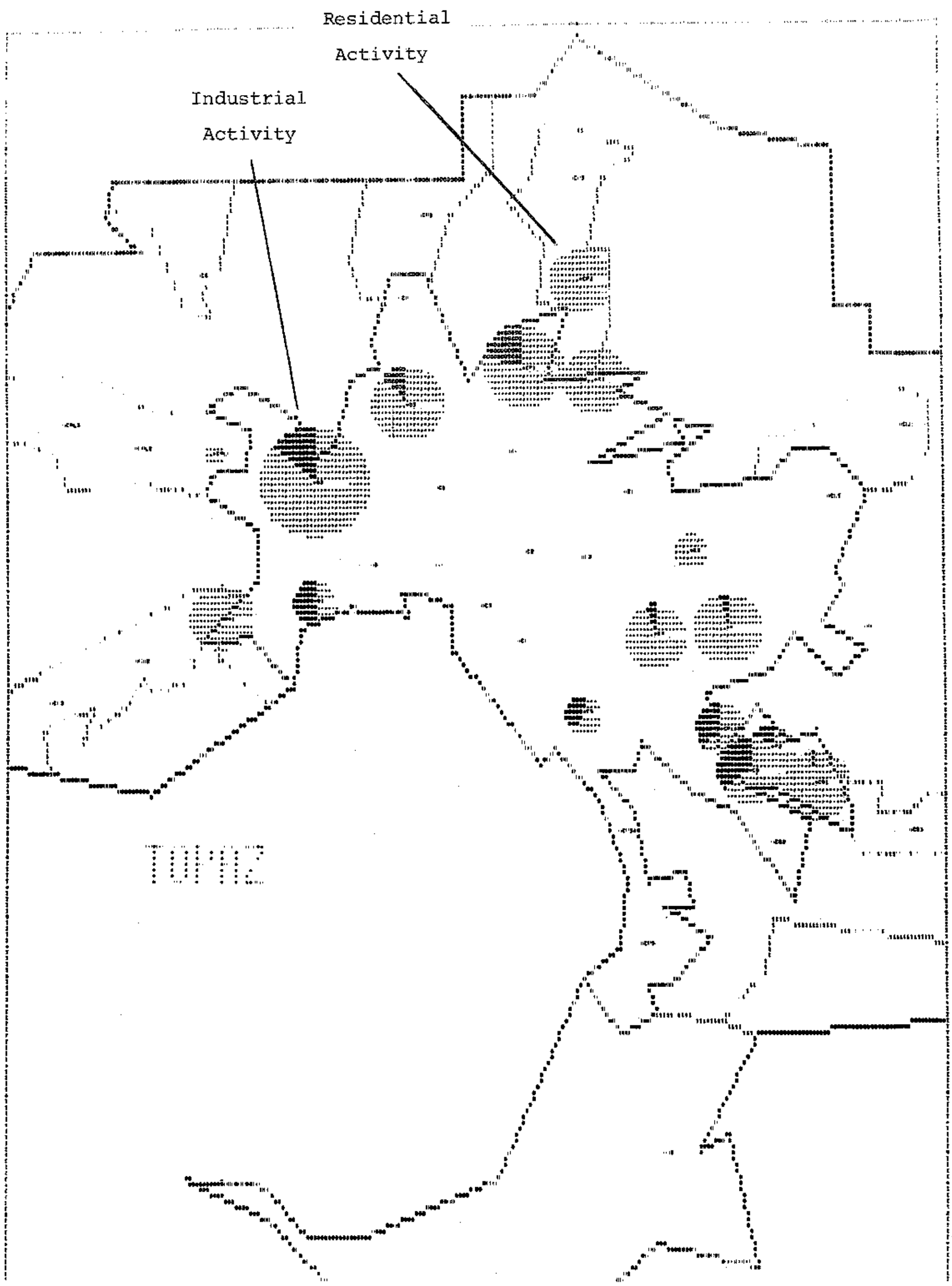

FIGURE 1

BASE SOLUTION SHOWING ALLOCATION OF RESIDENTIAL AND INDUSTRIAL ACTIVITY FOR MELBOURNE OVER 1970-85 PERIOD

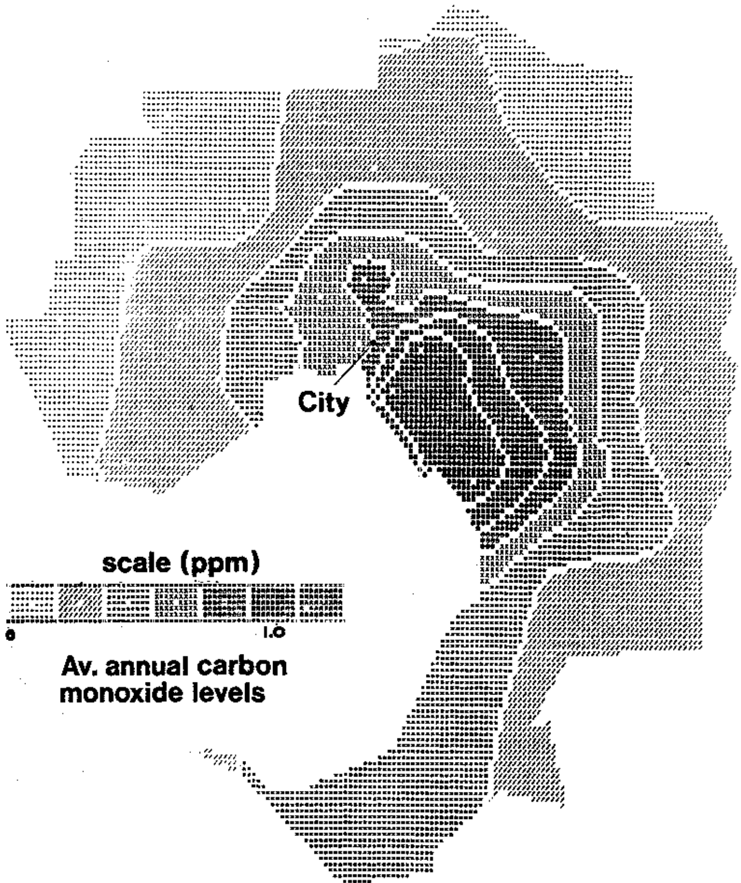

FIGURE 2

PREDICTED VEHICLE AIR POLLUTION LEVELS

WITHOUT EMISSION CONTROLS FOR MELBOURNE AT 1985

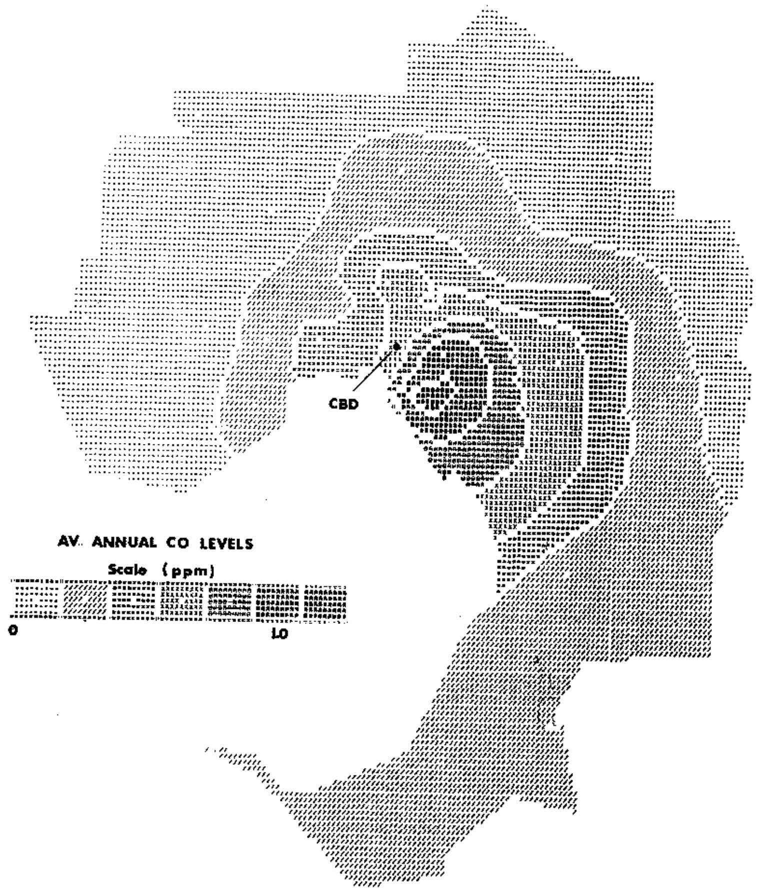

FIGURE 3

ESTIMATED VEHICLE AIR POLLUTION LEVELS
FOR MELBOURNE AT 1970