The effect of alternative urban forms on two-mode transportation system requirements

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INTRODUCTION

The interrelationship between urban land use and urban transportation has long been recognized as a phenomenon worthy of attention at the policy level. It is common to regard the provision of transportation services as an important policy variable amongst what is generally considered to be a limited set of policy options available to government control. The ability to influence accessibility levels through the control of the design, construction, and operation of the transportation network is a controllable variable which must be utilized in a responsible and positive manner. In a similar way, it is essential that we understand the effect which urban development patterns have on travel demands and hence on the transportation networks required to accommodate these demands. The direction in which the interrelationship between transportation and land use is approached matters little, since it is much too complex to be able to attribute causality to either determinant. The importance of the interrelationship to the transportation engineer or urban planner lies in the understanding and utilization of the relationship in a positive manner, rather than the need to know which is the dependent and independent variable.

The question which is addressed by the research described in this paper has to do with the potential for reducing transportation system requirements and improving transportation efficiency through modification in urban density and spatial patterns. In other words, it attempts to assess the nature and degree of transport sensitivity to variations in urban land use. The measures of effectiveness which are developed relate to both the performance and efficiency of the transportation system. Implications for energy consumption may be determined from operating conditions and implications for capital investment requirements from derived network capacities and configurations.

The typical approach to the type of investigation proposed is to conduct a static comparison of a series of alternative end-state or horizon-year plans, and to make a choice of 'best' alternative on the basis of future travel demand accommodation at an acceptable level-of-service. This is a rather limited perspective, however, since the interrelationship between transportation service and land use is very much a dynamic one. In effect, it is the *time stream* of the interaction and its associated benefits and costs which should be the object of evaluation, and not the terminal state at the end of the planning period. [Rice and Nowlan (1975)]. The implication of this realization is that the true nature of the transportation/land-use relationship is not likely to be revealed by a comparison of transportation systems for a range of urban forms, but this does not imply that such an exercise is without value. In fact, it is likely that, from an efficiency point of view, the evaluation of planning actions through time will still require the definition of an end-state or boundary condition.

It is the objective of the research described in this paper, then, to determine the most effective combinations of road and transit systems to serve a defined number of cities with differing density and spatial patterns, and thereby to assess the effects of varying urban form on transportation investment and service requirements. While the results of such an analysis are of direct relevance to the planning of new towns, the implications may also be extended to expanding urban areas. This is of concern in Canada, for example, where it is estimated that cities with populations of 400,000 and over will double in size by 1990. The urban development consequences are even greater since the rate of household formation is expected to be larger than the rate of population growth.

REVIEW OF THE LITERATURE

Given the fact that research interest in coordinated urban transportation and land-use planning has only developed in the last ten to fifteen years, the literature available represents quite a range of techniques and conclusions. For the sake of simplicity the studies which have been done have been divided into two categories:

a) those dealing with *sensitivity analyses*, either of transportation service variations on land development, or of land use alternatives on transportation system requirements, and

b) those which attempt to describe the *interactive nature* of transportation/land-use relationships, allowing for appropriate feedback effects.

The first group of studies deal almost exclusively with the sensitivity of transportation requirements to variations in urban density and spatial patterns, and make use of the established four-stage transportation modelling procedure. Representative of this group are the studies by Voorhees, Barnes and Coleman (1962), Jamieson, et al (1967), Voorhees and Assoc. (1968), Milton Keynes Development Corporation (1970), Bellomo, Dial and Voorhees (1970), Sjovold (1973), and Zupan (1973). All of these provide interesting insights into the variability of travel demands with changing development patterns, but conclusions often conflict due to differences in assumptions and in the choice of output variables. The same type of results derive from a smaller sub-group of studies which assesses the same sensitivity question, but through the application of optimizing procedures. Most notable among these are the research of Hemmens (1967), Black (1967), and Creighton et al (1964).

Very little research has been conducted on the sensitivity of the transportation/land-use relationship as perceived from the opposite direction: that is, the sensitivity of land-use growth patterns to changes in the transportation system. The research of simplest elegance in this area is that of Schneider (1968) and Hamburg, Brown and Schneider (1970), in which a model is postulated relating zonal growth to zone attractiveness and relative accessibility. The EMPIRIC growth allocation model has also been applied to this question [Hill, Brand and Hansen (1965)], where it is concluded that the provision of transportation facilities can result in a difference in land-use growth of as much as 20 percent.

The second major category of the literature which is relevant here relates to the two-way interaction of transportation and land use, so that not only is the effect of one on the other considered, but also the consequential feedback in the reverse direction. Most of the studies in this area make use of conventional transportation models and growth allocation models, and representative of these are Morison and Hansen (1968), Campbell (1968), Metropolitan Toronto Transportation Plan Review (1974), Putman (1974) and Maunsell and Partners Ltd. (1975). Once again, as was the case in the first area of the literature on sensitivity analyses, there have been a selective number of studies in this second area which approach the problem through the use of optimizing procedures. Most notable among these are the studies by Cockfield (1970) and Stewart and Grecco (1970).

In terms of the conclusions to be drawn from the two major areas of the literature, it is perhaps easiest to divide these into general results and those results which relate directly to particular urban forms. Generally, the primary result is simply that land-use distribution is a major determinant of urban travel requirements – the most important factor in this regard is the distribution and balance of employment opportunities and resident labour force, so that the adjustment of these land-use densities and their proximities may result in as much as a 10-30% decrease in travel. By way of modal comparisons, it appears that the roadway system is more flexible than the transit system, in that the forcer can support a wider range of land-use plans without changes in configuration or capacity. It is also true, however, that a mixed-mode plan is more desirable than a single-mode system, since improved travel conditions and greater modal operating efficiencies result. While it appears that the consideration of a range of land-use development alternatives produces an equally wide range of transit and road utilization, relatively little research has been conducted on the effect of development patterns on the use and requirements for the two travel modes.

An assessment of those conclusions in the literature which relate to the transportation requirements of particular urban forms indicates a high degree of conflict; however, this is almost always due to the range of indicator measures utilized in each study. For example, the use of average trip length indicates that the central core city results in the lowest requirement and the low-density sprawl pattern the highest. The determination of capital costs of the transportation system indicate the converse, however.

While several studies are concerned with the transportation "mode mix", they avoid the complexity of land-use variation. Those research efforts which do address the full land-use/transportation problem typically conclude quite generally with regard to mode usage: for example, the need for corridors of a particular trip density for the efficient use of rapid transit, or the suitability of particular modes for the line-haul and feeder components of urban travel. In essence, the assessment of the variation in mode utilization with changes in urban form remains basically unfulfilled.

RESEARCH METHODOLOGY

As has been indicated, it is the intent of the research described here to assess the effects of varying urban form on road and transit investment and service requirements. Given the perspective offered in the existing literature it is apparent that any effort in this area should allow, firstly, for full modal interdependence, permitting travel mode shifts with changes in land-use and socio-economic characteristics as well as level-of-service; and secondly, for a broader number and type of output indicators. In essence, the estimation of modal travel demands for each urban form must be sensitive both to the level-of-service supplied and to the spatial and density pattern of land-use activities. In order to permit the investigation of the transportation system characteristics for a range of urban patterns, there is a strong need for an analytical base which allows for the comparison of transportation measures between land-use plans. That is, the procedure for developing the transportation network and mode combination for each urban form must be consistent and not unduly bias any particular city pattern(s). Herein lies the central issue of the research procedure.

The description of the research method has been divided into three separate stages: the first deals with the derivation of the range of hypothetical urban forms, the second with the estimation of peak-hour travel demands for each city type, and the third with the generation of optimal two-mode transportation networks to accommodate the estimated travel demands in each city. Each of these phases is described in turn in the next three sub-sections.

Development of the Urban Forms

Due to the complexities associated with transportation/land-use interrelationships hypothetical rather than actual urban forms were generated for testing in the research project. It was necessary that the range of hypothetical city types be defined such that they resulted in a significantly broad range of transportation conditions. To accomplish this, three elements or components of urban form were defined as follows:

a) *spatial organization* – the configuration of the urban area in two-dimensional space on the horizontal plane,

b) *activity distribution* – the distribution pattern of land-use activities within the spatial organization, in terms of both the type and density of land use, and

c) *transport connectivity* – the transportation network which provides linkages between the land-use activities and thereby services the spatial organization, in terms of both travel mode type and capacity and the extent to which it provides linkages between all zone pairs.

These three components are represented diagrammatically in Figure 1. Using these definitions, the objective of the research may now be re-stated as the analysis of the effect of urban spatial organization and activity distribution on the requirements and nature of the transport structure.

By analyzing a range of conditions associated with each of the three component elements and through a review of similar studies, six distinctive city types were defined. These were the central core, uniform density, multi-centred, radial corridor, linear, and satellite cities, as shown schematically in Figures 2 and 3. It was then possible to define population and employment distribution characteristics for a total population size of two million for each of the urban forms. This was accomplished through a series of realistic and empirically-derived constraints on density variation, socio-economic characteristics, and relative population and employment location. Since all of the city forms had at least some degree of central concentration, distance from the core was the primary structural variable, with random variations in population and employment characteristics permitted on a zone-to-zone basis. The details of this allocation procedure have been described elsewhere [Rice (1975)], although further summary characteristics for each of the six urban forms are provided in Table 1 and in Appendix 1.

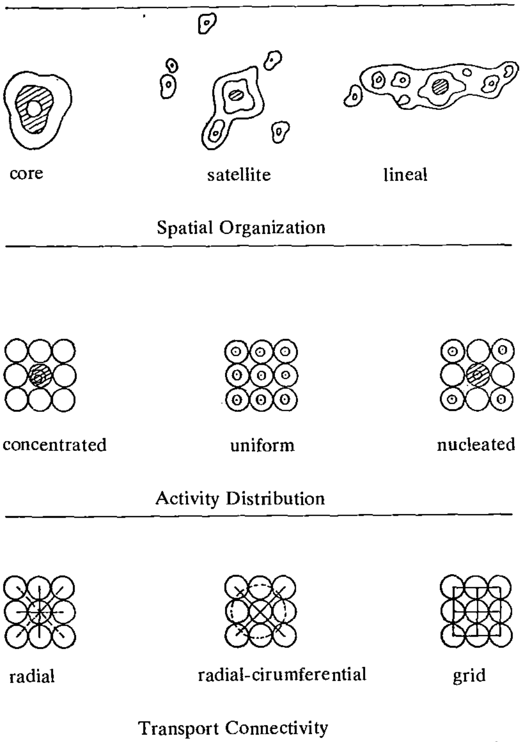

Figure 1 – components of urban form

Travel Demand Estimation

With the definition of the urban forms characteristics it becomes possible to estimate peak-hour travel demands. For this analysis attention was directed to the work trip, on the basis that it was this trip purpose which set the condition for the design of the transportation networks. The demand estimation procedure involved the use of the conventional four-stage process, applying zonal trip generation and attraction equations and the gravity model to produce a work-trip origin-destination matrix for each of the six urban forms. Trip distribution was assumed to be fixed, in spite of variations in the

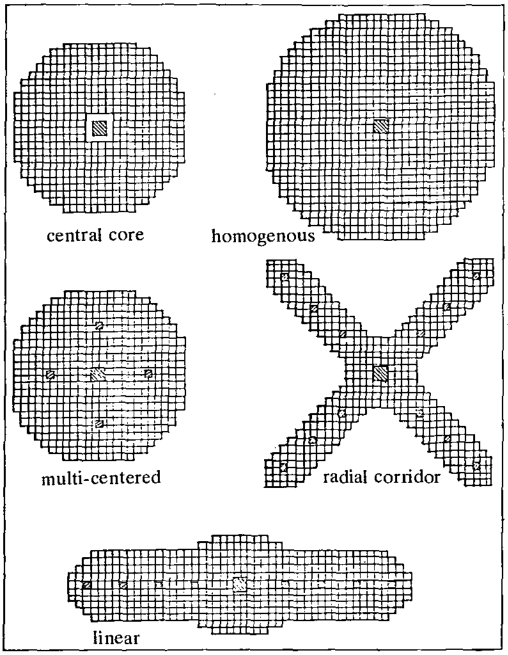

Figure 2 – selected urban forms

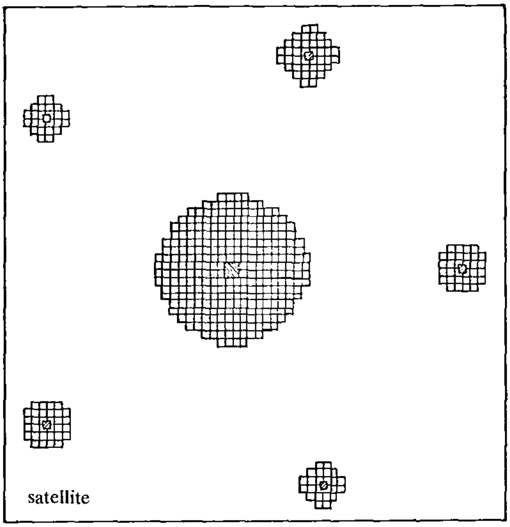

Figure 3 – selected urban form

Table 1 – General urban form characteristics

Urban Form	Population	Employ-ment	Developed Area	Gross Pop. Density	Average Net Resid. Density	Number of Dwelling Units	Average Pers. Per Dwell. Unit
Central	2,000,000	800,000	484 mi²	4130 pers/mi²	28,600 pers/mi²	565,300	3.54
Homogeneous	2,000,000	803,000	856	2340	13,300	534,300	3.74
Multi-centred	2,000,000	804,700	484	4130	30,800	567,000	3.52
Radial Corridor	2,000,000	802,200	408	4900	33,800	567,000	3.52
Linear	2,000,000	803,000	496	4030	29,500	566,100	3.54
Satellite	2,000,000	800,300	444	4500	32,300	567,300	3.53

transportation network at a later stage. These variations were only allowed to result in changes in mode and route choice. This assumption of inelasticity of demand for the work trip was thought to be suitable in the light of the research objectives.

A comparison of the trip production estimates for the range of urban forms is provided in Table 2 and the person-trip hours for all trip purposes as estimated by the trip distribution model are indicated in Table 3.

Within the trip distribution phase of the travel estimation procedure, it was critical that differences in travel behaviour for the six city types be permitted. Since trip distribution deals with interchange patterns, the relative location and distribution of employment and population will be the primary determinants of average trip lengths and transportation system requirements. It is apparent then that each hypothetical urban form must have a unique travel impedance function associated with it. The determination of this function was achieved by relating average trip length to the work opportunity distribution as defined by Voorhees and Associates (1968). Since this distribution is uniquely defined for each city type, it was possible to determine an average work trip length and, from this, an impedance function for each of the six cities. Finally, the work trip origin-destination matrices were assigned to spider networks, resulting in the desire line assignment results presented in Table 4[1]. The advantage of the desire-line assignment is that the volume flow condition that has been estimated is not constrained by the form or characteristics (capacity and mode) of the spider network. It therefore provides a relatively objective and consistent base for deriving more comprehensive two-mode transportation networks.

Table 2 – Trip production estimates by urban form

Urban* Form	Total Person-Trips/Day	Home-origin Trips/Day	Person-Trips by Purpose: Home-based work	Home-based non-work	Non-home-based	Truck Vehicle-Trips
UF-1A	4,250,000	1,830,000	1,524,000	2,130,000	596,000	425,000
UF-1B	4,420,000	1,900,000	1,526,000	2,274,000	620,000	440,000
UF-2	4,180,000	1,800,000	1,530,000	2,064,000	586,000	420,000
UF-3	4,100,000	1,750,000	1,526,000	2,000,000	574,000	410,000
UF-4	4,280,000	1,840,000	1,526,000	2,154,000	600,000	430,000
UF-5	4,180,000	1,795,000	1,520,000	2,074,000	586,000	420,000

* UF-1A – central core
UF-1B – homogeneous
UF-2 – multi-centred
UF-3 – radial corridor
UF-4 – linear
UF-5 – satellite

Table 3 – Person-trip hours by purpose and for all-day by urban form

Urban form	Trip purpose: Home-work	Home-non-work	Non-home-based	Truck	Total for 24-Hours
UF-1A	*64,766*	94,308	*43,580*	*31,274*	392,782
UF-1B	76,485	121,856	54,759	44,753	495,872
UF-2	65,187	*90,892*	45,007	33,700	*390,930*
UF-3	83,713	103,931	44,236	35,401	454,312
UF-4	81,598	118,645	48,591	36,968	485,268
UF-5	106,075	130,623	44,009	32,490	539,201
Ratio of high value to low	1.6	1.4	1.25	1.4	1.4

NOTE: The cursive values in the table indicate the lowest number of person-trip hours within each column (i.e., trip purpose).

Table 4 – Desire-line assignment summary

Urban form	Total network length (mi.)	Average link length (mi.)	no. of two-way links	Total trips: Avg. Vol. per Link	Total trips: Max. Link Volume	Total trips: Total Pers.-Mi.	Total trips: Total Pers.-Hrs.	Work Trips: Avg. Vol. per Link	Work Trips: Max. Link Volume	Work Trips: Total Pers.-Mi.	Work Trips: Total Pers.-Hrs.
UF-1A	376.4	3.6	104	32,710	104,500	20,550,000	342,470	5,465	34,600	3,400,000	56,700
UF-1B	462.4	4.2	108	31,360	103,000	27,030,000	450,230	4,900	24,000	4,150,000	69,200
UF-2	381.4	3.2	120	29,390	80,100	20,300,000	338,000	4,270	21,000	2,920,000	48,600
UF-3	289.9	3.5	82	50,800	170,500	23,700,000	395,000	8,530	47,100	3,730,000	62,200
UF-4	377.6	3.3	114	37,970	169,000	26,030,000	433,760	6,470	57,300	4,410,000	73,500
UF-5	597.0	4.9	122	30,520	107,300	30,340,000	505,640	5,130	28,800	5,740,000	95,700

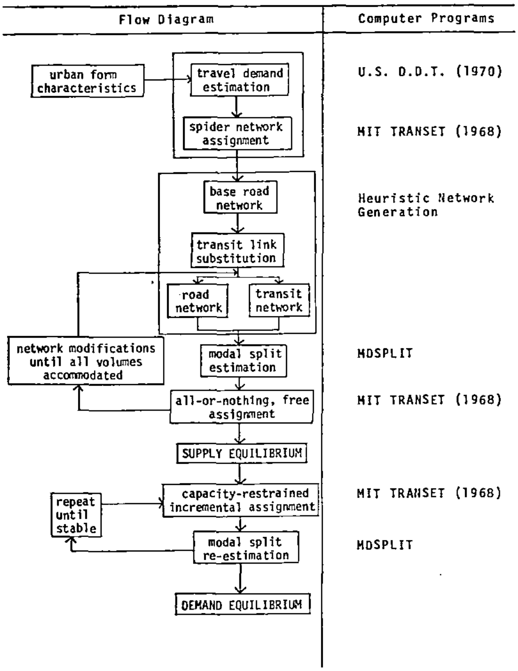

Figure 4 – Two-mode network generation procedure

Two-Mode Network Generation

The final phase of the research requires that a procedure be developed for generating a unique two-mode, capacity-restrained transportation network for each city type, thereby permitting a realistic and unbiased comparison of mode performance for the six urban forms. In very basic terms this procedure is dependent upon a definition of mode "balance" which might be stated as the condition in which both mode sub-systems are used effectively in and of themselves and in such a manner as to produce collectively optimal *total* system performance. [2]

The network generation procedure which was applied was a two-stage heuristic process, dependent on an initial division of mode service for each network link (the supply equilibrium cycle) and the refinement of model volumes in accordance with mode and route choices (the demand equilibrium cycle). This procedure is described in flow chart form in Figure 4, with an indication of the computer programs utilized in each step.

The supply equilibrium phase starts with the desire-line volumes from the spider assignment for each city type and defines an initial two-mode transportation network which is able to accommodate the expected demand. This was achieved by first designing a base road network which could just carry the estimated desire-line volumes. Modifications were then made to this initial "feasible" solution by substituting transit service on a link-by-link basis, such that a trade-off function between transportation facility space consumption and user travel time is always satisfied.[3] It is obvious that the introduction of transit mode service will have a substantial effect on both mode and route choice. It was necessary, therefore, to re-estimate modal split and trip assignment after the initial round of transit substitution. When this was done, however, it was found that the new routes selected take advantage of the higher level-of-service links, so that there is a natural aggregation of trip movements into specific modal corridors. In a similar manner, other links were depleted in trip volume, thereby modifying the service available on these links in the next round of transit service substitution. Within an iterative sequence then, a network rationalization process takes place, involving both traveller route and mode choice, so that natural corridors of travel demand build up in accordance with network geometry and demand orientation.[4]

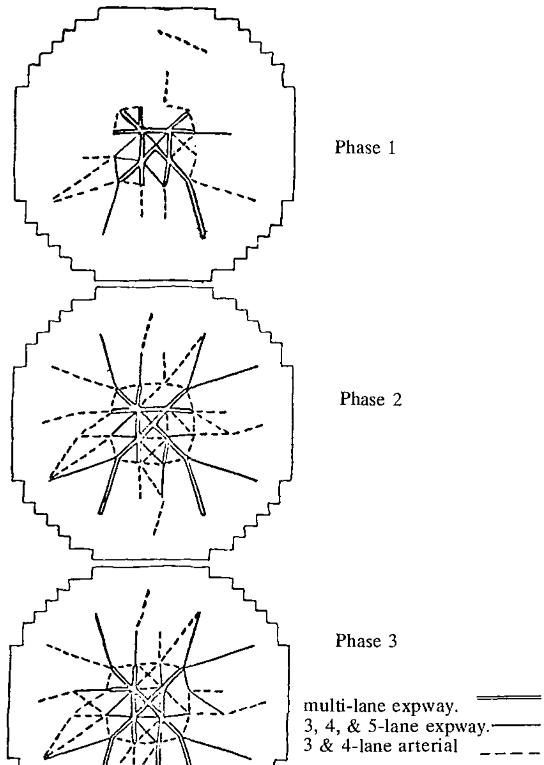

Figure 5 –
Transitional sequence for road network – UF1A

The network rationalization process is most easily demonstrated by the diagrams in Figures 5 and 6. These diagrams represent the results for the road and transit networks of the central core city (UF-1A) for three phases of the iterative supply cycle. While these figures only represent the high-capacity links in the modal networks it is quite apparent that the road network expands and the transit network contracts. This is obviously a function of the modal split function, but this phenomenon did occur for all of the six urban forms, as demonstrated in Tables 5 and 6.

The supply equilibrium cycle is repeated until no further changes are required in each of the modal network links to accommodate the travel volumes estimated in the previous iteration of the cycle. It should be noted (Figure 4) that the trip assignment component of the supply cycle is a free or desire-line assignment, since the objective of network synthesis is to develop a natural expression of the required transportation system. In other words, network rationalization must be unconstrained by physical limitations; modal capacity is simply provided in accordance with traveller demand. This results, therefore, in the need for the demand equilibrium cycle, which re-estimates modal split and route assignment in an iterative sequence, under assumptions of capacity-restrained flow on all links. This cycle is also

Table 5 – Lane-mile summary by urban rorm

Urban Form	Link Type	Number of Lane-Miles Phase 1	Phase 2	Phase 3
UF1A	road 1	172.0	256.6	258.1
	2	89.0	21.0	19.5
	3	801.6	905.2	856.8
	4	676.5	958.6	1123.7
	Total	1739.1	2141.4	2258.1
UF1B	road 1	162.0	229.8	233.8
	2	93.8	17.8	10.8
	3	1387.6	1479.4	1452.2
	4	375.7	814.4	972.4
	Total	2019.1	2541.4	2669.2
UF2	road 1	198.8	262.3	262.3
	2	77.6	18.2	18.2
	3	877.8	1029.0	884.4
	4	388.6	780.2	999.4
	Total	1542.8	2089.7	2164.3
UF3	road 1	197.8	228.0	228.0
	2	36.6	0.0	0.0
	3	392.0	416.6	394.0
	4	1063.0	1276.6	1287.4
	Total	1689.4	1921.2	1909.4
UF4	road 1	107.8	145.2	153.2
	2	56.2	20.0	12.0
	3	906.8	766.4	782.4
	4	1216.0	1677.4	1765.4
	Total	2286.8	2609.0	2713.0
UF5	road 1	480.2	476.0	484.0
	2	34.8	22.2	10.0
	3	945.6	727.2	709.8
	4	2015.0	2624.8	2694.0
	Total	3475.6	3850.2	3897.8

NOTE: 1. Road link type 1 – local
Road link type 2 – minor arterial
Road link type 3 – major arterial
Road link type 4 – expressway

2. Only link types 3 and 4 appear in Figures 60, 62, 64, 66, 68 & 70.

3. Since all links derive from the spider network with interzonal connections, many intra-zonal local and minor arterial links and lane-miles will not be represented in this table.

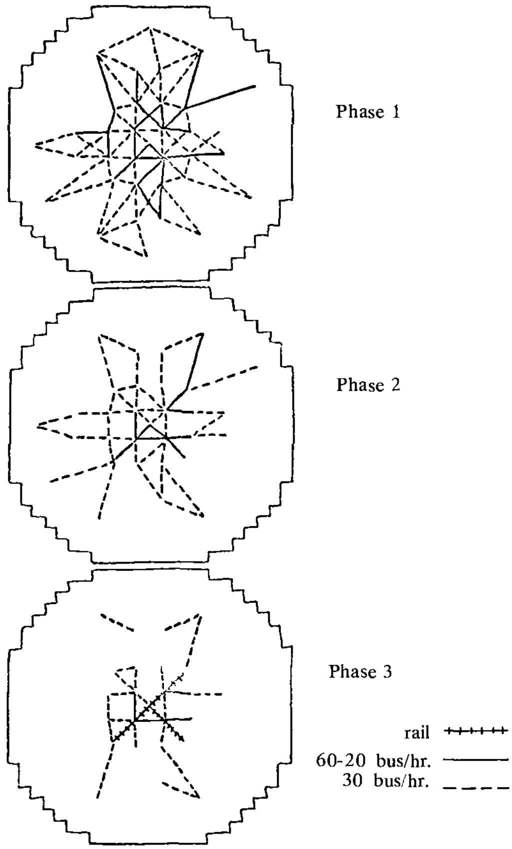

Figure 6 – Transitional sequence for transit network – UF1A

indicated in the flow diagram of Figure 4. The system output from the four required steps of this cycle for the radial corridor city (UF-3) is shown in Figure 7, as an example of the operation of the demand equilibrium process.

Table 6 – Train/bus-mile summary by urban form

Urban Form	Link Type	Number of train/bus-miles Phase 1	Phase 2	Phase 3
UF1A	rail	0.0	0.0	756
	bus	23,772	14,029	8,446
UF1B	rail	0.0	0.0	0.0
	bus	22,223	12,788	8,666
UF2	rail	0.0	0.0	0.0
	bus	19,730	10,676	6,815
UF3	rail	0.0	0.0	1,974
	bus	15,656	14,576	7,997
UF4	rail	0.0	0.0	1,356
	bus	23,378	16,729	9,508
UF5	rail	0.0	0.0	1,536
	bus	32,404	27,266	21,027

NOTE: Only a portion of the bus-miles are represented in Figures 61, 63, 65, 67, 69 and 71.

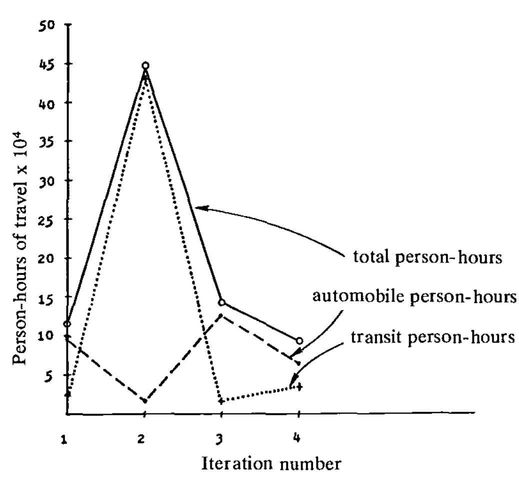

Figure 7 – System person-hour oscillation for UF3

Table 7 – Summary of final travel demand characteristics by urban form

Output Measure	UF1A	UF1B	UF2	UF3	UF4	UF5
	URBAN FORM					
1. Total System						
(a) total work trips	346,500	341,380	326,900	334,700	375,100	387,950
(b) person-hours	7.00 x 10^4	7.71 x 10^4	5.00 x 10^4	9.65 x 10^4	9.51 x 10^4	17.14 x 10^4
(c) mean trip length	11.68 min.	13.1 min.	9.07 min.	17.01 min.	14.49 min.	26.0 min.
(d) % transit	18.2%	8.0%	10.3%	33.8%	19.9%	8.0%
2. Road Network						
(a) work trips	293,100	313,900	293,500	221,200	300,350	357,950
(b) % on expwy.	63%	55%	59%	85%	75%	90%
(c) trip length						
– mean	11.78 min.	12.16 min.	8.30 min.	17.2 min.	13.58 min.	26.66 min.
– std. dev.	10.88 min.	7.64 min.	4.99 min.	18.8 min.	12.54 min.	40.8 min.
3. Transit Network						
(a) work trips	53,400	27,480	33,400	113,500	74,750	30,550
(b) % on rail	30%	0%	0%	51%	37%	26%
(c) trip length						
– mean	11.22 min.	24.06 min.	15.82 min.	16.62 min.	18.82 min.	18.39 min.
– std. dev.	8.27 min.	11.02 min.	8.98 min.	13.16 min.	13.94 min.	18.34 min.

COMPARATIVE ANALYSIS OF MODAL PERFORMANCE

The results of the network generation procedure are most easily demonstrated by the total system output measures in Table 7. The differences in travel conditions for the six cities are obviously quite significant. For both total person-hours and mean trip length, the first three urban forms (UF1A, UF1B and UF2) have lower conditions than the other three forms. This is not a function of mode usage, since modal split varies from 8% to 34%, and this variation occurs in both groups of cities.

The comparison of mode usage for the range of cities is indicated diagramatically in Figures 8 and 9. The percentage of trips using transit corresponds closely to the number of train-miles supplied, with the exception of the satellite city where the existence of rail transit has little effect on the use of public transit. With regard to the percentage of person-hours on the high-speed service links (expressway and rail), the two corridor cities (UF3 and UF4) and the satellite city (UF5) have the highest dependency on high service level facilities, as would be expected. While tranportation investment cost has not been estimated directly, it is possible to form some general conclusions on capital costs from the amount of high-service facilities required in each of the six city types. The two corridor plans and the satellite plan (UF3, UF4 and UF5) are dependent on high-service facilities for both modes, and hence will require high capital investment. The satellite plan easily claims the position of most expensive form, even though its rail service requirements are not the largest. The radial corridor plan is likely to be the cheapest of the corridor

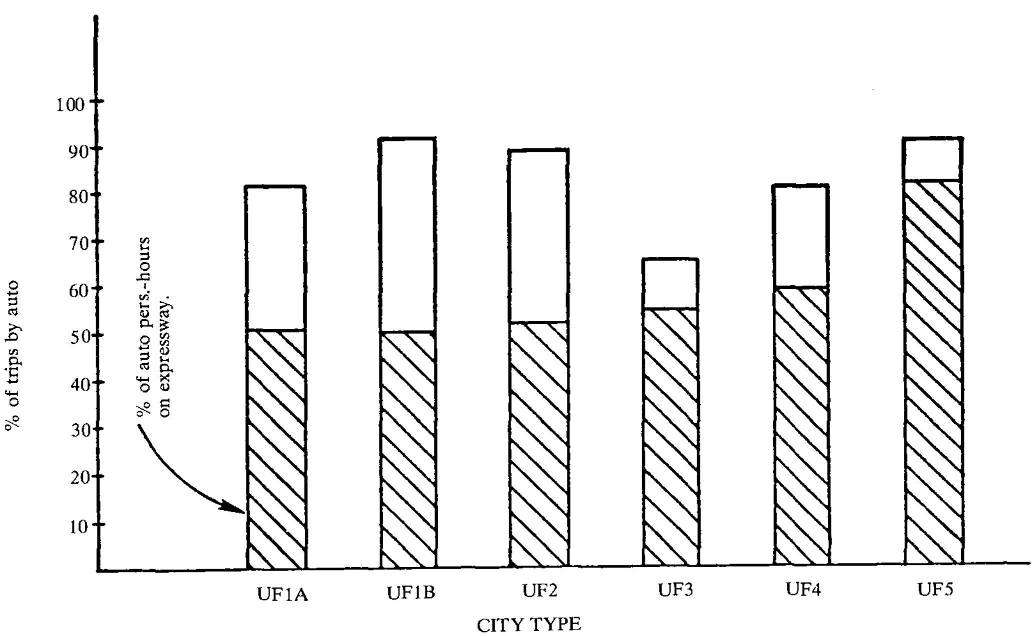

Figure 8 – Auto mode usage and expressway usage

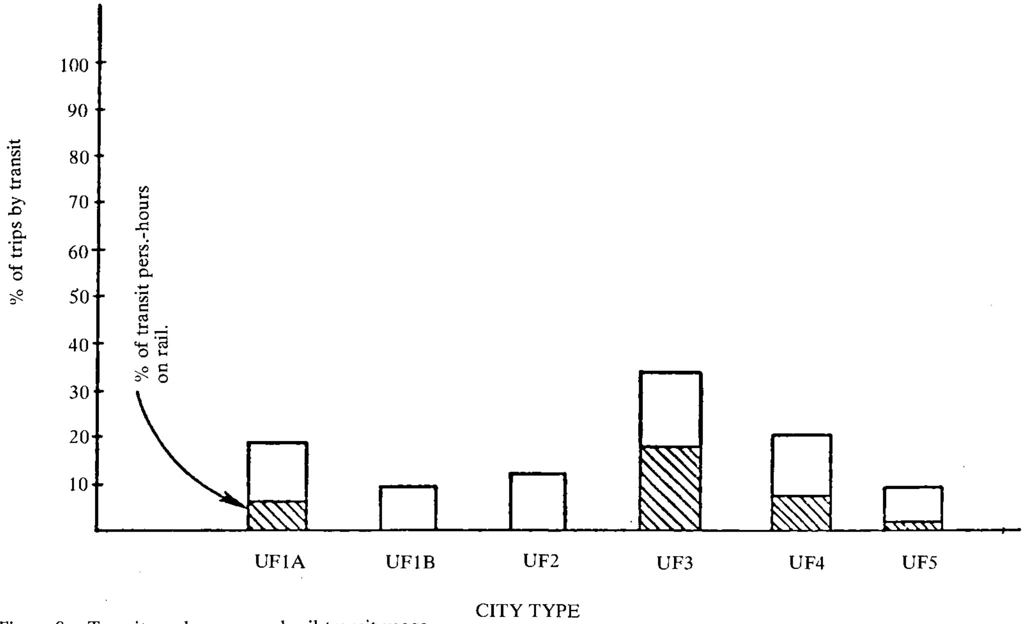

Figure 9 – Transit mode usage and rail transit usage

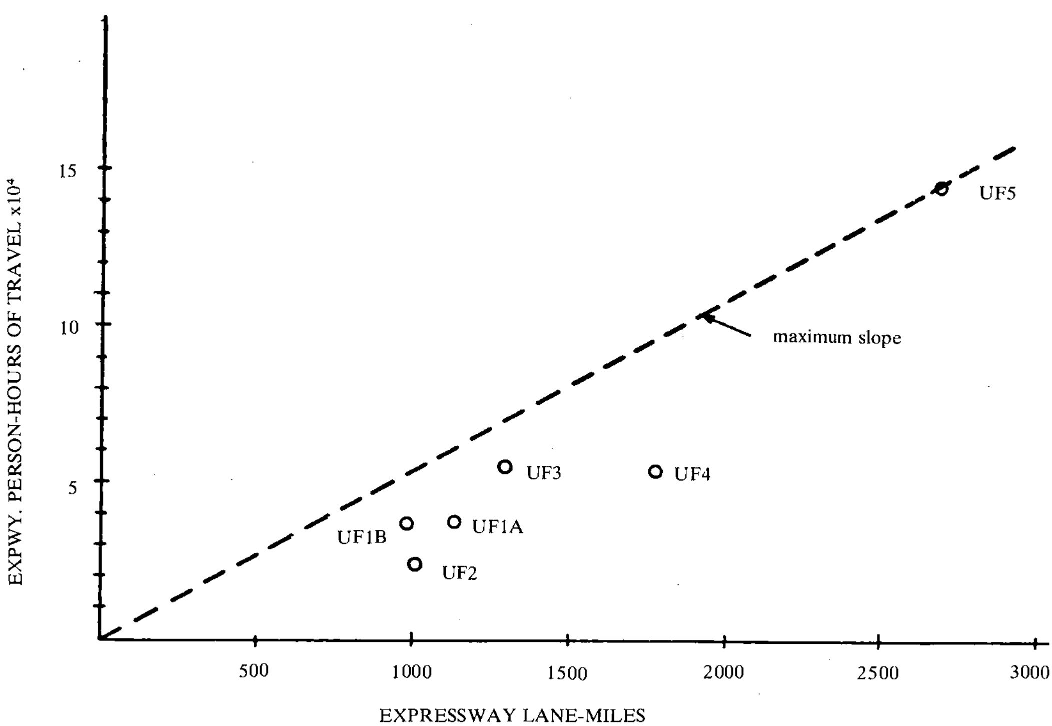

Figure 10 – Efficiency of expressway usage

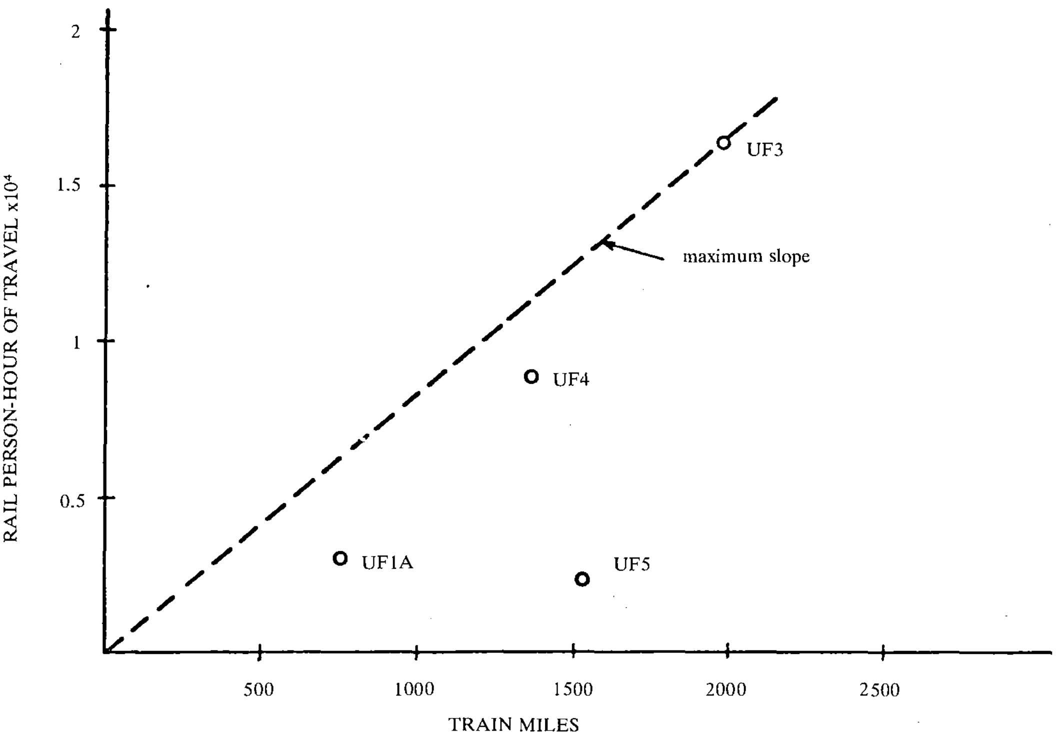

Figure 11 – Efficiency of rail transit usage

plans. The remaining three cities (central core, homogeneous, and multi-centred) require the lowest transportation investment, with the multi-centred city requiring the absolute minimum.

Finally, in order to measure the relative efficiencies of the high-service links in the modal networks Figures 10 and 11 have been constructed for expressway lane-miles and person-hours, and for rail transit train-miles and person-hours, respectively. It is apparent that for expressway efficiency, the satellite city (UF5) ranks at the top while the multi-centred (UF2) and the linear city (UF4) perform rather poorly. For rail transit, however, the networks of the radial corridor (UF3) and linear city (UF4) perform well and UF5 does exceedingly poorly. With regard to the efficiency of the total networks, including all link types, it may be concluded generally that it is more difficult to obtain an efficient transit network than it is to achieve the same for a road network. The satellite form is the primary example of this disparity, but it is demonstrated in the other urban forms as well. In terms of overall modal efficiency, the radial corridor city rates best in general, with little question. While this might be as expected, the homogeneous city takes second position. Even though this latter city has minimal transit service, what is available is effectively utilized.

CONCLUSIONS AND POLICY IMPLICATIONS

It is the task of this final section to indicate general observations and conclusions which derive from the analysis, to specify their relevance to policy considerations, and to describe the directions in which further research might be most profitably oriented.

The primary hypothesis assumed by the research reported upon in this paper is that, for a consistent set of assumptions, the transportation requirements of any particular urban form are uniquely defined. This hypothesis is strongly supported by the analysis in the previous section; in particular, average work trip lengths for the six cities differ by a factor of almost three. Also, the investment cost implications clearly indicate the relative inexpensiveness of the centrally-oriented city types (central core, homogeneous and multi-centred) relative to the two corridor plans and the satellite plan, and this conclusion is verified by the requirement for a large percentage of high-service links in the latter group of cities.

The verification of this hypothesis, therefore, generally supports similar research by Balkus (1967) and runs counter to the conclusions of Zupan (1973) and Hemmens (1967). With regard to specific urban forms, the research results are confirmed by Voorhees, Barnes and Coleman (1962), who conclude that the existence of sub-centres reduces average trip length, but conflict with Jamieson, et al (1967), who contend that the linear form is most efficient, rather than the radial corridor plan. In reference to the final conclusions of the Metropolitan Toronto Transportation Plan Review (1974), the research supports the contention that a nucleated pattern is preferable to a single core plan in terms of all transportation measures, but conflicts directly with the statement that a single transportation network is capable of supporting three different city forms.[5]

The first hypothesis of the research may be extended to relate to the effect which alternative urban forms have on transportation mode requirements. The analyses of the previous section indicate substantial variability in mode usage (8-34% transit use) between the six city types. In addition, the submode balance (rail/bus and expressway/arterial) is also dramatically different, with two urban forms (homogeneous and multi-centred) having no rail service at all.

The implications of these modal differences on user travel costs and agency transportation investment costs should also prove to be significant for policy input. While neither type of costs have been estimated directly in this research, it is possible to compare average trip length and personhours of travel with network supply requirements. Since the ranking of the urban forms by trip length or person-hours gives identical results (multicentres, central core, homogeneous, linear, radial corridor, and satellite), the choice does not matter. Comparing this ranking with that for implied investment requirement, the same ordering from low to high cost is obtained for the first three urban forms, and a change in order for the linear and radial corridor form in the last three forms. However, it is even more instructive to use an efficiency measure (relating output per unit of input, such as person-hours/lane-mile or bus-mile). Such a comparison indicates that the radial corridor plan, followed by the homogeneous and multi-centred city, make the best use of transportation investment funds.

As is the case with much policy-oriented research, the directions which are identified for further analysis are often as significant as the product produced. It is quite apparent in this case that there are several internal modifications to the modelling procedure which could be proposed. These include the use of simultaneous destination, mode, and route choice models, the incorporation of transportation investment and user cost functions, the empirical verification of results, the inclusion of new transportation systems, and the application of the model procedure to cities of different population size. The most important implication of the research, however, has to do with the planning process needed to effectively evaluate long-range plans.

The perspective taken by this research of the interrelationship between urban land use and transportation has been one essentially oriented to the transportation implications of a number of static urban forms. It therefore represents a method suited to the assessment of an end-state condition, but not to the means required to produce such an end-state through time. In many ways it is the latter question which is of prime importance in urban planning; in fact, it is contended that the evaluation of any plan may *only* be accomplished by assessing the path by which that plan is achieved (or, to determine if it is even possible to get there from here).

This assertion requires that increased attention be given to the staging of transportation plans in such a way that selected urban states may be promoted. This type of dynamic policy orientation will require the use of land-use forecasting techniques in conjunction with the transportation methods used in this research. With this combination it would be possible to assess the balanced and inbalanced state of a transportation plan in relation to the urban activity pattern, and to make changes in accordance with perceived objectives.

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FOOTNOTES

1. The spider networks developed for each of the six urban forms are described in Appendix 2.
2. A more detailed discussion of alternative definitions of mode balance and the possible use of this concept in planning is presented in Rice (1975).
3. This is somewhat akin to the space-time product used by Cockfield (1970), although he permits variations in both network connections and land-use activety location in an effort to minimize "wasted space-time content".
4. Rea (1972) also noted a similar network rationalization process in his research on the specification of transit technology and level of service.
5. Although in a dynamic sense this statement might be considered to be true; ie – alternative stagings of any transportation plan will produce different land-use configurations.

APPENDIX 1

– Comparative Urban Form Characteristics

The general population and employment characteristics of the six urban forms are very important for the subsequent travel demand analyses, so it is of some vulue to present further comparative information. Summary information on land-use distribution, employment distribution, and population and housing distributions is provided in Figures A-1 to A-6. In addition, Table A-1 indicates the degree of population and employment concentration in the central area of each of the six cities, and Figure A-7 presents the net residential density functions by distance from the core for each of the city types.

FIG. A-1

GENERAL CHARACTERISTICS GRAPHS – UF-1A

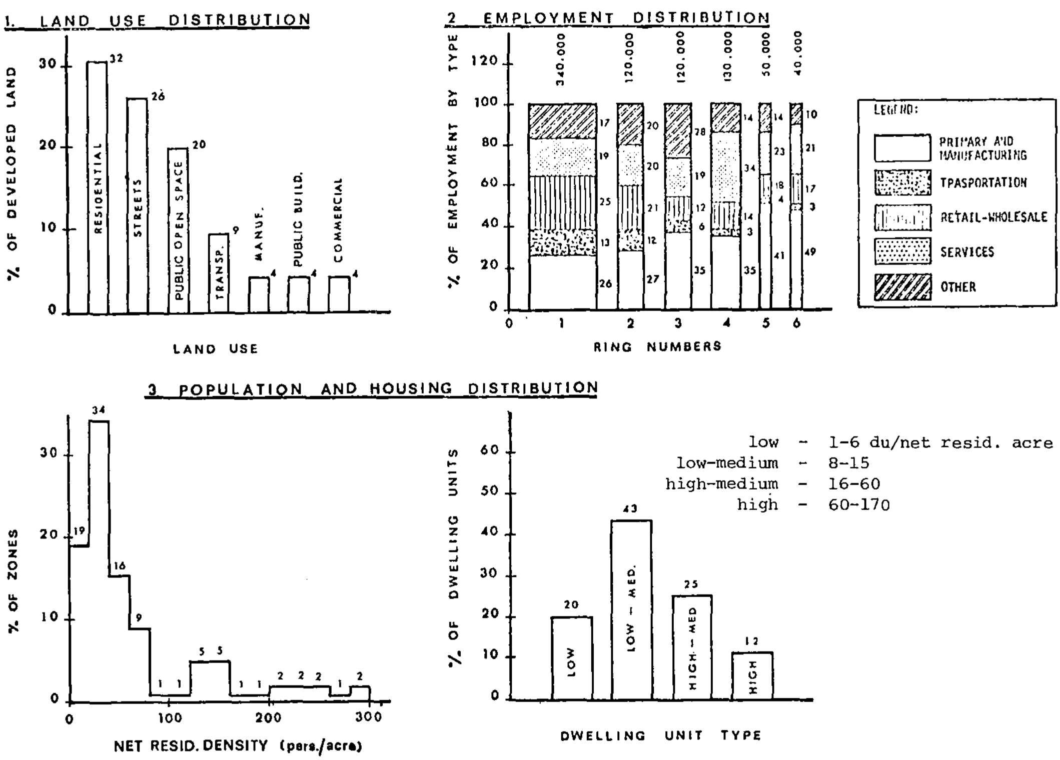
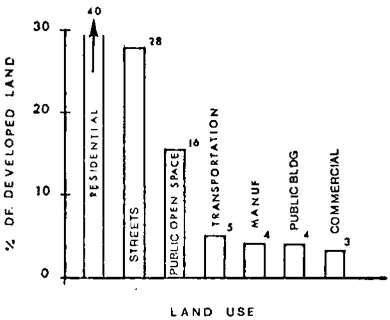
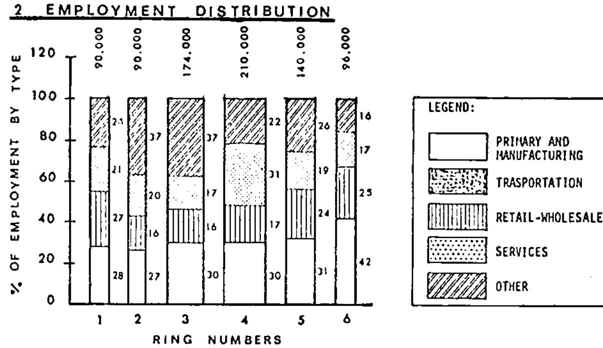


FIG. A-2
GENERAL CHARACTERISTICS GRAPHS – UF-1B

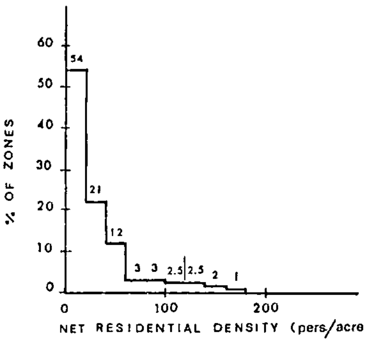
1 LAND USE DISTRIBUTION

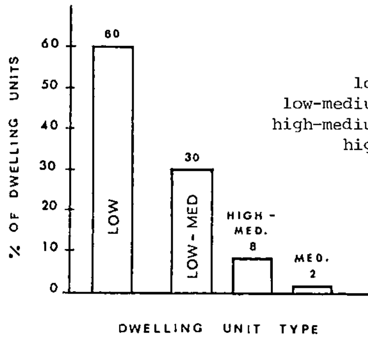


2 EMPLOYMENT DISTRIBUTION



3 POPULATION AND HOUSING DISTRIBUTION

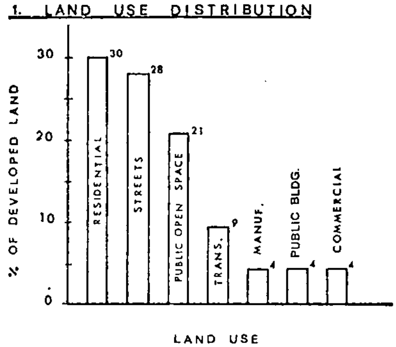




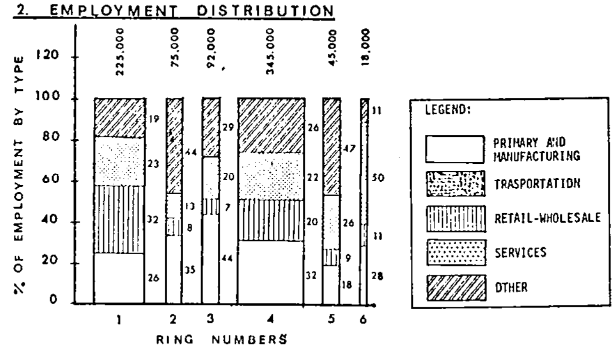
low - 1-6 du/net resid. acre
low-medium - 8-15
high-medium - 16-60
high - 60-170

FIG. A-3
GENERAL CHARACTERISTICS GRAPHS – UF-2

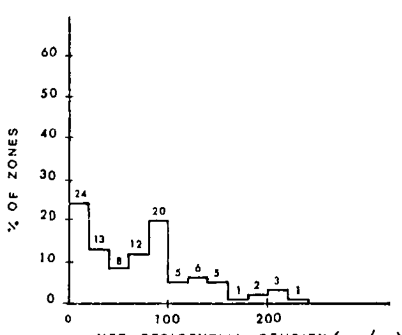
1. LAND USE DISTRIBUTION

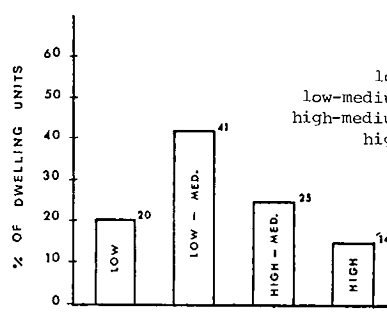


2. EMPLOYMENT DISTRIBUTION



3. POPULATION AND HOUSING DISTRIBUTION





low - 1-6 du/net resid. acre
low-medium - 8-15
high-medium - 16-60
high - 60-170

FIG. A-4

GENERAL CHARACTERISTICS GRAPHS – UF-3

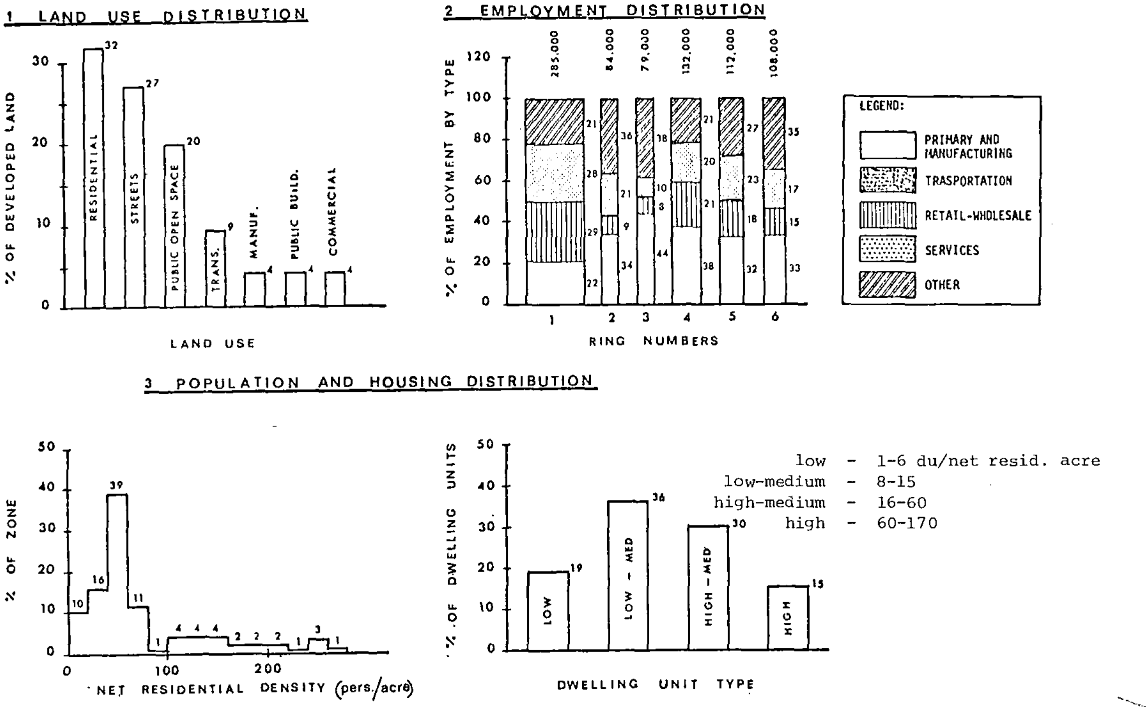


FIG. A-5

GENERAL CHARACTERISTICS GRAPHS – UF-4

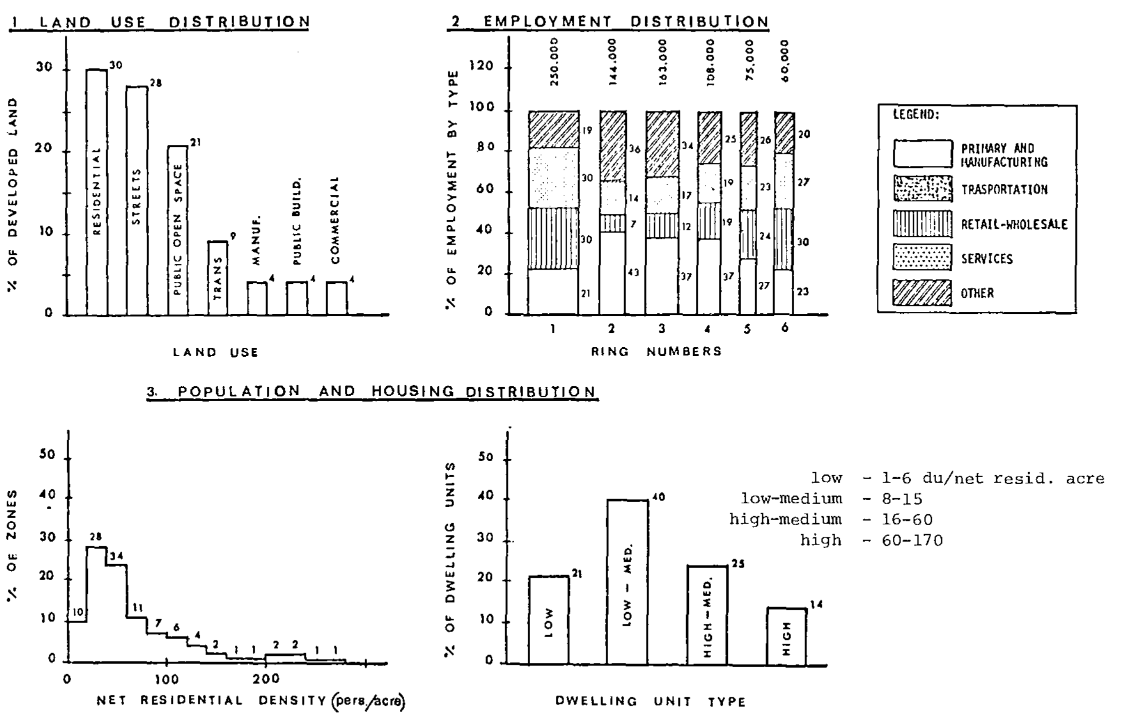


FIG A-6
GENERAL CHARACTERISTICS GRAPHS – UF-5

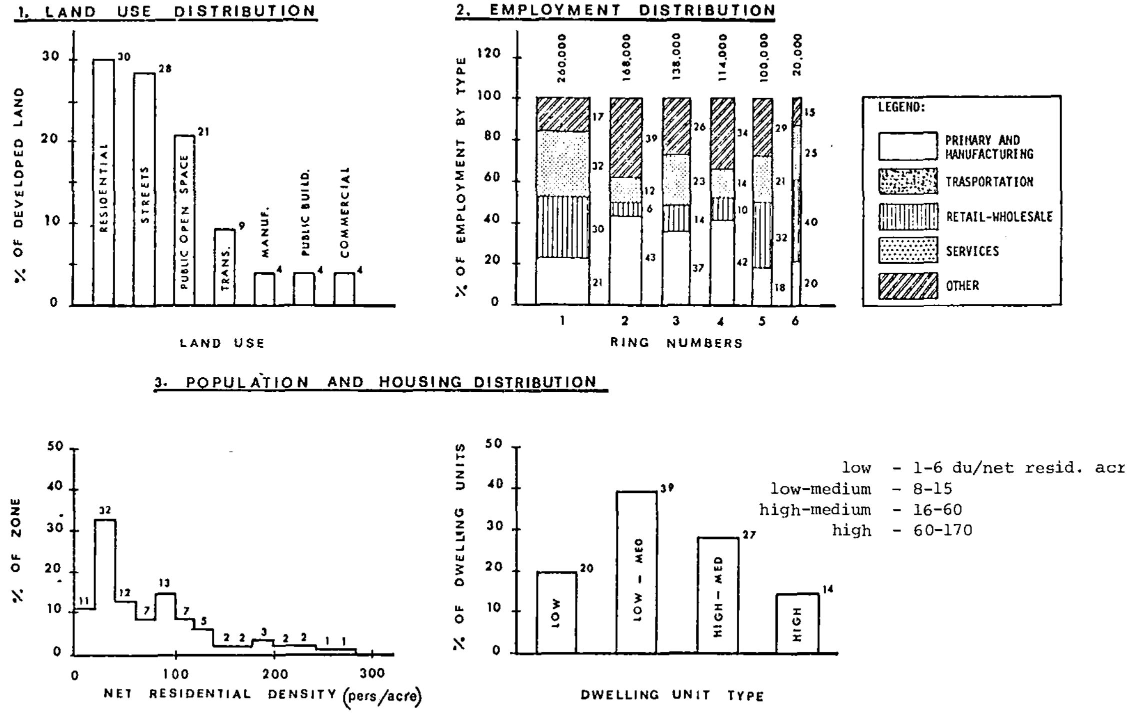


Table A-1 – Comparative distribution of population and employment

*Urban Form**	% of Population *in Central City*	% of Employment *in Central City*
UF-1A	56%	70%
UF-1B	14	30
UF-2	24	45
UF-3	36	56
UF-4	40	60
UF-5	50	70

* UF-1A – central core; UF-1B – homogeneous; UF-2 – multi-centred; UF-3 – radial corridor; UF-4 – linear; UF-5 – satellite

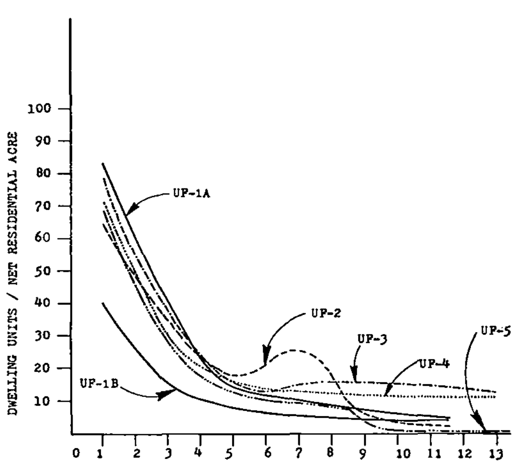
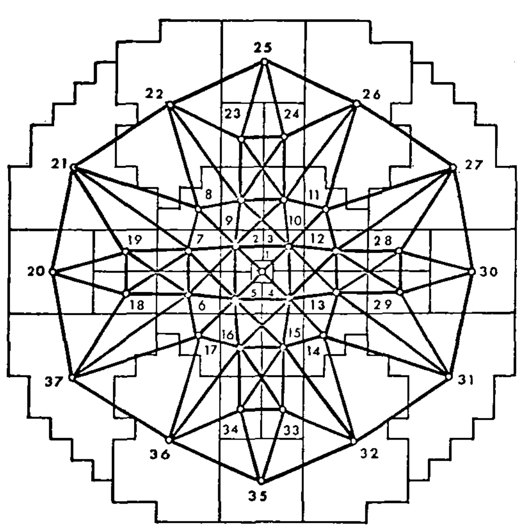


Figure A-7 – net residential density

APPENDIX 2

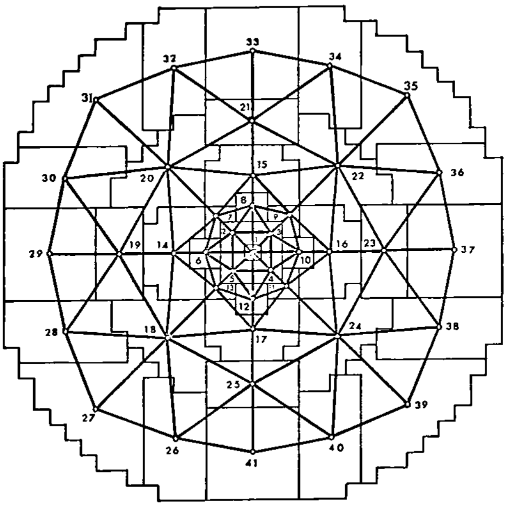
Spider Networks for the Six Urban Forms

It is the spider networks which form the initial basis for the network generation procedure so that their construction is of considerable importance to the research results. These are constructed in such a way that direct movement is possible between any trip origin and destination. The networks for the six city types are shown in Figures B-1 to B-6. These diagrams also indicate the zone system that was used throughout the transportation analysis.



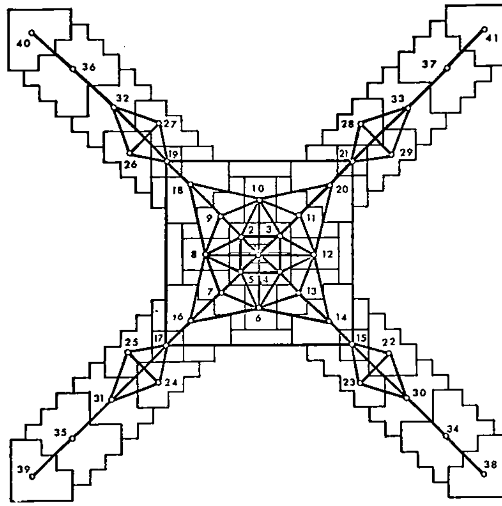
TOTAL 2-WAY LINKS =104

Fig. B-1 – Spider network UF-1A



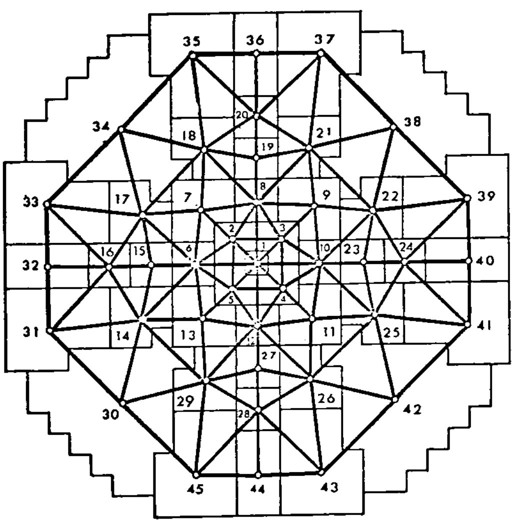
TOTAL 2-WAY LINKS = 108

Fig. B-2 – Spider network UF-1B



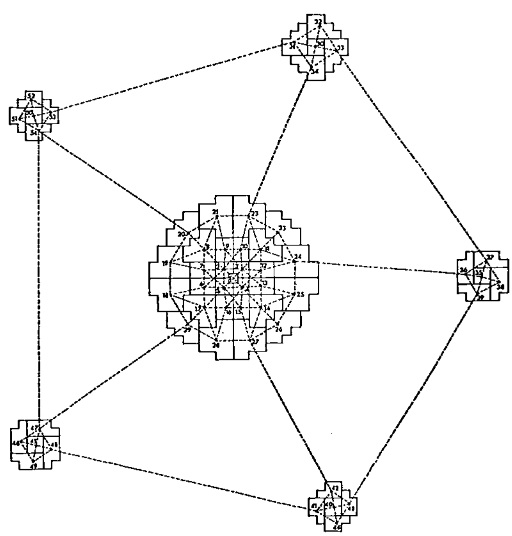
Total 2-way links = 82

Fig. B-4 – Spider network UF-3



TOTAL 2-WAY LINKS = 120

Fig. B-3 – Spider network UF-2



Total 2-way links = 122

Fig. B-6 – Spider network UF-5

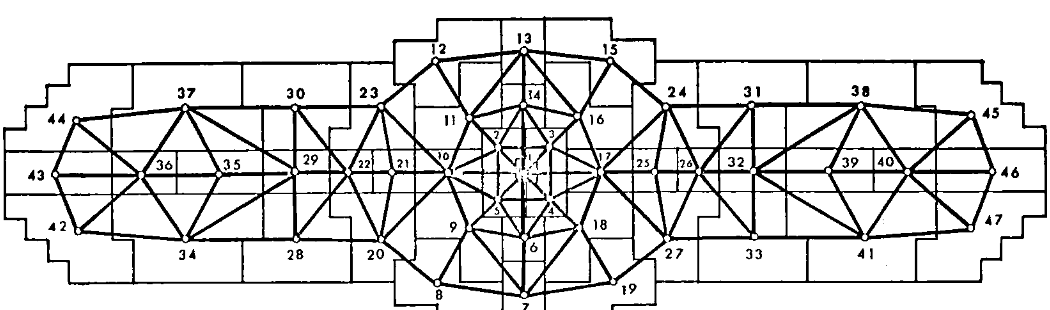


Fig. B-5 – Spider network UF-4

Total 2-way links = 114