SPATIAL INTERACTION MODEL ANALYSES USING METRO MANILA TRAFFIC FLOW DATA

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Abstract: The transportation problems of Metro Manila were analyzed and described using "Spatial Interaction Models" (Gravity and Entropy Models) in order to alleviate and manage the existing traffic congestion. The Gravity Model suggests that travel distance, monthly income and "jeepney" ownership all have varying effects on the population of the origin and destination areas. The Entropy Model, on the other hand, examined both origin-constrained ("from") and destination-constrained ("to") traffic flow in order to maximize entropy and minimize traffic congestion. Therefore, in order to achieve a state of minimum traffic congestion, the following should be attained: (1) population should be at its highest and travel distance, cost and time are at its minimum at the areas of origin; and (2) population and monthly income at its peak in the destination zones. The results will be beneficial in the study and use of land-use transportation models when forecasting future patterns of urban systems.

Key Words: Spatial Interaction Model, Gravity Model, Entropy Model

1. INTRODUCTION

Many developing countries around the world, particularly in urban centers, are experiencing problems related to transport – from congestion to environmental degradation – and Metro Manila is no exception. Heavy traffic has become "normal" for many people in the metropolis a situation described as having "too many vehicles, with too few rides" (Verzola, 1997:1). Heavy traffic definitely slows down the movement of people, goods and services resulting in higher opportunity costs. Moreover, the unregulated growth of motor vehicles in Metro Manila has greatly contributed to this problem.

Given this bleak transportation scenario, what then are the possible solutions to Metro Manila's transportation problems?

1.1 Objectives

Generally, the study aims to analyze and describe Metro Manila's traffic flow using "Spatial Interaction Models" in order to alleviate and manage traffic congestion. Specifically, the study aims:

- to assess the current urban transportation scenario in Metro Manila;

- to model trip behavior of Metro Manila residents using trip generation models and matrices;
- to examine "Origin-Destination" (O-D) matrices in order to calculate traffic flows and to predict bottlenecks in road networks; and
- to identify, evaluate and improve the current "Transportation Demand Management" (TDM) measures and policies in Metro Manila.

1.2 Research Framework and Methodology

The paper is divided into four major parts namely: (1) Urban Development Scenario; (2) Traffic Congestion and Transportation Mode Analyses; (3) Traffic Flow Analyses; and (4) Policy Recommendations. The first and the last parts will be qualitative in nature while the other two will be mainly quantitative in context. The major source of the data for the study will be the 1996 Metro Manila Urban Transportation Integration Study (MMUTIS).

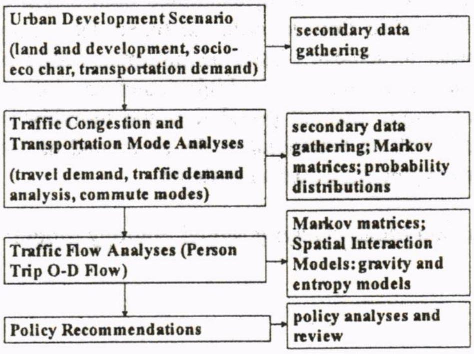

Figure 1. Research Framework and Methodology

The long-running cumulative impacts of these transportation problems have drained the economic and social vitality of the metropolis. It is for this reason that the MMUTIS was initiated, with funding and technical support from the Japan International Cooperation Agency (JICA). MMUTIS aimed to update empirical data, to apply knowledge, collaborate efforts and to efficiently allocate limited resources by updating a transportation database, formulating a comprehensive 20-year Master Plan for Transportation, and defining a priority program over the next six years (1999-2004).

2. OVERVIEW OF TRAFFIC DEMAND

About 78% of Metro Manila residents make daily trips and the average number of trips by a person above four years old is 2.3. There will also be a substantial increase in private motorized trips from 21% in 1996 to 34% in the year 2015. Whereas, a decline in public motorized trips and walking trips will be seen in the year 2015 and this can be attributed to the increase of motorized trips made by private vehicles.

When it comes to total number of daily trips, there is a 65% increase from 10.6 million in 1980 to 17.5 million in 1996. This can be attributed to the 63% increase in population from six million in 1980 to 9.5 million in 1996. Moreover, people with different socio-economic background differ in trip requirements wherein males (an average of 2.6 per day) make more trips than females (2.1). Car-owning households have more trips at 2.6 than non-car owning households who only have 2.2. Those with higher incomes (200,000 pesos monthly) make more trips (3.1) compared to those belonging in the lower income strata (3,000 pesos monthly income and 1.8 trips).

Car ownership and household income taken together, definitely takes into account the notion that the higher the income, the higher the possibility of car ownership. This means that those without cars are highest in the low-income bracket and lowest in the high-income bracket. Moreover, the number of cars owned increases as incomes become higher. A final note on car ownership, it is predicted that the number of cars will increase from 730,000 (18.5% of households) in 1996 to 2,340,000 (28.2% of households) in 2015.

Lastly on travel demand, different patterns of travel activities are exhibited throughout the day that corresponds to different trip purposes. During the day, trips tend to concentrate in the morning between six to nine and in the afternoon between four to seven. During the morning peak period of six to seven, "to-school" trips are the most significant traffic generators/attractors and at seven to nine, "to-work" trips are the most dominant. Since most people start and end their day at their homes, the most significant trip generator/attractors is the residence (47% of the total traffic demand) followed by educational facilities (18 to 19%) and office/commercial/trade facilities.

Moreover, traffic volume has intensified in all directions of Metro Manila since 1980. The most notable of these are found in the southern, northern and eastern part of the NCR. In 1980, the trips were largely confined within the area cordoned by the western part. As development took place along the east, trips started to gravitate toward this area converting it from a suburb and into an urban area. The number of trips had also increased at a very fast rate resulting to an increase both in travel distance and time.

According to the Philippine Transport Strategy Study conducted by the National Economic and Development Authority, traffic growth from 1995 to 2005 is expected to increase by as much as 50% and 100% in interurban areas and surrounding urban areas, respectively. Therefore, traffic demand is expected to double in ten years.

3. GRAVITY MODEL ANALYSES OF TRAFFIC ORIGIN-DESTINATION FLOW

Transportation problems, being experienced by society today, are among the most significant consequences of continued urban growth and sprawl. These problems have been dealt with much effort in order to search for transportation systems that are highly efficient, acceptable to the society, and compatible to the environment. Important in this search are the use and development of sophisticated mathematical models that can be used to analyze both simple and complex transportation problems. Moreover, these models pave the way for plans that will meet the transportation needs not only of the present but also of the future.

"Gravity and Entropy Maximization Models" belong to a class of trip distribution models which are based on the concept of network entropy (to be discussed in detail in the succeeding parts of the paper). In order to formulate gravity and entropy maximization as mathematical transportation models, trip distribution requires the determination of the number of trips f_{ij} from centroid i (origin) to centroid j (destination), given the total number of trips a_i produced at i, the total number of trips b_j attracted to j, and the cost c_{ij} of a trip from i to j. The essence of the mathematical models is the functional dependence of f_{ij} on the a_i, b_j and c_{ij}.

The gravity model has been the most widely used distribution model in transportation planning and has formed the basis of traffic predictions for many cities (Potts and Oliver, 1972). The model takes into account the various differences in frequency distributions of different trips. It also takes into account the "length" of the trips which is usually measured by one of the following factors such as distance, travel time and travel cost.

The gravity model is based on mathematical assumptions that resemble Newton's law of gravitational attraction. Gravity models are also a particular case of the broader class of spatial interaction models. Newton asserted that the force of attraction, F, between two bodies is the product of their masses m_1 and m_2, divided by the square of the distance between them, d_{12}^2:

$$F = {G \cdot m_1 m_2}\Big/{d_{12}^2} \tag{1}$$

where G is the universal constant of the pull of gravity.

Translating this into a transportation-geographical context (spatial interaction), force is regarded as the number of flows (in this case, trips) between two regions and treat mass as a structural variable such as population size. With these base calculations, it is possible to measure a region's capacity either to generate or to attract trips, representing distance in physical terms or in some surrogate form (e.g., travel cost or travel time). The basic gravity model is obtained:

$$T_{ij} = k \cdot \frac{W_i W_j}{d_{ij}^{\alpha}} \tag{2}$$

3.1 Input Data and Assumptions

The Metropolitan Area, also known as the National Capital Region (NCR), consists of 17 cities and municipalities. In this paper, the National Capital Region is subdivided into the following groupings for ease of computation and analyses (especially for the modeling process which calls for a limited number of variables): *Metro Manila*, *Intermediate North* (Malabon, Navotas and Valenzuela), *Intermediate East* (Quezon), *Intermediate South* (Pasay, Makati, Mandaluyong), *Outside North* (Marikina and Caloocan), *Outside East* (Pasig, Pateros and Taguig), and *Outside South* (Paranaque, Las Pinas and Muntinlupa).

Table 1 outlines the origin-destination flow of person-trips at the National Capital Region (NCR). The person trip survey takes into account the movement of people and not of vehicles. The vertical column represents the origin-constrained data ("from") while the horizontal column expresses the destination-constrained ("to") data. In this particular survey (taken by MMUTIS in 1996), there are a total of 44,352 person trips done at a particular day at a particular time.

Table 1. Origin-Destination Flow in the National Capital Region (Household Head Respondents)

to	Metro		Intermediate			Outside		Outside	
from	Manila	*North*	*East*	*South*	*North*	*East*	*South*	Metro	TOTAL
Metro Manila	2,579	510	1,801	1,634	760	503	632	983	9,402
Intermediate									
North	687	269	907	595	353	146	163	388	3,508
East	611	171	870	396	269	81	110	238	2,746
South	1,490	276	1,255	1,702	538	553	648	792	7,254
Outside									
North	463	164	635	456	237	160	161	336	2,612
East	941	197	1,169	938	432	344	386	573	4,980
South	1,299	340	1,325	1,120	586	357	599	862	6,488
Outside Metro	1,364	395	1,296	1,030	684	346	567	1,680	7,362
TOTAL	9,434	2,322	9,258	7,871	3,859	2,490	3,266	5,852	44,352

source: MMUTIS, 1997

3.2 Numerical Results of Gravity Model Analyses

Generalizing the basic gravity model (Equation 1), the following expression is obtained:

$$f_{ij} = k \cdot \frac{P_i^{\alpha} P_j^{\beta}}{D_{ij}^{\gamma}} \tag{3}$$

where f_{ij} is the transportation flow from i to j, k as the constant; α, β and γ as the parameters that will be estimated using regression analysis. Although the concept still follows the simple linear regression analysis, the application and solution using the multiple regression analysis is more feasible since the equation now deals with more than two independent variables.

The gravity model above is based on the regression model, namely, a straight-line equation relating to the dependent variable f_{ij} to the independent variables alpha (α), beta (β) and gamma (γ). Theoretical considerations usually indicate that a linear equation is required. However, the linear equation may not sufficiently approximate complex or unknown theoretical models. Thus, in all cases of regression analyses, the resulting regression model should result from a combination of theoretical reasoning, practical consideration, and careful scrutiny of the available data (Hamburg and Young, 1994).

Transforming the basic gravity model into the natural logarithm, the new equation is as follows:

$$\log f_{ij} = \log k + \alpha \log P_i + \beta \log P_j - \gamma \log D_{ij} \qquad (4).$$

This logarithmic model implies that there is a constant *percentage* change in f_{ij} per unit percentage change in alpha (α), beta (β) and gamma (γ) as opposed to the straight-line model that implies a constant *amount* of change in the dependent variable per unit change in the independent variables. A final and important note in the purpose of predicting a model lies not in obtaining an equation that is the best fitting of the observed data, but rather in obtaining a model that will predict and hold well in the future.

The modeling process started with the use of the origin-destination table (Table 1) and the following socio-economic variables such as population, vehicle ownership and monthly income. The alpha (α) and beta (β) parameters were reserved for the origin and destination population data, respectively. While gamma (γ) working as a resistance employed the following variables: (1) distance, (2) travel time, (3) travel cost, (4) monthly income, (5) vehicle ownership, (6) car ownership and (7) jeepney ownership. These are then subjected to multiple regression analyses where the R-squared (R^2, coefficient of determination which measures the strength of the relationship between the dependent and the independent variables), coefficients (slope), *T*-statistics (check of the equality of mean samples) and Significance *F* (determination of differences in variance) were all taken. The results are summarized in Table 2.

Table 2. Summary of Regression Results

	Population and Distance	**Population and Time**	**Population and Cost**	**Population and Monthly Income**
R Square	0.526900459	0.484141514	0.526900459	0.533000942
Coefficients				
α	-0.415181176	-0.347656576	-0.415181176	-0.498799253
β	2.167960065	2.282719574	2.167960065	2.199365302
γ	-0.639345482	-0.413034445	-0.639345482	1.11765891
t-Stat				
α	-1.104968412	-0.884511789	-1.104968412	-1.332373952
β	5.739137036	5.817871694	5.739137036	5.874862527
γ	-3.213891447	-2.413673314	-3.213891447	3.322470156
Significance F	2.81207E-07	1.81492E-06	2.81207E-07	2.12485E-07

Table 2. (continuation)

	Population and Vehicle Ownership	Population and Car Ownership	Population and Jeepney Ownership
R Square	0.420418714	0.423477687	0.731253145
Coefficients			
α	-0.21425243	-0.12742422	1.064562408
β	2.483912126	2.570740336	3.762726963
γ	-0.331426978	-0.412153821	-3.480280618
t-Stat			
α	-0.406889861	-0.231142971	3.04789142
β	4.717233129	4.663230914	10.77286136
γ	-0.589623539	-0.763518449	-7.186129342
Significance F	2.20701E-05	1.97091E-05	1.29413E-12

Taking into account the results with an R^2 of 0.50 and above, the following pairs were taken to be highly significant for the gravity model: (1) population and distance, (2) population and travel cost, (3) population and monthly income, and (4) population and jeepney ownership. The *T*-statistics and Significance *F* are all significantly low which make the results highly reliable. Moreover, the identification of the coefficients plays an important role in the analysis and application of gravity models.

The basic gravity model expresses that gamma (γ) should be a resistance to the network flow from origin to destination. For example, if gamma (γ) is taken as the distance, this implies that the farther one zone is to another zone, the fewer the trip movement is between the two areas (distance decay). Likewise, if the distance is shorter between two zones, it is to be expected that there is more travel demand between these zones.

Among the significant results, "population and jeepney ownership" adheres most to the basic gravity model. It is obviously the best fitting, since, among the models, it has the highest R^2 compared with the other pairs. It can also mean that that the response variable (actual trip) has inherent variability on the explanatory variables (population of origin and destination and jeepney ownership). Moreover, if alpha (α) is bigger than gamma (γ), which is 1.0645 and –3.4802 respectively, the resistance is very dominant. Therefore, jeepney ownership does play an important role in the movement of trips from one zone to another or the lack of movement thereof. Suffice to say, the jeepney has been the most popular commuting mode in Metro Manila, and jeepney owners who are very likely to be using this mode for business (jeepneys are for hire) definitely move from one zone to another. However, the constraint being the ownership of jeepney, lies on the fact that jeepney drivers in Metro Manila are only allowed to ply certain routes within their zones. The jeepney drivers and owners are less likely to go from one zone to another since, firstly, jeepneys are only allowed to ply a limited and fixed route and secondly, longer routes are already sufficiently and efficiently handled by buses.

Of the other significant pairs, "population and monthly income" is fascinating due to the fact that its alpha (α) is negative and its gamma (γ) is positive. Gamma (γ) has always been taken as resistance to travel, say, for example, distance. In this case, gamma (γ) being positive and alpha (α) being negative (thus, γ being bigger than α) means that income is not a deterrent to traveling from one zone to another. It is usually taken that the when incomes are low, people have a lower propensity to travel farther. The results certainly dispel the latter argument since income itself does not restrict the movement of people to different zones. What deters the residents of Metro Manila and the other zones, with respect to their monthly incomes, is that their places of origin have more to do with their travel choices rather than their monthly incomes. Thus, a person with a higher income, who is known to have a higher propensity to travel farther, restricts his traveling to areas within his zone or to zones that are relatively nearer. Conversely, a person with a lower income may have to travel farther for a particular travel purpose. No matter what the income is, a person still has to travel, or the lack thereof, to arrive at his destination. Therefore, income (taken as gamma) is not a deterrent to travel between different zones but the origin itself may restrict the movement of persons.

The last two significant pairs being "population and distance," and "population and travel cost," both have negative alpha (α) and gamma (γ) coefficients. In this case, beta (β), which is destination, dominates the flow. Destination (β), being positive, plays a very dominant role in the travel behavior of Metro Manila and non-Metro Manila residents. By going back to the origin-destination figure (Table 1), the distances of some regions may be far apart but, still, the demand is very high. For example, those living in the Outside South travel a lot to Metro Manila and so do those living in Metro Manila traveling a lot to the Outside North. On the other hand, those coming from the Intermediate East seldom travel to Metro Manila despite its given short distance.

The explanation for travel distance and travel cost is very much the same since travel distance is directly proportional to travel cost. The farther the trip activity, the more expensive it becomes. In this case, origin, cost and distance are all resistance factors when Metro Manila and non-Metro Manila residents decide to travel. Thus, more expensive and farther trips entail less transportation demand. However, as stated earlier, destination is still dominant and a number of persons will eventually discount travel cost and distance for the sake of arriving at their appointed destination.

A note on urban transportation and its effect on geography are clearly evident in this scenario. The growth and urbanization of the National Capital Region has paved the way for an increase in the number suburbs and new industrial and economic centers. These areas shied away from the crowded and expensive capital city of Metro Manila. This outward movement brought about an increase in travel time and cost when commuters have to go to Metro Manila. Consequently, this phenomenon has led to more travel time and congestion on certain roads in different areas of the capital. For the people in NCR, distance and cost can still act as deterrents to travel activities but when they have to go to a particular destination, these issues of distance and cost are laid to rest.

A last look at the regression results may entail wonder why travel time is not directly related to travel distance. The reason is mainly attributed to the fact that travel time in Metro Manila depends solely on road traffic volume during different times of the day. Various travel times are attributed to the same road network during different periods of the day. This scenario makes distance act as a constant and time as variability. Thus, this situation represents that both travel time and distance are not related except if travel times are studied at the same time intervals in different days.

4. ENTROPY MODEL ANALYSES OF TRAFFIC ORIGIN-DESTINATION FLOW

The concept of entropy, familiar in thermodynamics and information theory has been one of the most commonly used in trip distribution models. It also offers a theoretical framework for spatial interaction models. Having its base on statistical mechanics, entropy is primarily concerned with finding the degree of likelihood of the final state of a system. Data for urban systems are not easily available (thus, having a dearth of transportation data needs). There is obviously, a need for a method that makes reasonable estimates of the likely state of an urban transportation system using the information that is abundantly available. In this sense, maximized entropy is subjected to constraints of known information.

There are two important concepts in entropy that are applied to urban contexts (and in this case, transportation) - the macrostate and the microstate. The transportation system comprises of flows between origins and destinations. It is then assumed that the macrostate description of transportation is the number of individuals flowing between origins and destinations. This macrostate is composed of many microstates wherein it is a description of the actual individual or items that make up a macrostate. Just as there are many possible arrangements of individuals that could make up a train of hundreds of commuters traveling from one location to another, there are many possible microstates that can make up a given macrostate.

The number of microstates associated with any given macrostate can be calculated as:

$$\rho = \frac{N!}{\prod_{i}^{n} N_i!} \tag{5}$$

where ρ is the number of microstates associated with any given macrostate for the system, N is the number of individuals or items assigned to asset of categories, N_i is the number of individuals in a category i, $N!$ is the factorial value of N: $N(N-1)(N-2)(N-3)\ldots(N-n)$, and $\prod_{i}^{n}$ is the product of the factorial value.

The concept of network entropy can then be introduced in terms of the dimensionless quantities of ρ_{ij} as seen in Equation 6. The quantity of ρ_{ij} is interpreted as the joint probability of a trip being produced at zone i and attracted to zone j, implying the following constraints:

$$0 \le \rho_{ij} \le 1, \tag{6}$$

$$\sum_{i,j} \rho_{ij} = 1 \tag{7}$$

From Claude Shannon's entropy (where he used it as a measure of information), the following optimization problems are defined:

(i) maximizing the entropy:

$$H = -\sum_i p_i \log p_i \tag{8}$$

(ii) minimizing the "congestion:"

$$C = \sum_i l_i p_i \tag{9}$$

where l_i represents the appropriate integer ratio corresponding to the "congestion." Optimal solution to the problem above can be given as:

$$p_i = W_0^{-1}{}_i$$

$$i = 1,2,\ldots,\mathrm{n}$$

$$W_1^{-1} + W_2^{-1} + \ldots W_n^{-1} = 1, \tag{10}$$

where W_0 is the solution to the equation above.

The definition of one-factor entropy is the same as that used in thermodynamics and information theory and the familiar conventions such as the following are adopted herein. Firstly, entropy is nonnegative and concave:

$$-\rho_{ij} \ln \rho_{ij} \text{ is concave, for } 0 < \rho_{ij} < 1 \qquad (11).$$

Secondly, the entropy of a probability distribution that represents a completely certain outcome is zero and the entropy of any probability distribution representing uncertain outcomes is positive:

$$-\rho_{ij} \ln \rho_{ij} = 0, \quad \text{for} \quad \rho_{ij} = 0,1 \qquad (12),$$

$$-\rho_{ij} \ln \rho_{ij} > 0, \quad \text{for} \quad 0 < \rho_{ij} < 1 \qquad (13).$$

Lastly, given a fixed number of outcomes, the maximum possible entropy is that of the uniform distribution:

$$0 < \rho_{ij} < 1 \text{ has a maximum of } \ln n^2 \text{ when all } \rho_{ij} \text{ are equal} \qquad (14).$$

The network entropy, as stated earlier, is a measure of uncertainty, and entropy distribution models are based on the principle that *an equilibrium distribution maximizes the entropy* (Potts and Oliver, 1972).

4.1 Input Data and Assumptions

The notion of entropy, as discussed earlier, is concerned with finding the degree of likelihood of the final state of a system. This problem is based on the idea that data for transportation systems are not readily available. Thus, entropy maximization results are based on making reasoned estimates on the likely state of an urban system using information that is not available, subject to the constraints of known information.

The origin and destination constraints will be separately analyzed in the formulation of the entropy models. As seen in Table 1, it does not necessarily follow that a symmetrical relationship with respect to origin and destination arises. This means that people living in a certain zone do not only travel within their zone of residence, but also travel to zones outside of their zone.

The data from the origin-destination table will be used both for the origin-constrained ("from") traffic flow data and destination-constrained ("to") models. In the entropy modeling process, the "Metro-Manila-to" and "from-Metro-Manila" data will be removed in order to avoid favorably skewing the data towards Metro Manila. In this regard, other zones will act as outliers and the results will not be able to represent the dynamism among the zones.

The solution of the entropy model requires information that would explain the factors behind transportation cost. Therefore, the models calls for a maximized entropy with a minimized travel cost. As entropy models require no set criteria for the state of information that is to be gathered (due in part to the difficulty of data gathering), the available data (culled from different socio-economic variables available for this study) will be used in the analysis. Therefore, the available data become the constraints when dealing with entropy models.

The entropy maximization modeling process is as follows. Firstly, the collection of transportation data in these two areas is needed: (1) origin-destination traffic flow data, and (2) socio-economic and transportation-related variables. Secondly, a trial-and-error method is employed to choose socio-economic and transportation-related variables that more or less follow the distribution pattern of the origin-destination data. Thirdly, integer ratios, from a low of one to a high of ten, are given to the optimal combination of variables from the previous step. Fourthly, the entropy probabilities are taken from the one-factor entropy table. Lastly, the entropy probabilities and the original origin-destination distributions are plotted in a graph and compared. If the two distributions more or less follow the same trend, then the optimal solution to the model is found. If not, the process is repeated all over again until the likely probabilities (entropy) are found.

The first part of the entropy modeling process has been accomplished since the first set of data being the origin-destination data has already been culled. The second set being the socio-economic variables will also be selected from the list of socio-economic variables used in the gravity modeling process. The use of socio-economic variables may not be instantly attributed to transportation as opposed to the transportation-related variables such as travel time, cost and distance. These variables after careful examination will produce the necessary information to explain the principle of entropy being maximized while price levels are minimized.

4.2 Entropy Maximization Model Results of Origin-Constrained ('From") Traffic Flow

The origin-constrained "from" traffic flow (from Metro Manila to another zone) and has the following share components with respect to total flow share which are arranged from a descending order: (1) *Intermediate East* (1801 trips, 30.8390%); (2) *Intermediate South* (1634 trips, 27.9795%); (3) *Outside North* (760 trips, 13.0137%); (4) *Outside South* (632 trips, 10.8219%); (5) *Intermediate North* (510 trips, 8.7329%); and (6) *Outside East* (503 trips, 8.6130%).

The process for the origin-constrained ("from") traffic flow started by arranging the percentage shares of the zones from the highest to the lowest. Through trial-and-error, different variables were tested in order to obtain percentage shares with are more or less very near the actual origin-destination percentage share data. After careful, computation, iteration and analysis, the following variables were found to be significant in the case of origin-constrained date: travel distance, travel cost, travel time and population (Table 3).

Table 3. Results of Origin-Constrained Entropy Model

	Distance	Cost	Time	Population	D+C+T/P	IR	Entropy
Intermediate East (IE)	5	5	25	1.775	19.718310	3	0.308
Intermediate South (IS)	6	5.5	30	1.192	34.815436	4	0.229
Outside North (ON)	10	6	40	1.306	42.879020	6	0.171
Outside South (OS)	11	7	40	1.202	48.252912	7	0.127
Intermediate North (IN)	7	5.5	35	0.968	49.070248	8	0.095
Outside East (OE)	9	6.5	40	0.934	59.421842	10	0.071

The variables were not to be taken at face value. Instead, as seen in Table 3, a new variable (dummy) has been created wherein "D+C+T/P" stands for the summation of distance, cost and time divided by the population. This process also entailed the trial-and-error method. The results of the "D+C+T/P" variable follow the same descending order of the original origin-destination share that shows promise with regard the possible similarity of distributions between the original origin-destination share and the soon-to-be calculated entropy probabilities.

The "IR" column of Table 3 stands for the integer ratios (Kunisawa, 1975). This part also entails a trial-and-error method wherein different integers ranging from one to ten are assigned to the new variable ("D+C+T/P"). After coming up with the most suitable ratios, these ratios were then extrapolated from the one-factor-entropy table and the resulting probabilities were taken.

Restating the general principle of entropy, *"out of all probability distributions satisfying given moment constraints together, with the natural constraint on the probabilities, choose the distribution that is closest to the given a priori probability distribution,"* the origin-destination share and the results of the entropy model were both plotted in one figure (Figure 2) to see if the entropy principle applies. By inspection, the two curves are very close to each other and this means that the results of the entropy model are sufficient. Furthermore, these probability distributions will be the most likely origin-constrained shares in the future.

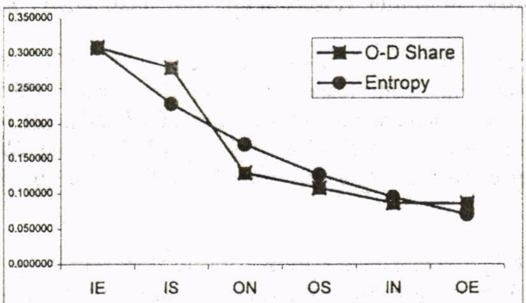

Figure 2. O-D Share and Entropy in Origin-Constrained Traffic Flow

The resulting entropy means that, the chosen variables, travel distance, travel cost, travel time and population have a significant relationship with the origin-constrained data and the resulting entropy probabilities will likely hold true in the future. Moreover, distance, cost and time are all complementary to the maximized entropy while population has a substitute relationship. The latter is due to the fact, that its inverse is needed in order to come up with a mix of likely distributions while the former can stand as is.

The results suggest that in order to maximize entropy and minimize traffic congestion, travel distance, travel cost and travel time must be taken at its minimal state and population at its highest. The shorter the distance, the lesser time, the cheaper the cost and the higher the population, there will definitely be a scenario which involves very little traffic congestion. Thus, this type of distribution that is presently prevailing will likely to happen as well in the future. Planning for this scenario will be helpful in improving the transportation networks and the overall urban quality of life.

5.3 Entropy Maximization Model Results of Destination-Constrained ("To") Traffic Flow

The same process is applied to the destination-constrained traffic flow data. The destination-constrained ("to") traffic flow (from other zones to Metro Manila) has the following share components with respect to total flow share which are arranged in a descending order: (1) *Intermediate South* (1490 trips, 27.2353%); (2) *Outside South* (1299 trips, 23.6569%); (3) *Outside East* (941 trips, 17.1371%); (4) *Intermediate North* (687 trips, 12.5114%); (5) *Intermediate East* (611 trips, 11.1273%); and (6) *Outside North* (463 trips, 8.4320%).

After iterating the socio-economic and transportation-related variables also used in the origin-constrained traffic flow data, the following variables were found to be significant in these case: "population and monthly income." Table 4 summarizes the results of the network entropy modeling process while Figure 3 represents the extrapolated data taken from the one-factor-entropy table.

Table 3. Results of Destination-Constrained Entropy Model

	Population	Income	P+I	1/P+I	IR	Entropy
Intermediate South (IS)	1.192	2.225	3.417	0.292654	5	0.285
Outside South (OS)	1.202	1.902	3.104	0.322165	7	0.173
Outside East (OE)	0.934	1.078	2.012	0.497018	9	0.105
Intermediate North (IN)	0.967	0.899	1.866	0.535906	10	0.081
Intermediate East (IE)	1.775	1.269	3.044	0.328515	6	0.222
Outside North (ON)	1.306	1.044	2.350	0.425532	8	0.134

In the case of destination constrained traffic flow data, the new variable that was created is "1/P+I" that stands for the inverse of the sum of population and monthly income. Having taken their inverse, population and monthly income is said to have a substitute relationship. The results are of the same descending order found. However, the last two variables did not reflect a continued downward slope for these two abruptly increased (Intermediate East) and slightly decreased (Outside North), respectively. Therefore, plotting both entropy maximization likely probabilities and destination-constrained percentage share in Figure 3 show that the new distribution is relatively close to the original share only up to the first four zones.

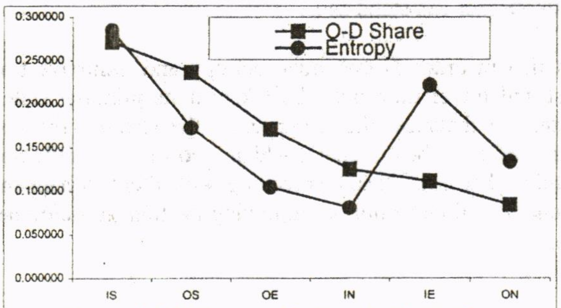

Figure 3. O-D Share and Entropy in Destination-Constrained Traffic Flow

The results suggest that in order to maximize entropy and minimize traffic congestion, population and monthly income must be at its peak. However, in the future, as seen in the likely probabilities, the share for the Intermediate East has abruptly increased and so does the share of the Outside North. This can be attributed to the very high population of these zones as well as its high monthly incomes. This has also been seen in the previous tables and figures and that the residents from these areas are less likely to move from one zone. The results above can improve future policy and planning activities in these regions, and more importantly, the last two regions. The Intermediate East and Outside North should be planned accordingly. Urban planning and policy can improve the situations of not just these two regions, but also all of the National Capital Region itself.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

Form the traditional city center, Metro Manila, the metropolitan region (National Capital Region) has expanded and metamorphosed into a polycentric structure. Given these changes, the metropolis is plagued with many problems. However, one problem can be really just a result or a residual of a more fundamental one. To really understand these interrelationships is the job of the policymakers, planners, researchers and the society as a whole.

The following urban planning issues were concluded from the study:

- sub-urbanization has not decreased the density on inner areas with the stepping-in of various activities;
- land uses have transformed into mixed-activity giving away to competing uses of existing road spaces (i.e. no clustering of land-use activities, thereby increasing road congestion)
- infrastructure has not been improved and the environment is deteriorating;

- the spatial separation of residences from workplaces and educational centers has worsened. With more households opting to live outside Metro Manila and farther away from jobs and schools, the number of trips and trip distances has increase proportionately (therefore, movement to different zones causes congestion in inter-zone road networks);
- motorization has increased rapidly. During the period from 1980-1995, the number of registered vehicles has increased at an average of six percent per year. The increase in private car use is especially high. It is a fact that 40% of all vehicles registered in the Philippines are concentrated in Metro Manila;
- the percentage of car-owning households has jumped from ten percent in 1980 to 20% in 1996;
- the growth in travel demand since 1970 is quite dramatic – from less than seven million motorized trips a day to 10.6 million in 1980 and 17.5 million in 1996.

From the models, it could also be stated that the overall urban quality of life has deteriorated since people have to travel more and pay more for trips in different zones. The destination, regardless, of other factors has been a dominant force in trip choices even if it means more burdensome on the commuter's part.

It is therefore recommended that:

(1) the use of land-use transportation models to forecast future patterns of urban systems be strengthened and institutionalized (such as the institutionalization of the "Traffic Impact Analysis"), and;

(2) urban planning and redevelopment with emphasis on transportation demand management since road networks (supply) are very limited.

Transportation Demand Management (TDM) measures will be used at present in order to partially alleviate the problems of traffic congestion. TDM measures include:

- land-use controls (such as administrative approvals in the form of traffic impact statements);
- discouragement of private car use and ownership;
- public transport operations (such as mass transport facilities, allocation of high-occupancy vehicle lanes); and
- traffic signalization improvements (engineering aspects).

Lastly, as with most solutions to compounding urban problems, it is important that a holistic and integrated approach to policy planning and implementation is applied.

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REFERENCES

Bowman, A.W. and Robinson D.R. (1990) **Introduction to Regression and Analysis of Variance: A Computer Illustrated Text.** Bristol: IOP Publishing Ltd.

Fang S.C., et al. (1997) **Entropy Optimization and Mathematical Programming.** Massachusetts: Kluwer Academic Publishers.

Hamburg, M. and Young P. (1994) **Statistical Analysis for Decision Making (Sixth Edition).** California: Duxbury Press.

Hamerslag, R. and Immers BH. (1990) Estimation of trip matrices: Shortcomings and possibilities for improvement, **Transportation Research Record 1203,** 27-39.

Kunisawa, K. (1975) **Entropy Models.** Tokyo: Kabushikigaisha Nikkagiren shuppasha (in Japanese).

Metro Manila Urban Transportation Integration Study (1997) **Transportation Demand Characteristics Based on Person Trip Survey (MMUTIS Technical Report No. 4).** UP-NCTS, DOTC, DPWH, NEDA, PNP-NCR, EMB, JICA, August.

National Economic and Development Authority (2000) **Philippine Transport Strategy Study (Volume 1).** Makati City, Philippines.

Potts, R.B. and Oliver R.M. (1972) **Flows in Transportation Networks.** London: Academic Press.

Sidro, M.J. (1998) **Entropy Modeling Approach in Japanese Coastal Shipping Transport (Master's Thesis).** Graduate School of Policy Science, Saitama University, Japan.

Srivastava, A.S.M. (1990) **Regression Analysis: Theory, Methods and Applications.** New York: Springer-Verlag.

Torrens, P.M. (2000). **How Land-Use Transportation Models Work.** Working Paper Series No. 20. Centre for Advanced Spatial Analysis: Univeristy College London, April.

Verzola, R. (1997) Transport and society, **Paper presented during the Greening Urban Transport Forum,** Ateneo de Manila University, Philippines, December 11-12.