Intermodal Network Accessibility in Eastern Asia: System Building and Case Studies

Chapter 1

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Antonio Paez
Kazuaki Miyamoto
Eri Yamada
Keiichi Kitazume
Yoshiyuki Tokunaga

Abstract: The globalization process observed during the last decade contributed to the rise of international economic blocks worldwide. Eastern Asia, for years a hot spot of economic growth, is an immediate example of this trend. It is conventional wisdom that such regional economies would have not surged, and would not remain viable, without supporting infrastructure and services – in particular transportation. So far there have been no attempts, however, at measuring the levels of accessibility, the main product of a transportation network, at the continental level in Eastern Asia. In this study we adopt an indicator of accessibility and use a Geographic Information System to estimate continental accessibility levels, and then examine the relationship between accessibility and economic growth. Furthermore, as an example of the kind of scenarios that could be explored using our system, we estimate accessibility gains due to two hypothetical situations involving new transportation facilities and regional socioeconomic changes.

1. INTRODUCTION

The globalization process observed during the last decade contributed, through a combination of better communications, more integrated markets and competition, to create international economic blocks of various sizes and scales. Eastern Asia, for years a hot spot of economic growth, is an immediate example of this worldwide trend. Economic blocks in the region include the Northeast Asian Sub-Region, followed by the Yellow Sea Sub-Region, the South China Economic Zone, the Mekong Economic Zone, as well as the "Indonesia-Malaysia-Thailand" Growth Triangle, the Singapore-Johore-Riau Economic Zone, and the Baht Economy among the most important (figure 1). In addition, another large-scale Free Trade Area in the ASEAN region has been proposed (AFTA: ASEAN Free Trade Area). Since the total population of the ASEAN region is as large as 480 million, it represents one of the largest markets in the world, comparable to, and potentially competitive with EU and NAFTA. Although current regional demarcations of economic zones in Asia are more or less informal, the lack of a hard definition does not detract from the reality of economic integration. It is generally agreed that the factors leading to economic integration and the creation of regional economies are likely to be varied and complex. In this study, however, we concern ourselves with arguably one of the most important among them. Conventional wisdom has it that economic blocks such as those mentioned above would not have surged and hereafter would not remain viable without supporting infrastructure and services – in particular transportation. It is therefore generally accepted that well-organized transportation networks are the *sine qua non* of economic growth and the development of regional economies. So far, however, we are not aware of any study that estimates, in an Eastern Asian context, the levels of accessibility (the main product of a transportation network), or that relates accessibility to economic production in the region. The reasons for this apparent lack of attention include the difficulties associated with building a large and comprehensive data base for as many as 20 countries and regions, on top of the technical difficulties of processing and analyzing large amounts of data to obtain coherent and easily interpretable output.

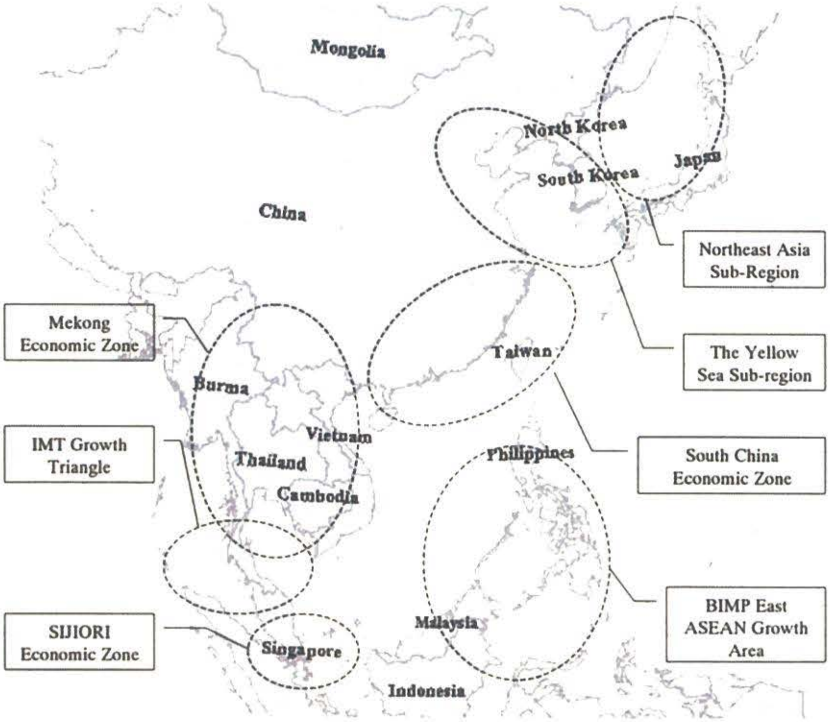

Figure 1. Regional Economies in Eastern Asia

In this study we address the above points by adopting an indicator of accessibility that is at the same time simple and theoretically sound (section 2), and by basing our analysis on a Geographic Information System, whose database, and graphical and analytical capabilities greatly facilitate the analysis of data and the presentation of results (section 3). In particular, we draw from the European EUNET project (Schürmann *et al.*, 1997) that aims to explain economic development using factors ranging from accessibility to demographic conditions. The objective of the present study is twofold: firstly, we attempt to quantitatively evaluate the levels of accessibility in the Eastern Asia Region, and secondly we examine the potential link between transportation development and the generation and growth of regional economies.

To achieve these goals, we build a region-wide GIS database that includes economic production and demographic data for a large number of major cities, in addition to length, cost, speed, travel time and other link attributes for an extensive roadway-airway Asian network (section 3). Based on this data and powerful GIS-based network analysis capabilities, we calculate disaggregated accessibility indicators for nearly 700 major cities, and map the results to depict continental accessibility levels throughout the region (section 4.1). Following, we explore the relationship between the accessibility levels thus obtained and economic production (section 4.2). These results show the current situation of accessibility and economic production in the continent. Finally, as an example of potential applications, we examine two hypothetical situations in which new transportation facilities and/or services are introduced (section 4.3), or geo-political circumstances change (section 4.4). In the conclusions (section 5) we summarize our findings and suggest some possibilities for further research.

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2. ACCESSIBILITY INDICATORS

Accessibility is a term used in common parlance to signify nearness, proximity, or more generally ease of interaction: a place is accessible when it is easy to reach, and conversely accessibility is bad when it is difficult to reach. In a more technical sense, accessibility represents the configuration of opportunities for interaction between locations in space. The concept of accessibility has played, since its inception and for some time now, an important part in regional science, trade, and particularly transportation studies (Martellato and Nijkamp, 1998). It is not difficult to find examples of studies that have put the concept of accessibility to work, including some that focus on the relationship between transport and urban form, investigate the effects on growth by infrastructure projects (Schürmann *et al.*, 1997), or include measures of accessibility as elements in models of travel behavior (Bhat and Zhao, 2001). Indeed, in the most recent World Conference on Transport Research (Seoul, 2001), over 170 papers were presented that discussed, applied or extended the concept of accessibility, thus demonstrating its popularity and power to describe and study spatial interaction configurations.

In mathematical terms, accessibility is defined as a multiplicative function of two elements. The first element is an activity function or weight, which represents a measure of how attractive a location is, whereas the second element is an impedance function, controlled by travel or interaction costs, and thus determined by the position within, and the state of a network. This definition is more specific than the layman's usage of the term accessibility, because it is meant to indicate not only how easy it is to move between locations, but also how attractive locations are. The refinement is important because clearly big cities are more attractive than small cities, commercial centers with many shops are more attractive than single shops, and industrial parks are more attractive than isolated industrial facilities. In its most general form, the accessibility A_i for location i is given by an expression such as:

$$A_i = \sum_j g(W_j) f(c_{ij}) \tag{1}$$

In (1) above, $g(W_j)$ is the activity function, that is, the function that measures the attractiveness or weight (W_j) of location j (j= 1, ..., n; the number of destinations). The impedance function $f(c_{ij})$, on the other hand, quantifies the ease of moving from location i to location j based on cost c_{ij}. It is clear that the larger the weight, the higher the accessibility. Impedance is naturally assumed to be a decreasing function on its argument, and therefore, as cost increases the attractiveness is progressively discounted for the purposes of interaction. Reggiani (1998) and Schürmann *et al.* (1997) review a number of accessibility measures, including commonly used functions such as lineal, inverse, quadratic and exponential among others. Some of these are shown below in table 1.

Table 1. Accessibility Measures

Conventional Accessibility Measures	Activity Function	Impedance Function	Formulation
Potential of Opportunity	W_j	$\exp(-b \cdot c_{ij})$	$A_i = \sum_j W_j \exp(b \cdot c_{ij})$
Travel Cost	$W_j = 1$ if $W_j \geq W_{min}$ $W_j = 0$ if $W_j < W_{min}$	c_{ij}	$A_i = \sum_j W_j c_{ij}$

Daily Accessibility	W_j	1 if $c_{ij} \leq c_{max}$ 0 if $c_{ij} > c_{max}$	$A_i = \sum_j W_j c_{ij}$

Source: Adapted from Reggiani (1998) and Schürmann *et al.* (1997)

These measures of accessibility have interpretations that make them suitable to certain applications. For instance, in the case of daily accessibility, the cost could be measured in terms of travel time with maximum travel times c_{max} of 3, 4 or 5 hours as the limit for daily interaction (e.g. the places accessible for a one-day round business trip). In the present study, we opt for a lineal function for the case of the weights, and a negative exponential function for the impedance, to give an indicator of accessibility of the following form:

$$A_i = \sum_j W_j \exp(-b \cdot c_{ij}) \qquad (2)$$

The above formulation is founded on the theoretically sound and well-established concepts of agglomeration economies and distance-decay. In addition, its simple form with only two arguments (W_j and c_{ij}) and one parameter (b) allows us to experiment, without much difficulty, with various parameter definitions, which in turn permit different interpretations of the meaning of accessibility. This is further discussed in sections 3.3 and 4. Moreover, since we deal with the Asian roadway-airway network, we adopt a definition of intermodal accessibility in which the cost is decomposed in two parts, one corresponding to each mode – road (r) and air (a):

$$c_{ij} = c_{ij}^{r} + c_{ij}^{a} \qquad (3)$$

The analysis of intermodal networks is generally more complex than single-mode networks because it requires the ability to calculate the shortest (minimum cost) path between nodes including exchanges and modal switches. In the present study, we take advantage of powerful GIS-based network analysis functions (TransCAD) to calculate the cost of travel between nodes in the network, with the system automatically selecting the modes that minimize transportation costs. Network analysis is facilitated by the ability of our selected Geographical Information System to handle network data structures, matrix data structures, as well as other common data types such as tables, lines, areas, points, etc.

Variables commonly used to represent activity (or weight) include the size of target facilities, number of jobs, population, and economic production. Since presently our objective is to explore the relationship between accessibility and economic development, we decide to use the local share of GDP as a measure of attractiveness, which leads to the interpretation of accessibility as an indicator of the potential for economic interaction. A plausible alternative (which is not explored here) would be to use the local population, to give the potential for interpersonal exchanges. Measures of cost frequently found in the literature include distance, time, cost, or combinations thereof to obtain a generalized cost. In the case of the EUNET project (Schürmann *et al.*, 1997), time was used as a measure of cost. In an Eastern Asian context, time is of limited interest, because one important aspect of accessibility analysis here is thought to be the economic disparities among countries/regions. Other important differences with the European case are the geographical extent of the analysis, and the existence of immigration controls, which result in pecuniary as well as time costs. We thus opt for a generalized cost given by a combination of pecuniary and opportunity costs. Summarizing, the variables used by our system are economic (GDP, Local Share of GDP, Per Capita GDP), demographic (population), and link-related attributes to calculate transportation costs (length of link, speed, unit cost, etc.) These are used to build a GIS database as described in the following section.

3. GEOGRAPHICAL INFORMATION SYSTEM: DATABASE AND OPERATION

Data was collected for 17 countries/regions/cities in Eastern Asia (Table 1), and for the continental road-air network. Two types of data were used: geographical data (points to represent cities, lines for network links, areas to depict regions), and alphanumeric data for the corresponding attributes (GDP, costs, population, etc.) In some instances, data was not readily available, and it had to be derived from primary sources. This limitation, which argues for an integrated and comprehensive database for regional transportation studies, must be kept in mind when interpreting the results. Before describing the elements of our database, we briefly discuss the type of data structures that can be used to optimize and add flexibility to the performance of our system.

3.1 Data Structures

Geographical Information System commonly support two kinds of data: geographical data (points to represent cities, lines for network links, areas to depict regions), and alphanumeric data for the corresponding attributes (GDP, costs, population, etc.), usually stored in a tabular format compatible with spreadsheet and database packages. However, according to the characteristics of the analysis, and in particular of our accessibility model, in some cases alphanumeric data is better represented in matrix form to facilitate the integrated calculation within the GIS. In addition, network data structures are used to represent transportation networks, needed to calculate shortest path costs between origin-destination pairs. The availability of these data structures in the GIS allows a seamless integration with the transportation accessibility model. An example of the use of matrix data structures to calculate large-scale network accessibility is shown in section 3.5 below.

3.2 Population and Economic Production

In the present study, we consider the city as the basic unit of analysis. Geographical data was obtained from the World Geographic Data '99 (see Caliper Corp., 1999), which contains a large number of cities and other populated places. Other data regarding population and income was obtained from diverse sources, including Asian Development Bank and UN data. To reduce data gathering tasks and to maintain the size of the sample within manageable limits, we selected 682 Asian cities with populations above 100 thousand persons, and capitals regardless of the population. Data was matched by name with the cities in the geographical database. It is clear that the criterion of using only cities with 'large' populations is likely to introduce bias in the case of regions where there is a large component of rural population (for example, non-urban population in China was about 64% of the total in 2000). The alternative, however, of introducing a larger number of less populous settlements, is extremely data intensive especially considering that the data is not readily available in digital form. In any case, it is our guess that the bias is not extremely large and that the big picture will not be considerably altered by this omission. The total number of cities by region considered in the present study can be seen in the second column of table 2 below. 'Total' urban population considered only those cities in the sample.

As with population, local share of Gross Domestic Product is not a statistic readily available, and therefore, it must be derived from available (primary) data. In order to calculate the local share of GDP for each city (the measure of activity in Equation 2) was calculated using expression (4). In order to make this figure representative of urban economic production, only the secondary and tertiary sectors' contributions to GDP were considered. The local GDP was then calculated as a weighted average of total GDP with respect to population as follows:

$$W_i = D \cdot P_i / \sum_n P_i \qquad (4)$$

where:

W_i : City i – Local share of GDP

D : sum of secondary and tertiary sector components of GDP

P_i : City i – population

n : number of cities with population > 100 000 in the country/region

The third column of table 2 shows the total 'urban' GDP, followed by the figure for GDP per capita. An important point to keep in mind is that, by calculating the local share of GDP in the above fashion, we are smoothing away regional within-country differences – or in other words, we are assuming the distribution of income to be homogeneous. This is clearly an unrealistic assumption even for a country with more or less homogeneous income distribution as Japan, since income in Tokyo may be twice (or more) the income in less developed parts of the country (e.g. the Tohoku region). It is plausible, on the other hand, that the availability of more detailed data sets, would probably only accentuate the accessibility trends obtained in this manner. At this stage, and in the absence of more detailed data, this seems to be the most parsimonious solution. A quick examination of the table reveals that the largest economy in the region is Japan, followed by China, the most populous country in the area. It is therefore to be expected that these two countries will represent perhaps the two biggest components of accessibility – basically by dominating the region in terms of economic production, and number of connections available, conditional to the state of the network. After these two countries, we expect that South Korea and Taiwan, the third and fourth biggest economies in the region respectively will also be of some influence and therefore worth of attention during analysis and interpretation of results.

Table 1 Data Summary – Countries, Regions and Cities.

City/Region/Country	Number of Cities with Pop>100 000	Total Local GDP (USD)	GDP Per Capita (USD)	Value of Time (USD)	Purchasing Power Parity
Brunei	1	6,231.00	18000	9	0.735
Cambodia	1	4,514.99	715	0.358	0.029
China	390	679,517.17	3460	1.73	0.141
Hong Kong	1	153,732.91	23674	11.837	0.966
Indonesia	34	183,247.07	4600	2.3	0.188
Japan	143	4,447,313.76	24500	12.25	1
Laos	1	2,764.80	1150	0.575	0.047
Malaysia	11	89,994.46	11100	5.55	0.453
Mongolia	2	3,578.69	3460	1.1	0.09
Myanmar	8	54,168.40	262	0.131	0.011
North Korea	9	21,800.00	900	0.45	0.037
Philippines	34	68,243.93	3200	1.6	0.131
Singapore	1	91,336.18	24600	12.3	1.004
South Korea	21	494,206.47	13700	6.55	0.559
Taiwan	6	272,344.07	14200	7.1	0.58
Thailand	10	165,883.72	8800	4.4	0.359
Vietnam	8	18,274.53	1700	0.85	0.069

The value of time, an element needed to calculate generalized travel costs in the continent, was estimated individually for each country/region. In order to do so, it was considered that a working day is 8 hours long, and that the active year in general consists of 250 days. Again, more detailed data could be introduced to refine the analysis. Based on these considerations, the value of time was obtained from the following formula:

$$VT = E/(250 \cdot 8) \tag{5}$$

where E is the corresponding country/region/city GDP per Capita. Finally, a GDP-based Purchasing Power Parity was introduced to account for economic disparities in the region.

3.3 Road and Air Networks

In this study we calculate accessibility to economic production from the viewpoint of the Asian roadway-airway network, which can be seen in figure 2 below. The road network was obtained from the World Geographic Data '99 CD provided by Caliper, Corp., including information regarding the type and functional status of the links (Caliper Corp., 1999). All links of type 'paths and trails' were excluded from the original dataset, and where appropriate, new links were digitized. The links were classified according to size, status and importance, with classifications ranging from 'Road' to 'Double Lane' (a category unique to Japan and South Korea). The corresponding attributes are as shown in table 2. The air network was not available, and therefore we proceeded to digitize it in order to connect the 49 most important international airports in the region, obtained from the World Geographic Data files. We introduced two types of air links: active and project. For active lanes economy-class costs for one-way tickets were obtained from Air Tariff 2000 (IATA and SITA, 2000). It is worth noting that the costs were in general asymmetric, with different tariffs according to the direction of the flight, even between identical endpoints. In-flight times and distances were obtained from OAG Flight Guide (2000). Other attributes are as shown in table 2.

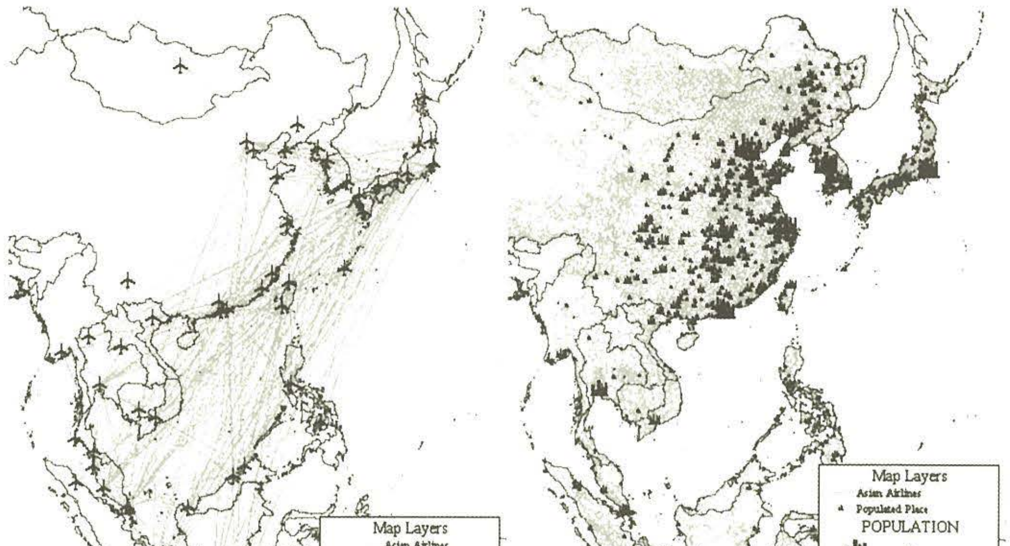

Figure 2 Asian Road-Air Network – Major Cities and Airports.

Table 2 Asian Road-Air Network – Link Summary, Speeds and Costs.

Link Type	Number of Links	Total Length (km)	Speed (km/h)	Cost
Road				
Asia Arterial Road	50303	789396.49	40	$ 0.05 / km
Asia Highway	3675	47257.86	80	$ 0.07 / km
Japan & Korea Arterial Road	10955	79693.26	60	$ 0.10 / km
Double Lane	826	5423.81	100	$ 0.30 / km
Air				
Air Active	379	864773.21	616.95	As per OD pair
Air Project	8	10821.81	616.95	$ 0.32 / km

3.4 Generalized Travel Cost

As discussed in section 2, accessibility is jointly determined by a measure of attractiveness, in this case local share of GDP by city, and an impedance function that depends on the cost. In this study we use a generalized cost measure, in which pecuniary (out-of-pocket) costs and opportunity costs are taken into consideration. Moreover, the cost has two different components, for the road and the air segments of each route (equation 3). The form of the components of the cost function is as follows:

$$c_{ij}^{r} = \sum_{t} l_{ijt} u_t + VT_i \cdot t_{ij} + v_j \qquad (6)$$

where

c_{ij}^{r} : Generalized road cost from city i to city j (USD)

l_{ijt} : total road length of link type t between city i and city j (km)

u_t : unitary transportation cost for link of type t (USD/km; see table 2)

VT_i : City i residents' value of time (USD/h, as per country/region; see table 1)

t_{ij} : total road travel time between origin city i and destination city j (h)

v_{ij} : Visa cost; 50 USD if a visa is required to travel from i to j, 0 else

The air cost component is as follows:

$$c_{ij}^{a} = C_{ij} + VT_i \cdot t_{ij} + v_j \qquad (7)$$

where

c_{ij}^{a} : Generalized air cost from city i to city j (USD)

C_{ij} : total air tariff between cities i and j (USD; unitary cost by length in the case of links of type project – see table 2)

VT_i : City i residents' value of time (USD/h, as per country/region; see table 1)

t_{ij} : total air travel time between origin city i and destination city j (h)

v_{ij} : Visa cost; 50 USD if a visa is required to travel from i to j, 0 else

In addition to travel time, we have set transfer penalties for moving between links of different types (i.e. switching modes) as follows: 2 hours for moving from a road link to an air link (as the estimated length of airport check-in procedures); 1 hour for moving from an air link to a road link; 1 hour for moving between air links (transit); and 0 hours for moving between road links. Network analysis is used to find the shortest (minimum cost) path between origins and destinations. In some cases this involves several transfers between modes; for instance, a trip starting in Beijing would go to the nearest international airport by road, by plane to Hong Kong, transfer to Chiang Kai Shek International and finally by road to Taipei. The result is a matrix of (minimum) generalized costs between locations that are adjusted by the PPP by origin (table 1), and that can be used to calculate the accessibility. This is further discussed in section 3.5 below.

Before accessibility can be calculated, however, it is first necessary to select parameter b in equation 2. This parameter (called an impedance parameter) defines the steepness of the decay curve and can thus be interpreted as a parameter of scale: small parameters produce flat curves (i.e. smoother rates of discount) whereas large parameters result in more dramatic short-distance rates of discount. This can be observed in figure 3. In the present context, there is no obvious procedure to estimate parameter b (for instance using statistical methods), and we must examine different situations and then justify the selection of a parameter by comparing the results to some other quantity, for instance per capita GDP. In this study we select four different parameters, used to reflect situations ranging from mainly local trips (trips more costly than about 500 USD receive very low weights) to international trips (the weight of a location about 3000 USD apart is discounted by about 60%), as shown in figure 3 below. In the next section we apply these elements to calculate the levels of accessibility in Eastern Asia.

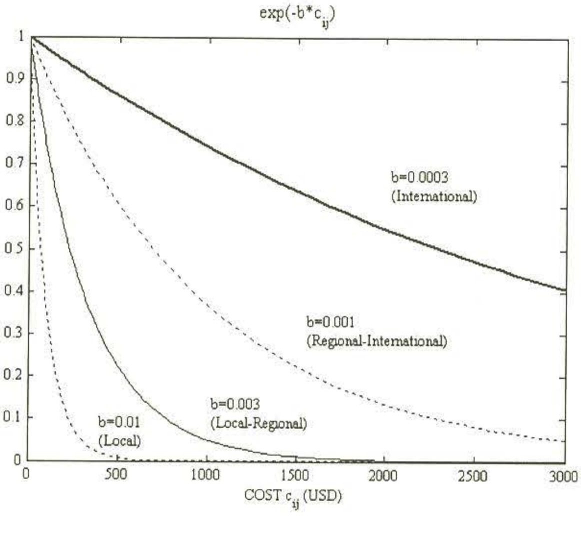

Figure 3 Impedance Function and Choice of Parameters.

3.5 Network Analysis

Network analysis is used to find the shortest (minimum cost) path between origins and destinations. As mentioned above, in some cases this may involve several transfers between modes. Also, as discussed in the preceding section, before accessibility can be calculated, we must select an impedance parameter to introduce in equation (2) above. Although most modern GIS packages include network analysis capabilities, the system selected for the present study includes the most advanced network analysis routines, which moreover can be customized and automated to perform simultaneous analysis of large datasets with hundreds of origins and destinations. In addition to powerful network analysis capabilities that allow us to find the shortest path in an intermodal network, we also take advantage of the matrix data structure to display and make calculations using data including local share of GDP, travel costs, etc.

An example of how matrices are used to calculate large-scale network accessibility is presented in figure 4 below. The figure shows three matrices. The first one is a cross-classification of cities by destination city (city i) and cities by country of origin (city j). This matrix contains information about the local share of GDP by city. Since generalized costs are modified using the Purchasing Power Parity (PPP, see table 1), we must conduct analysis by groups of cities classified by country (or region) of origin. The figure, for example, shows the matrix with Japanese cities at the origin position (rows), and all destinations within the system as columns. The second matrix contains the results of the network analysis, that is, the generalized cost of traveling between cities i and j. Finally, the third matrix contains the accessibility indicators by city, which aggregated over the columns give the total accessibility contribution by all cities in a given country (Japan in the example below). This analysis is repeated for every country/region and the national accessibility components are aggregated to give the total accessibility of city i.

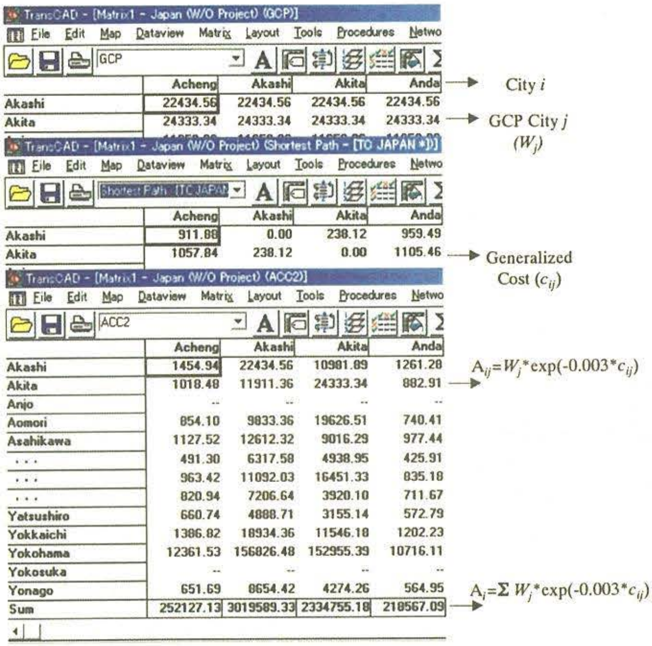

Figure 4 Calculation of accessibility using matrices.

4. APPLICATIONS AND DISCUSSION

4.1 Present Situation

The first application that we present in this section is concerned with the present situation of accessibility in Eastern Asia. At this step, we concentrate on finding some facts about accessibility in the region. Therefore, we conduct network analysis without considering a small number of air 'project' links (non-operational links that we included in order to analyze physical changes to the network; see section 4.3). Moreover, to reflect the particular situation of isolation in North Korea, for North Korean cities we consider only domestic accessibility while ignoring their contribution to calculate the accessibility of cities in other countries/regions in the continent. Using parameters as discussed in section 3, minimum generalized cost between cities, and the local share of GDP as a measure of attractiveness we are able to calculate the continental accessibility levels using equation 2. Results appear in figures 2-5, where ACC1 uses b= 0.01, and ACC2, ACC3 and ACC4 use b= 0.003, b= 0.001 and b= 0.0003 respectively, progressing from local to international accessibility.

Examining figure 5a, in which accessibility due to short distance (or small costs, i.e. local) interactions can be seen, the first thing that we notice is that accessibility levels are high in Japan, in particular along the Tokyo-Osaka corridor, and in South Korea. These results are consistent with our definition of accessibility as access to economic production. Accessibility levels in China do not appear to be very high, in spite of being the second largest economy in the region. Upon reflection, this seems to be due to three factors: economic production is more evenly distributed among a large number of populated places, and at the same time, distribution disparities between coastal cities and others have been smoothed. In addition, the effect of applying a Purchasing Power Parity correction to the costs is to make trips originating in China a relatively more expensive matter.

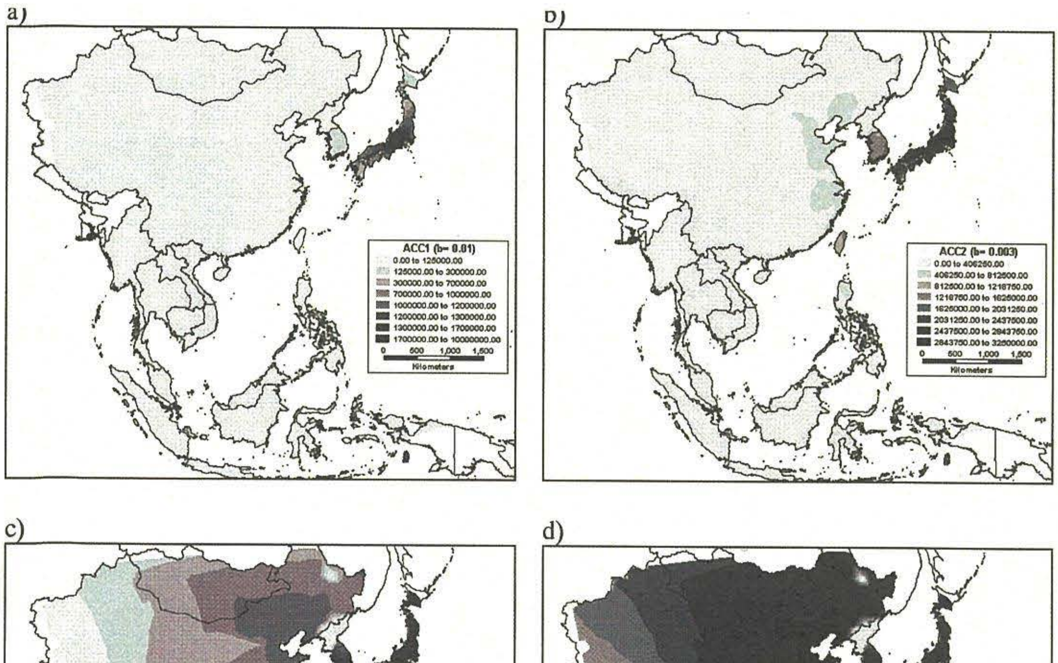

Figure 5 Potential Accessibility – Present Situation: Local (b=0.01), Local-Regional (b=0.003), Regional-International (b=0.001), International (b=0.0003)

Figures 5b, c and d show the effect of making the impedance function less steep, or in other words, of moving from local to regional and international interactions. There is a clearly discernable trend consisting of increased levels of accessibility radiating from Japan towards the east coast of China. Accessibility 'gains' due to a decreased rate of discount, are more marked among the coastal cities of western China, the southernmost part of the Korean Peninsula, and Taiwan. North Korea, on the other hand, shows consistently low levels of accessibility due to the lack of an international component in its accessibility.

At this point (figures 5b and 5c), accessibility to economic production in Southeast Asia does not appear to be very high. This is initially puzzling, especially when one notes that some middle size economies locate there: Singapore, Thailand and Malaysia. On the one hand, this might be partly due to lower levels of transportation service in that area. On the other hand, there is the fact that most accessibility increments in Northeastern Asia are due to the Japanese component of accessibility. Domestic accessibility in Japan tends to a plateau, but the effects spillover to neighboring regions. However, due to the effect of applying a PPP correction, the converse is not true: domestic levels of accessibility in China, South Korea and Taiwan increase, but no to the extent of affecting accessibility in Japan. This trend is clearly seen in figures 6 and 7, which shows the regional components of accessibility in Northeastern Asia.

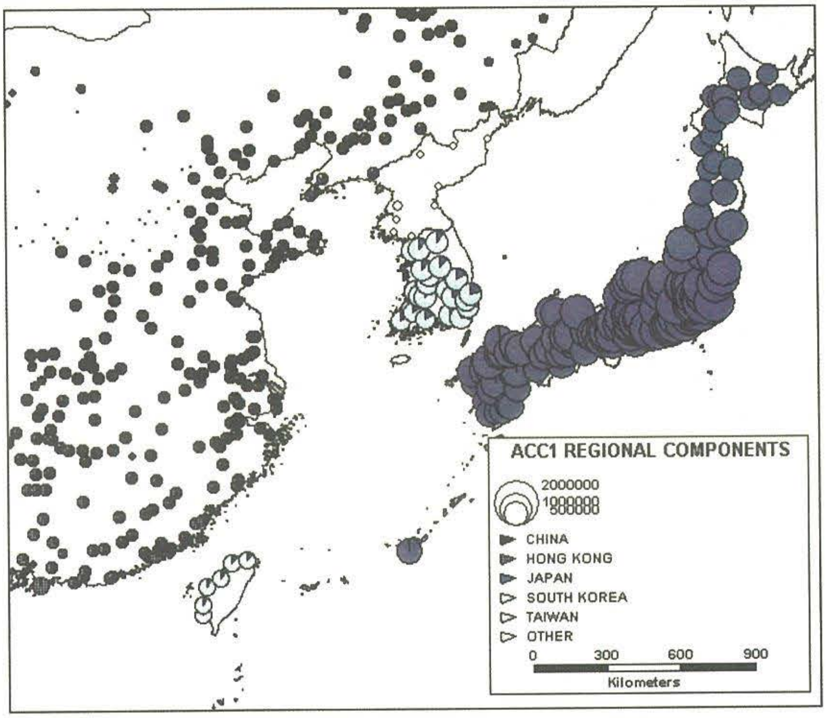

Figure 6 Northeast Asia Potential Accessibility – Regional Components (b= 0.01)

When using b=0.01 for 'local' interactions (figure 6) accessibility is mainly a result of domestic travel, with very small international components. High accessibility to economic production is high in Japan, South Korea and Taiwan mainly to domestic interactions, while in Chine the dispersed distribution contributes for relatively lower levels of accessibility, with a peak in Hong Kong and surrounding areas.

At the other end of the accessibility spectrum, when using b=0.0003, accessibility levels increase rapidly in South Korea, northeast China and Taiwan. Higher accessibilities are a result of wider areas of influence. At this point, however, accessibility in most of the region is considerably affected by the size of the Japanese economy (figure 7). In this sense, it is natural that accessibility becomes higher in this area (where transportation infrastructure is available) because the tendency is towards better accessibility in the geographical center of the region. Accessibility increments in Southeast Asia are better appreciated when the cost of travel does not result in drastic discounts in the impedance function.

In this study we are concerned with economic production. However, it seems likely that if we used population instead of economic production as a measure of attractiveness (i.e. to define opportunities of interpersonal exchange), the overall picture would show a shift of high accessibility levels towards the west coast of China. Verifying this remains a possibility to explore in future research.

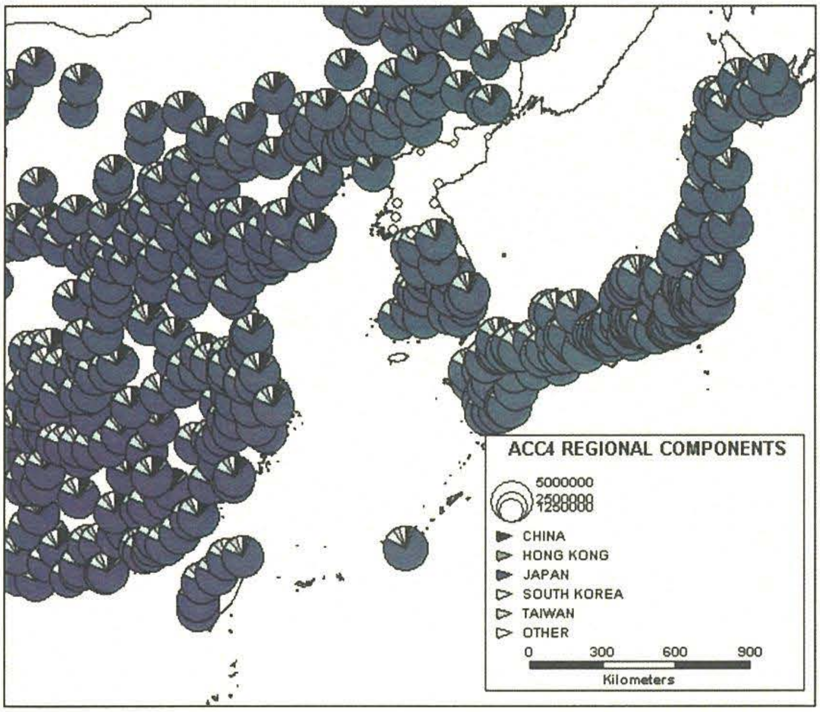

Figure 7 Northeast Asia Potential Accessibility – Regional Components (*b*= 0.0003)

4.2 Accessibility Indicators and Economic Production

The previous section was devoted to the calculation of accessibility levels corresponding to the present situation of economic development, transportation infrastructure and service levels in Eastern Asia. In this section the link between accessibility and economic development is explored. We mentioned before that economic development is likely to be a complex combination of several perhaps interrelated factors. It is interesting to note, however, that according to our results there is a good degree of correlation between accessibility and per capita GDP, the main indicator of economic development. Scatterplots showing the distribution of values of accessibility and per capita GDP appear in figure 8 below. Two goodness-of fit indicators accompany each figure: the correlation coefficient, and the coefficient of determination for a simple linear regression of accessibility on per capita GDP. The values of these indicators show that in general there is a good correspondence between variables, with correlation coefficients as high as 0.94 for ACC2, and values above 0.8 for ACC1 and ACC3. The coefficients of determination are also high: 0.89 for ACC2, 0.79 and 0.63 for ACC1 and ACC3 respectively. This means that per capita GDP can be explained in almost 90% by the relatively local accessibility measure given by ACC2. On the other hand, the relationship breaks down for the case of ACC4, where high accessibility does not correlate well with high per capita GDP, most likely due to the influence of international accessibility components, as seen in section 4.1.

Appealing as these figures are, it must be kept in mind that statistical correlation does not necessarily imply causal relationships and at best suggests some potential links. In addition, it is important to consider, beyond the goodness-of-fit indicators, at least some of the most evident characteristics of the data. For instance, one striking characteristic made evident by the scatterplots is the considerable variability of values at the high-income end of the scale. This is likely to translate into high variance in linear models and poor predictions at the extreme. On the other hand, it is clear that this effect is at least partially a consequence of the method used to distribute GDP into local shares, in fact ignoring domestic income distribution disparities. If detailed data could be obtained, then per capita GDP would be more continuously distributed, instead of being at discrete intervals as in figure 7. It seems safe to assume that a more realistic distribution of per capita GDP that considered regional disparities would reduce high variability in the extreme, and result in more accurate accessibility indicators and better correlations with economic production.

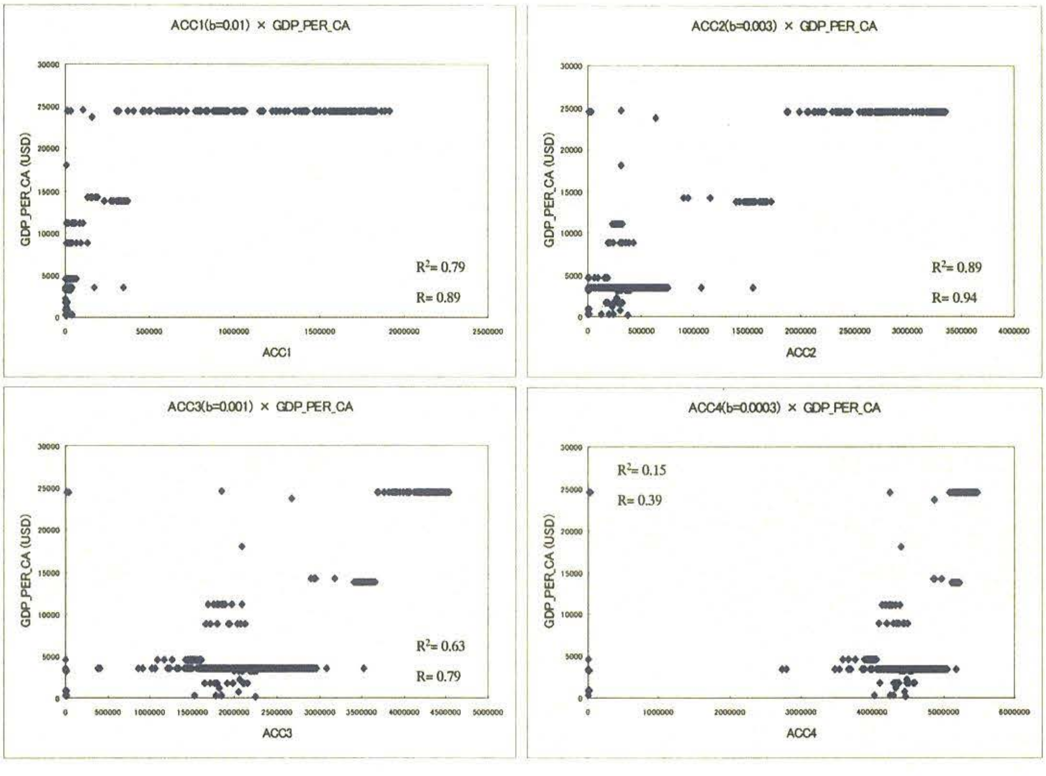

Figure 8. Economic Production and Accessibility – Correlations and Coefficients of Determination.

Another factor to consider is the convenience of using linear regression, since it seems that perhaps some transformation of the data might give a more adequate functional form to represent the relationship. All these factors counsel caution in the interpretation of results, and highlight the notion that accessibility is better seen as an enabling condition, rather than a determinant of economic development (Schürmann *et al.*, 1997; p. 4). However, even after all the above has been considered, it is still of interest to find that causal relationship or not, accessibility and economic development appear to go side by side, at least as far as local to regional accessibilities are concerned.

4.3 Accessibility Changes I: Direct Flights between Mainland China and Taiwan

The results in the previous two sections show the current situation of accessibility and economic production in the continent. They do not represent, however, the only use of our system. Potential applications include: the identification of necessary accessibility conditions for the development of regional economies, the study of influential transportation development projects to create new economic zones, and the localization of future transportation network bottlenecks that could limit further growth of existing economic zones. With talks undergoing regarding important transportation projects in the region, such as the Siberian Rail that would also connect North and South Korea, the High Speed Train between Beijing and Shanghai, and rail projects in the Malay peninsula, the importance of an evaluation system is highlighted. At this stage, unlike the EUNET project, we do not benefit from specific projects to analyze, so in order to demonstrate the scenario-analysis capabilities of the system, we resort to a hypothetical situation. This section explores the accessibility consequences of a new transportation service, assuming that direct flight routes are established between some important airports in China and two airports in Taiwan

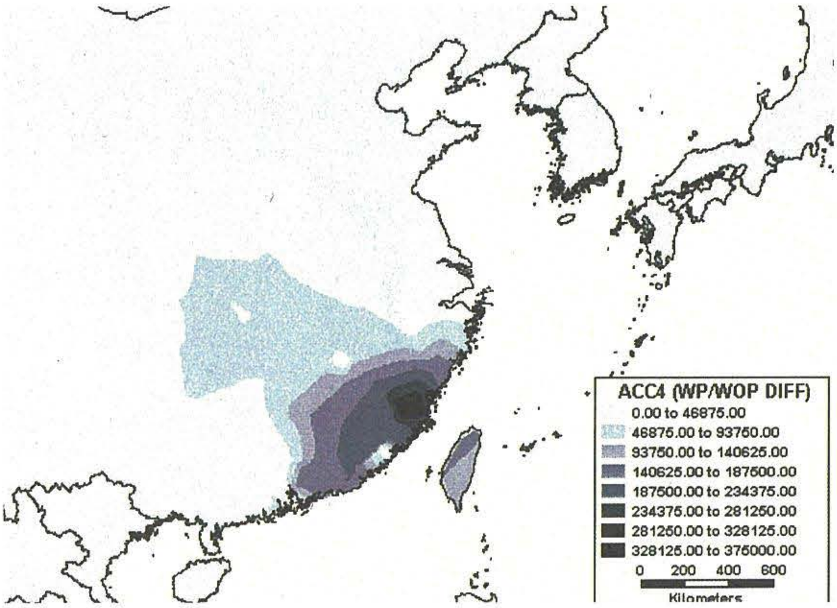

Figure 9 Accessibility Change from Direct Flights between China and Taiwan (b=0.0003)

Recalling equation 2, it is clear that there are two factors that affect accessibility levels: the weight of cities (in this case local share of GDP), and the cost of moving over the transportation network. In the present example, economic conditions are held constant so that the effect of new service is expected to be lower transportation costs. In effect, after introducing the new lines and conducting network analysis, we find that in general transportation costs are substantially lower for locations on both sides of the straits. The generalized cost between Beijing and Taipei, for instance, is 657 USD without project. However, after the new service has been introduced, the cost drops almost by half to 331 USD. Reduced costs lead to higher accessibilities, and the interest lies mainly in finding where do the accessibility gains concentrate. In what follows, we use ACC4 (setting b= 0.003) in order to emphasize the effect of cheaper long distance interactions. Figure 8 shows the regional accessibility gains due to the project (i.e. the difference of 'With Project' and 'Without Project' accessibilities), and it can be seen there that the effect is more important in the southeastern coast of China, and northwestern Taiwan.

5. ACCESSIBILITY CHANGES II: ACCESSIBILITY CONTRIBUTIONS BY NORTH

KOREA

In this section we explore other possible application of the system presented in this paper. As seen in the previous section, one application deals with changes to the transportation network (e.g. new links are introduced or existing links are deleted), or to the characteristics of the network (e.g. the attributes of the links, such as unit price, travel time on the link, etc.) An application different in character is to study accessibility changes due to altered circumstances in the set of possible origins and destinations, and/or their attributes (e.g. local share of GDP by city, eligibility as an origin or destination, etc.) The case study is set as follows. In section 4.1 above we calculated accessibility levels for Eastern Asia. In order to reflect the particular situation of North Korea and the strict requirements for travel within, from and to North Korean cities, we did not considering their international component of accessibility. Accordingly, accessibility in North Korea is relatively low at the local level, and remains low as the ease of interaction increases from local to regional and international (see figure 5). In this section we analyze accessibility changes that result from integrating North Korea to the international transportation networks.

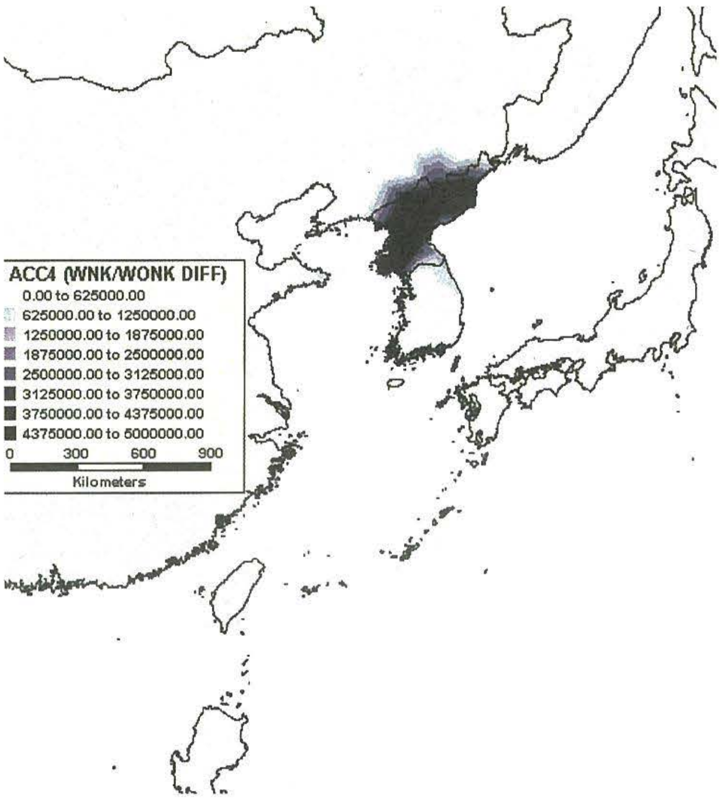

Figure 10 Accessibility Change from Increased Communications with North Korea (ACC4)

The results of this exercise appear in figure 10 above. The figure shows the difference between a base level of accessibility (ACC4 in figure 5) and the levels of accessibility attained when North Korea is fully integrated with the international transportation network. It can be appreciated that accessibility gains are marginal for most of the region, except for North Korea and its borders with China and South Korea. In this case, the accessibility gains are moderate at the borders and dramatically increase to bring accessibility levels in North Korea to a level equivalent to those in South Korea. Clearly, given the relatively small size of the North Korean economy, the gains are more impressive within than without this country. This result also suggests that, barring truly dramatic changes in the region, accessibility gains due to economic and/or socio-demographic changes are likely to be very localized.

6. CONCLUSIONS

In the present study, we have built a preliminary GIS database, which covers the Eastern Asia region, and the analysis tools needed to obtain international accessibility indicators. Based on a review of accessibility indicators appearing in the literature, one was selected to combine the criteria of agglomeration economies and distance-decay. We suggest that this indicator can be used to substantiate discussions of transportation, accessibility, and economic growth in the region. When comparing different accessibility indicators, we have shown the usefulness of the local and regional accessibilities by changing the travel cost parameter. The main application was to obtain accessibility indicators corresponding to the current situation of economic development and existing transportation infrastructure and services. Our applications helped to tease out various implications to the discussion as described in the case introduced in this paper. If more detailed data, such as economic production at the regional or local level was made available, the tools introduced in this paper could be used to conduct more varied and insightful analysis on the relations between accessibility and present/future regional/local economies. This team is still working on the development of a GIS tool and the methodology to use it.

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