

The Mass Transit System in Metro Manila: From Tranvia to MRT, 1879-2014

University of the Philippines System Emerging Inter-Disciplinary Research 06-008

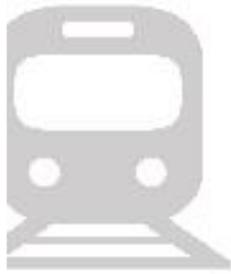
Historical Transport Network: Mapping Manila's Settlements and Railway Systems (1895-1945) Using Geographic Information Systems and Graph Theoretic Analysis

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Abstract: This study explores the simultaneous evolution of mass transport and settlements in the City of Manila from 1895 to 1945. This system was mainly composed of the tranvia streetcars and the trains of the Manila Railway Company. Information from documents, maps, and plans from the National Archives of the Philippines, the Manila Electric Company Archives, and online libraries are digitized, georeferenced, and accommodated in a Geographic Information System. These are then processed to create maps depicting the city's historical landscape and rail networks over time. The locations of transport stations are identified and transformed to a graph afterwards to perform graph-theoretic analysis of the network. The resulting maps of transport connectivity, density, and accessibility reveal positive correlation of the railways with district populations and the concentration of built-up areas. Through GIS-aided calculations, railways and stations are observed to be denser and more robust across commercial and governmental land uses. On the other hand, residential areas known before as "nipa districts" were relatively far from the city center and were connected to the commercial districts through less concentrated lines of a radial pattern. This research seeks to visualize the chronology and co-development of transport and settlements in the City, as well as uncover past trends related to commuter mobility, transport and urban planning in the Philippines.

Keywords: Manila, historical GIS, railway, transport, urban planning





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1. Introduction

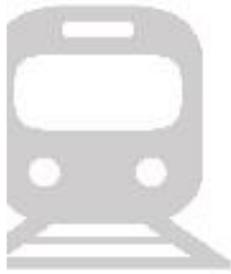
As data is often in various formats and are available in multiple initially-incompatible sources, researching the historical geography of transport systems can be challenging. Preparing a historical Geographic Information System (HGIS) for the creation of maps usually require digitization and georeferencing by digitally rubbersheeting historical maps and images (Rumsey 2002). The same can be said for the *tranvia* network system of Manila from the late 1800s to the early 1900s.

The latter part of the nineteenth century is said to be a period of rapid economic progress in Philippine society particularly centered in its capital, the City of Manila (Xenos 2010). Manila is located in the island of Luzon, with its centroid located at 14.5995 degrees latitude north and 120.9842 degrees longitude east. Manila became the seat of the Spanish colonial government in the 1500s (The Philippines Company 1899). During the 1890s, it became a center of rapid inbound migration due to economic opportunities, resulting in rapid population growth (Doeppers and Xenos 1998). The early rail-based transport in the area supported the movement of the population across the inner city called “*Intramuros*” and its surrounding districts (Figure 1). The streetcars that roamed these rails, known then as “*tranvias*”, started out as horse-drawn vehicles but they were later modernized into electric railcars under the American colonial period starting in the early 1900s. This is under the management of the Manila Electric Railway and Light Company (MERALCO) which would soon be the present-day Manila Electric Company, still by the same abbreviated name.

Damian (2016) mapped the location of *tranvia* lines and its evolution through the years using documents from the National Archives of the Philippines (NAP) (Figure 2). This serves as the seed for this preliminary study in further describing the landscape and transportation environment of historical Manila. The information obtained from documents and maps from the MERALCO Museum and archives effectively allowed the researchers to identify the locations of stations at the peak of the *tranvia* system from the 1920s to the 1940s before the operations halted and the lines got destroyed during the Second World War.

The intra-urban *tranvia* coexisted with the inter-urban heavy rail of the Manila Railroad Company (MRC). In contrast to the *tranvia*, the MRC railways connected Manila to peripheral areas in Luzon such as the Ilocos Region in the North and the Bicol Region in the southeast. While there are other populated areas in Luzon, it was argued that they pale in comparison with the evident clustering of population and settlements in Manila. It was even described as the only urban area in the country for the time period (Le Roy 1968).





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Fig. 1. Districts of Historical Manila reconstructed in GIS

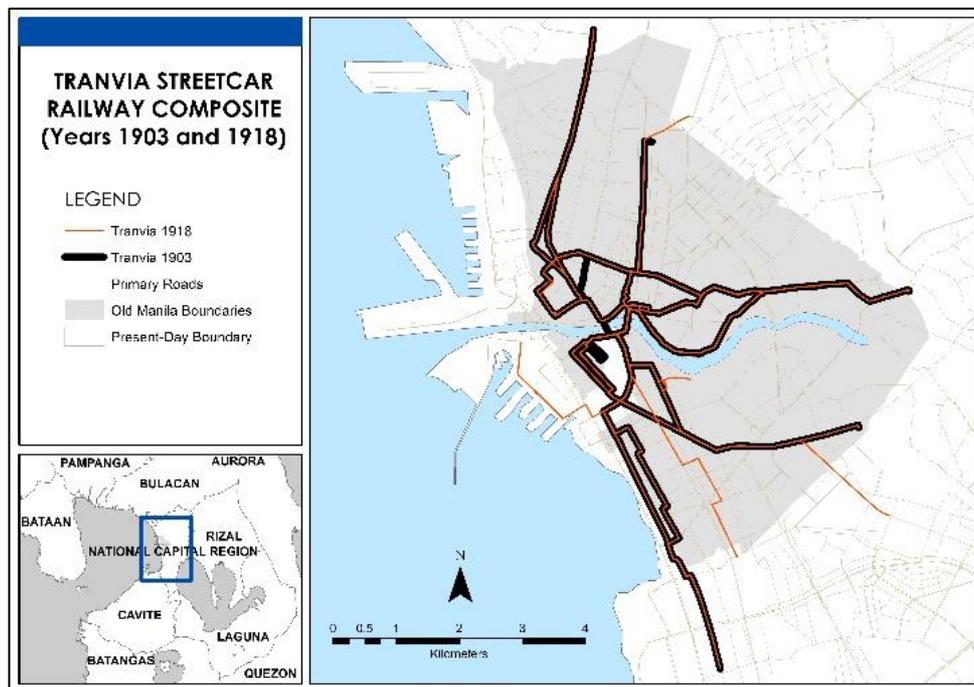
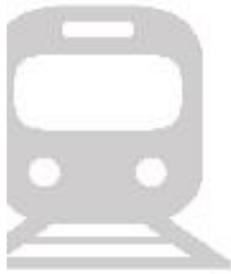


Fig. 2. The Study Area: Tranvia Lines and Major Roads
in Manila's Historical Boundaries (Damian 2016)





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This study is an attempt to describe movement patterns in Manila for the period using HGIS and graph theory. With the extent of archival data recovered, digitized, and/or translated from Spanish, there is insufficient information in completely rendering the locations of economic activities and flows of people in the area using GIS. Graph theory is an approach that transforms the transport network into an analog model of nodes and vertices. It serves as good approximation of movement and transport data that is otherwise unavailable at this point. Moreover, this study aims to visualize the historical landscape of Manila and how it changed with respect to the location of rail facilities in the area. Though with a certain level of abstraction, creating the graph allows the analysis and connectivity of places through the computation of graph-theoretic indices for Manila. Graph transformation reduces the real-world network into a fully connected collection of nodes (stations) and edges (routes or railways) where each route is not measured in physical units but in topological distance instead. Topological distance is determined by counting the number of links between a series of nodes. (Lowe and Moryadas 1975). The data source for the georeferenced tranvia stations can be found in Figure 3. The spatial relationships among the nodes and the stations were reduced to a topological graph.

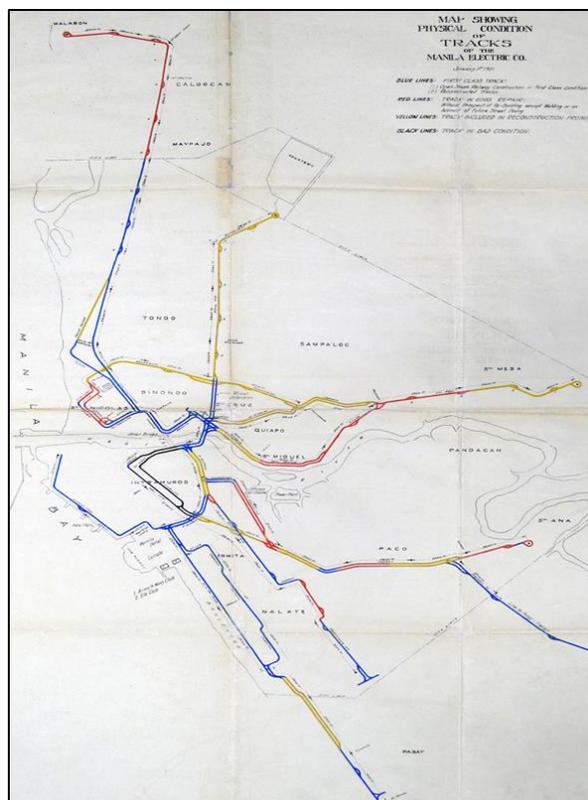
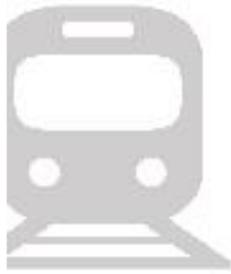


Fig. 3. Digitally Reconstructed Tranvia Stations Map in 1921
(MERALCO Museum n.d.)





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2. Objectives

The main objective of the research is to apply GIS and graph theory to archival transport information to visualize the growth of the tranvia network and to describe the connectivity of places in 1900s Manila. Graph theory is primarily used as proxy indicator in lieu of actual building foot print and high-resolution population data since information on these is still insufficient at the time of the study.

Drawing from the positively intertwined relationship between commercial establishments and the existence of a public transport system (Hoel 1992), this study posits that there are differences with the characteristic of the rail across the districts. These differences can be quantified using the aforementioned graph-theoretic indices and symbolized on a map.

While still in its preliminary stages and more information is yet to be mined from NAP and various archives, this paper intends to visualize movement and accessibility through GIS-rendered maps that show various graph-theoretic scores and indices. This is accomplished through: a) digitizing and georeferencing historical tranvia lines and stations data (Figure 3), b) determining graph-theoretic indices which describe the connectivity and accessibility of tranvia stations, c) identifying Manila's districts with high concentration of nodes and routes, d) symbolizing these indices and concentrations of transport features on GIS-rendered maps, and e) associating these indices with land use and activities inside the respective districts.

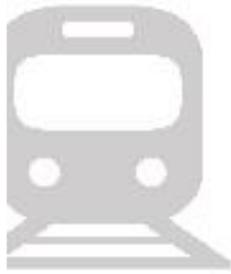
As such, specific datasets in various formats were gathered from the NAP, online shapefile databases, and printed sources. These datasets include: a) historical district boundaries, b) railways, c) water bodies such as the Pasig River and prominent waterways, d) present-day boundaries (OSM 2016) to compare with old boundaries, and e) built-up areas (Atlas of Urban Expansion 2016).

3. Methods

The methods used in this research is greatly inspired by the works of Lagman et. al. (unpublished work) and Damian (2016), which are some of the pioneering works in HGIS in the Philippines. The former digitized archival data and illustrated the location and characteristics of business settlements in late 19th century Manila through maps, while the latter laid out an HGIS strategy for the past mass transit systems in present-day Metro Manila.

The methodological framework was also inspired by the historical GIS works of Felis-Rota (2012) who analyzed the growth of urban settlements in England from 1851 to 2000. Felis-Rota spatially correlated the growth of the railway system with the growth of settlements and found that there was greater growth in land use





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intensity in areas with dense railway lines. Another work is that of Wang (2006) who mapped emerging settlements with the density of lines and stations of the mass transit system in China during the 1900s.

3.1 Archival Research and Data Transformation

The researchers implemented several labor-intensive steps due to the nature of data from various sources. Maps, text, and *ytinerarios* or plans of *tranvia* railways from 1895 were obtained by the researchers from the NAP to complete the map and rail measurements since the beginning of the *tranvia*. Using the maps of de Gamoneda (1898), Bach (1918), and Pante (2011), the researchers used ArcGIS 10 in drawing the boundaries of historical Manila, including Intramuros and its surrounding 13 suburbs. The information is then overlaid with the station map (Figure 3) and station addresses obtained from archival documents

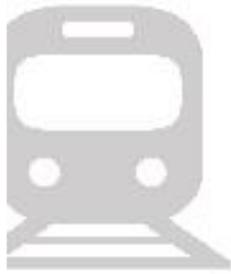
3.2 Graph-theoretic Indices Used

The GIS-reconstructed maps and stations of the *tranvia* were reduced to a fully connected graph of nodes and edges (Figure 4) superimposed with the historical boundaries of Manila (Figure 5) for reference. Note, however, that the positions and orientations of nodes and edges on the graph no longer exactly represent real-world locations and directions. Some nodes were nudged to establish linkages without intersections. For the purposes of simplicity, nodes found outside the districts but were connected to the network were excluded in counting the Kőnig indices, particularly with Pasay in the south and Malabon in the north. The three stations at the interface of Intramuros with Manila Bay specifically belong to the port area but were included in Intramuros because of proximity.

Specific graph-theoretic scores were deemed applicable and used in this research. These indices and statistics are the following: a) node density, b) alpha index, c) beta index, d) gamma index, e) Kőnig index, and f) summaries per district of applicable indices. These indices, based on Lowe and Moryadas (1975) and Ruohonen (2013), were computed outside of GIS and were later entered into the attribute table of Manila's districts. These would then be used as symbolization for the resulting maps. The indices also serve as auxiliary or referential data that can be used for understanding the general picture of urban and transport planning (Lee 2004) in the region during this the time period.

Node density is computed by dividing the number of stations by the land area of the containing district. Higher node density can be an indicator of prioritization of an area with respect to transport planning and/or an indicator of denser economic activities (Mori 2002). Meanwhile, the alpha and gamma indices are related measures





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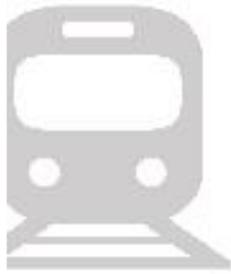
since they compare the provided graph with the maximum potential that can be theoretically reached in terms of numbers of circuits and routes, respectively. On the other hand, a circuit is defined as a closed loop of at least three stations fully connected with routes, indicating better connectivity (Ruohonen 2013). A higher number of circuits and routes generally correlate with better connectivity and mobility (Ortuzar 2001). Lastly, the beta index is another network-wide index that tells the ratio between the existing number of nodes and routes. A score of one or higher indicates a fully connected network. Higher beta scores indicate higher connectivity and existence of alternate paths.

The Kőnig index is a measure of distance from a particular node or station to the station that is farthest from it in terms of topological distance. Also called the associated number or Shimmel distance, the Kőnig index is determined by counting the number of route segments along the shortest path between a selected node *I* to the farthest node *J* from it (Lowe and Moryadas 1975). For the purposes of this study, the computed Kőnig index (*K*) per district is based on the node nearest to the settlement's geometric center. In other words, the node chosen to represent the *K* for the district is the station assumed to be the central and most accessible within the district. A large *K* indicates that a location is in the periphery while a smaller *K* shows that a location can easily be reached from other places in the network. In other words, it is a measure of the centrality of a station respective to the location of other nodes (Barabasi 2002). The formula for each index is summarized in Table 1.

Table 1. Summary of Graph Theory Formulas

Statistic/Index	Formula
1. node density	$f = V/A$
2. alpha index	$a = U/(2v-5)$
3. gamma index	$g = E/(3(V-2))$
4. Kőnig index	$K = \max$ $D_{IJ} = \text{number of edges from reference node } I \text{ to the farthest node } J \text{ from it}$
where <i>V</i> is the number of vertices, <i>E</i> is the number of edges, <i>D</i> is the topological distance between any nodes <i>I</i> and <i>J</i> , and <i>U</i> is the number of circuits	





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4. Results

4.1 Graph-Theoretic Analysis and Initial Cartographic Findings

After digitizing historical boundaries and projecting the map, the land areas of each district were estimated. Note that these land area estimations are subject to errors resulting from rubbersheeting and digitization. The area occupied by the Pasig River was accounted for except the esteros and creeks distributed across the area. A total of 54 stations were identified from several historical maps, including some from the Meralco Report (1941). The total number of edges recorded is 62, after including all railways with parallel tracks and interchanges were simplified to a single linkage at most between every two nodes (See simplified graphs and stations per district in Figures 4 and 5). The beta index $b=1.148$ indicates that there are more edges than vertices in the whole network and that there are areas with a surplus of paths. The number of stations contained in each district and computed node densities are also summarized in Table 2. It should be noted, however, that a node may be counted more than once if it is located on a boundary shared by two or more settlements. The node densities are represented on a choropleth map (Figure 6).

Table 2. Historical Districts' Estimated Land Area and Node Densities

DISTRICT	LAND AREA A (square kilometers)	NUMBER OF CONTAINED STATIONS (nodes)	NODE DENSITY (V/A) stations per sq.km
1. Binondo	0.66	3	4.54
2. Ermita	2.40	6	2.50
3. Intramuros	1.98	8	4.04
4. Malate	2.85	3	1.05
5. Paco	2.55	3	1.16
6. Pandacan	1.14	0	0
7. Quiapo	0.61	2	3.28
8. Sampaloc	5.67	4	0.71
9. San Miguel	0.97	4	4.12
10. San Nicolas	0.73	2	2.74
11. Santa Ana	2.05	4	1.95
12. Santa Cruz	3.79	6	1.58
13. Santa Mesa	2.39	4	1.67
14. Tondo	5.39	6	1.11
MANILA	35.12		





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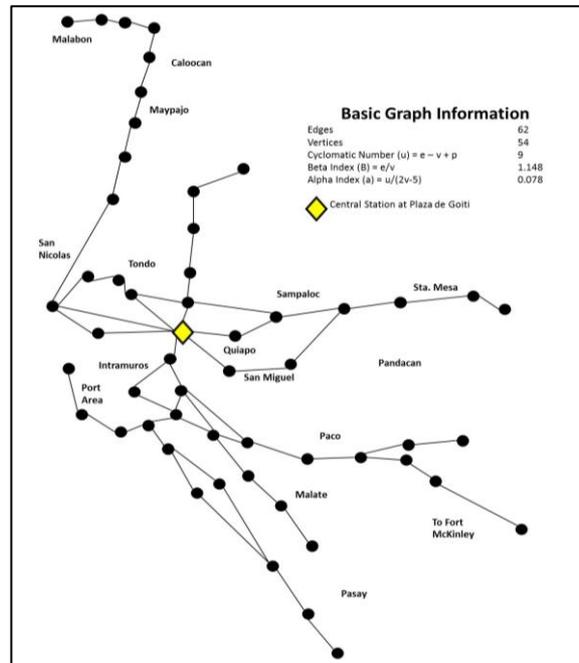


Fig. 4. Graph Transformation of the Historical Tranvia Network

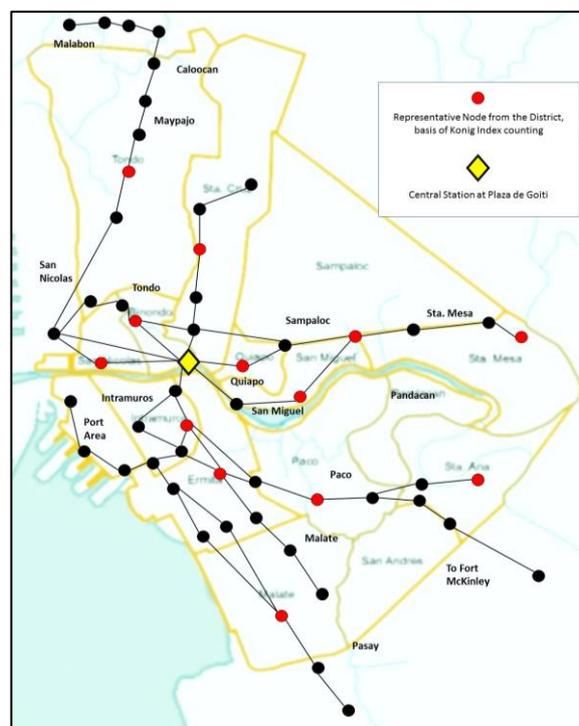
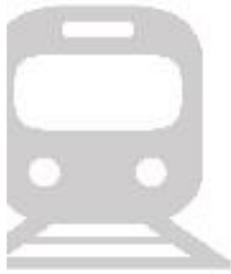


Fig. 5. Tranvia Graph Overlaid with Manila's Historical Districts, Central Station and District Representative Stations Marked





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As for determining K \ddot{o} nig indices, a representative node is chosen for each district, given that the selected node is near the geometric centroid of the settlement. Then, the number of steps to the farthest station in other districts from it is recorded. For instance, the station at the center of Binondo is chosen as its representative node. Its topological distance to the farthest stations are 8 to Tondo, 8 to Santa Ana, and 8 to Malate. Hence, Binondo's K \ddot{o} nig score is 8. Tondo's most accessible node, on the other hand, takes 14 steps to reach the farthest node from it, which is in Santa Ana. Hence, its K is 14. The same principle is applied to other districts, resulting in the summary in Table 3 and the map in Figure 7.

Table 3. District Node Density and K \ddot{o} nig Indices

DISTRICT	NODE DENSITY (V/A) stations per sq.km	K \ddot{o} nig Index "K" of the District's Central Node
1. Binondo	4.54	8
2. Ermita	2.50	12
3. Intramuros	4.04	8
4. Malate	1.05	14
5. Paco	1.16	10
6. Pandacan	0	Not applicable
7. Quiapo	3.28	9
8. Sampaloc	0.71	10
9. San Miguel	4.12	9
10. San Nicolas	2.74	9
11. Santa Ana	1.95	15
12. Santa Cruz	1.58	14
13. Santa Mesa	1.67	12
14. Tondo	1.11	12





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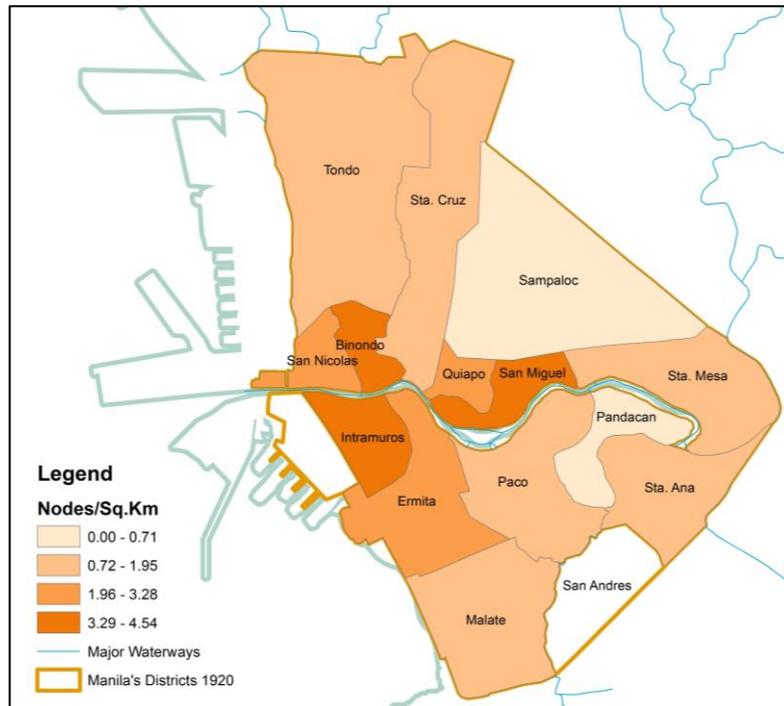


Fig. 6. Node Density per District from 1920-1940

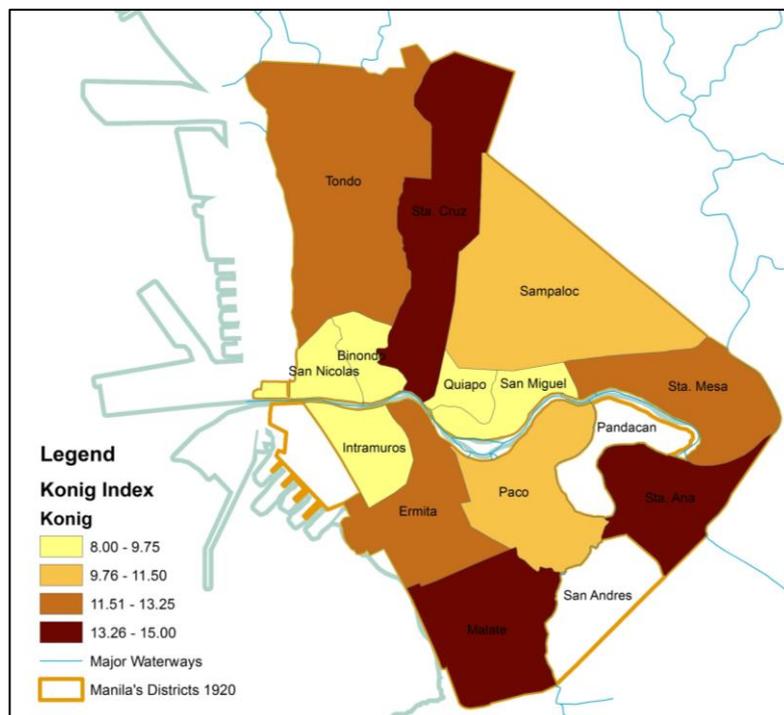
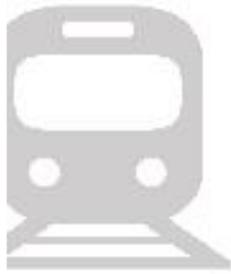


Fig. 7. König Index Map from 1920-1940





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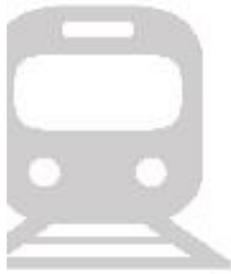
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The three districts with the highest node densities are Binondo, Intramuros, and San Miguel. Despite having relatively smaller land areas, these districts had around four stations per square kilometer, suggesting high passenger demand and density of movement. Intramuros was the seat of the government while Binondo was the commercial center (The Philippines Company 1899). Binondo was also labelled as the “real commercial capital” where several shopping centers used to be found along the streets of Escolta and Rosario (Cruz 1990). San Miguel's proximity to the central station and Pasig River apparently made it a strategic location to situate four stations despite its small land area. It is also evident that most concrete built-up areas started to grow mostly within these three districts, as far as the 1895 historical maps show (Figure 8). The district of Quiapo should also be noted as a close runner-up, with a node density of 3.28 in just 0.61 square kilometers. It was a busy cultural center and residential area for artists, silversmiths, and sculptors during the time (Cruz 1990). Quiapo had also been a bustling site for neobaroque architecture such as the design of the Quiapo Church, which was reconstructed in the 1930s (Moore 1921).



Fig. 8. Built-up Areas Emanating from Intramuros, Binondo, and San Miguel, overlaid with railways in Manila, 1895





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Santa Cruz, though with a relatively low node density of 1.58, is worth mentioning because it has one of the most central stations in the network. The Plaza de Goiti, located in the district of Santa Cruz at the north of Pasig River, was designated as the central station of the horse-drawn tranvia lines as early as the late 1800s. Even after the replacement of the old streetcars with new electric ones, the network of lines centered at Plaza de Goiti remained mostly the same. The graph's cyclomatic number of 9 indicates that there had been nine closed circuits within the network. Five of those nine have Plaza de Goiti as their common node. It also appears that the land area of Santa Cruz is relatively larger while most of its transport stations clustered only within its southern edge.

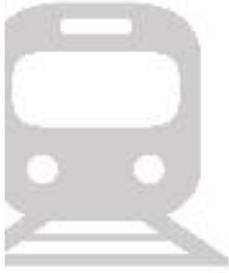
The König index per district reiterates the findings from the previous maps that there were higher node densities, greater mobility, and more circuits near the city center close to Plaza de Goiti, while there were fewer lines and node density at the peripheral nipa districts and residential areas. Cases in point are Binondo, Intramuros, and Quiapo having the lowest K indices of 8, 8, and 9, respectively. Highest K indices of 14 and above can be observed with peripheral districts such as Santa Ana and Malate.

Three of the remaining circuits are within the walls of Intramuros and one is in the southward railways across Ermita and Malate. This suggests that there had been good mobility around the Plaza de Goiti area and that there had been busy commuter traffic in the circuits around it as well.

4.2 Changes over Time of Related Features in Manila's Landscape

The temporal evolution of the tranvias highlights a sudden growth at the onset of the American colonial period in the 1900s (Figures 9). The railway's development was clustered around the districts of Binondo, Quiapo, and San Nicolas just adjacent to the Pasig River. The year 1905 marked the first year of Meralco running the operations of the tranvia. The lines reached Malabon in the north, Pasay in the south, and Fort McKinley in the southeast. The network peaked in terms of the number of stations and lines in the 1920s, and this configuration remained generally stable until it got decommissioned and destroyed during World War II.





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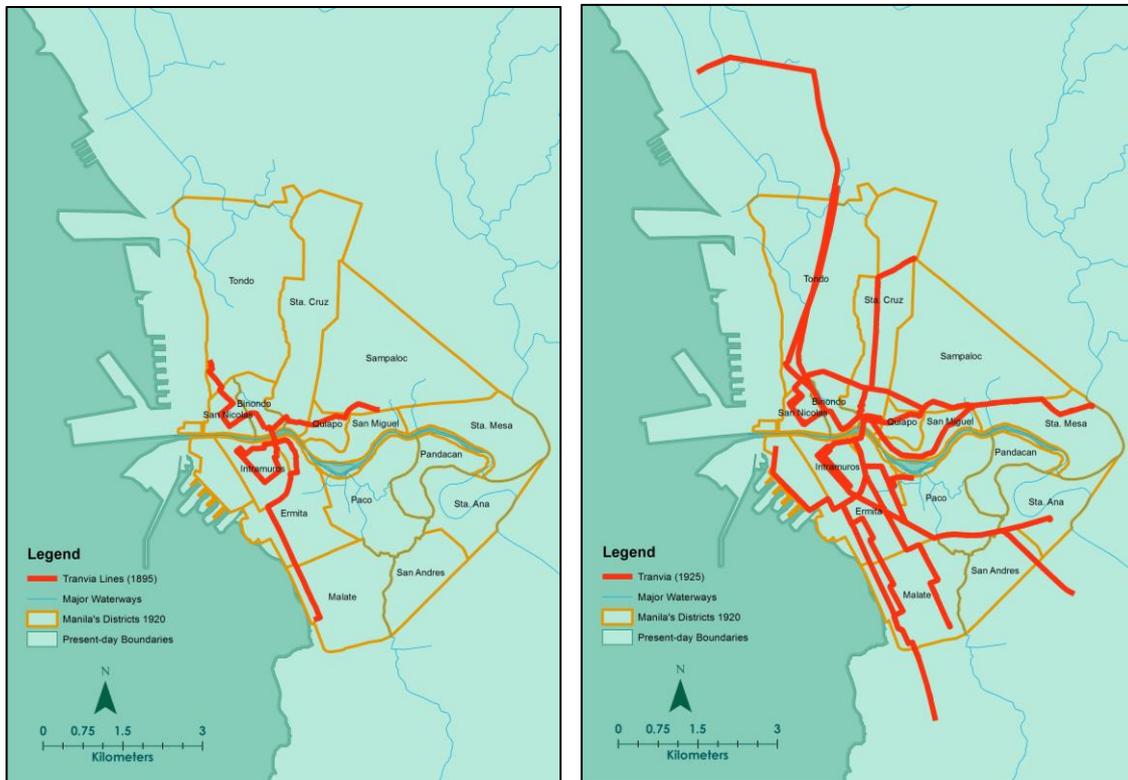
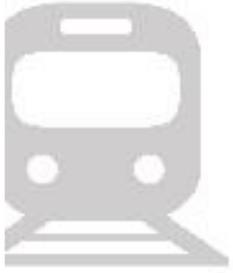


Fig. 9. Tranvia lines during the Spanish colonial era (1895),
and during the American colonial period before World War II (1940)

Areas with high node density or stations per unit area and low K \ddot{o} ning indices, indicating high connectivity, also correlate with the growing extent of built-up areas over Manila, as previously mentioned. Data digitized from Bach (1918 and 1920) and the Atlas of Urban Expansion (2016) indicate that the earliest built-up areas in Manila are around Plaza de Goiti near Binondo, Intramuros, and Quiapo. These areas had low K \ddot{o} ning indices, indicating centrality among the other settlements. The built-up areas eventually spread in a radial pattern following districts with higher K \ddot{o} ning indices. This exhibits the positive spatial correlation and co-development between land use intensity and transportation infrastructure (Hoel 1992). The extent of built-up areas following the direction of the rail can distinctly be visualized in maps of Manila starting in 1895 through 1925 (Figures 10 to 12). Illustrated in Figure 12 is a map of concrete built-up areas in 1945. It can be observed that the extent of concrete physical structures was already dominant in Manila and beyond its original districts. This is an indicator that the size of the city was taking a more metropolitan form, which would soon include nearby settlements. This is the beginning of the region that would be known today as Metro Manila, which consists of the original districts and adjacent municipalities (Paderon 1970).





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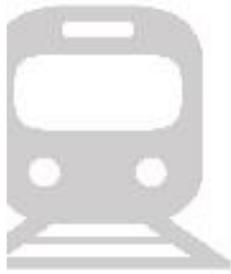


Fig. 10. Tranvias and MRC against the Extent of Concrete Built-up Areas (1895)



Fig. 11. Tranvias and MRC against the Extent of Concrete Built-up Areas (1925)





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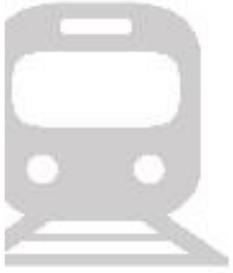
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Fig.12. Tranvias and MRC against the Extent of Concrete Built-up Areas (1945)

It should be noted that areas at the periphery of the network are characterized with high K scores and low network density values. This correctly correlates with the radial pattern of the network, with extensions leading to Manila's north, south, and southeast directions. These areas of low network density also coincide with the nipa districts (Figure 13). These districts, namely Tondo, Santa Cruz, Sampaloc, and Malate, were characterized as mostly residential areas of high population but low in concentration of economic activities and concrete structures. Most houses are made of nipa, hence the name "nipa districts" (Municipal Board Report 1905). Tondo, for example, was a sector of slums inhabited by laborers, fishermen, and sailors, given its proximity to the Bay of Manila (Cruz 1990). In contrast, the districts near Pasig River, specifically Intramuros, Quiapo, and Binondo, could be described as highly commercial and heavily populated (Pante 2011). These commercial and religious centers were mostly made of concrete structures.





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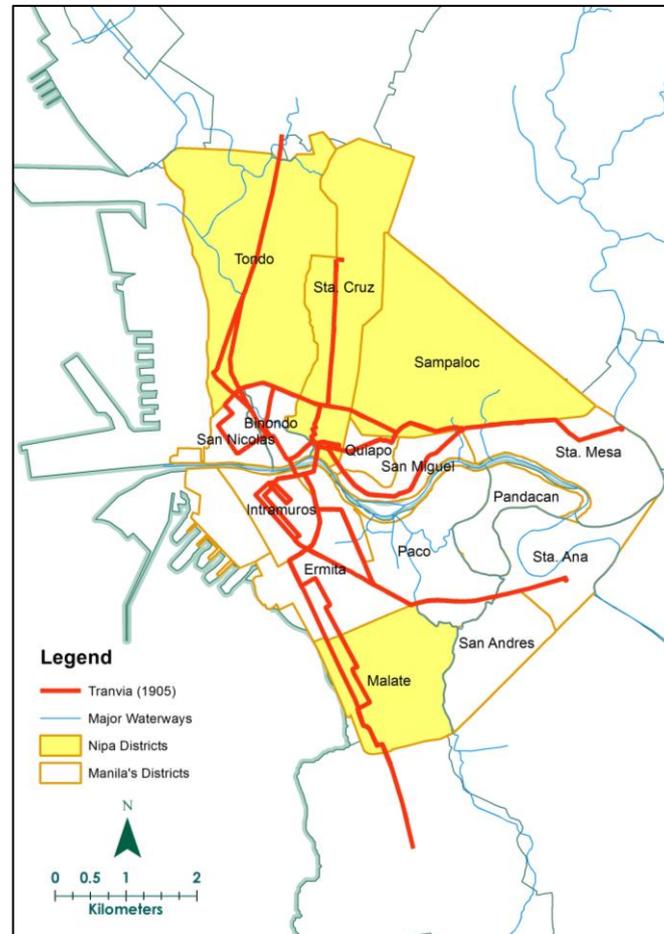


Fig. 13. Tranvia Lines and Nipa Districts

After overlaying historical population data with the tranvia lines and noting the location of residential areas, it is also evident that the density of nodes did not always positively correlate with the location of heavily populated areas and residential areas of notable population growth north of Pasig River (Figures 14 to 15). Low König values, hence high connectivity, could be observed in commercial districts that are low on population. High K values, on the other hand, could be observed in dormitory areas at the northern and southern peripheries of Manila. There was a prioritization of central areas by providing it with greater accessibility and node density, and the density of railway features generally decrease with distance from the center. The same pattern could be observed in historical development of cities such as London (Felis-Rota 2012).





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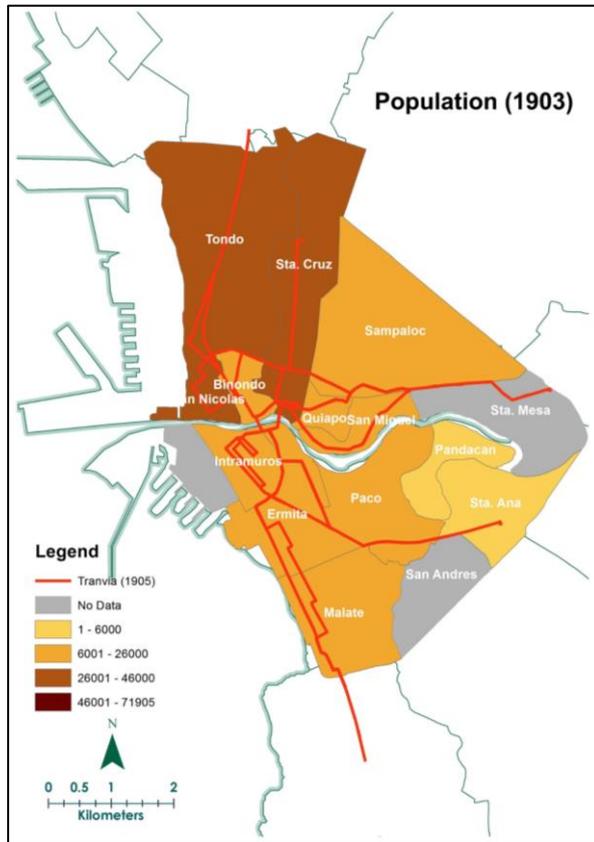


Fig. 14 Tranvia Lines and Population (1903)

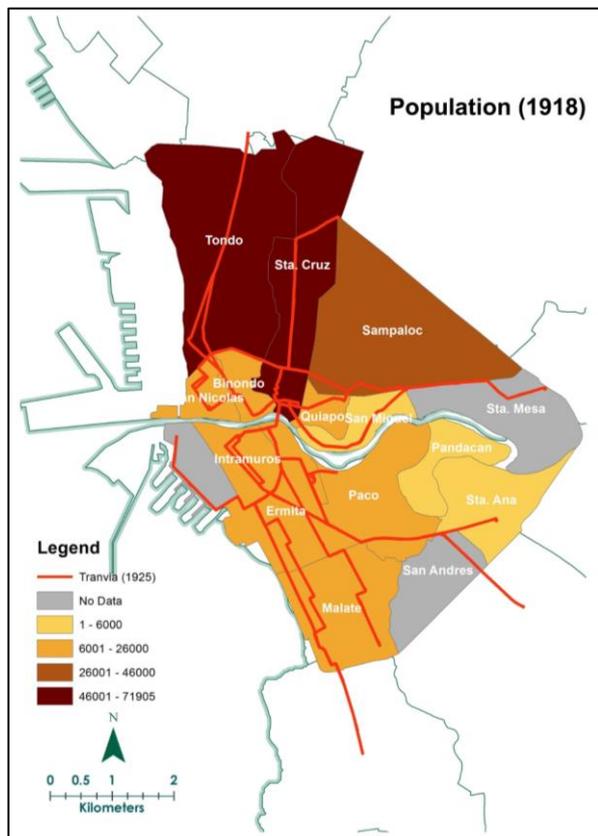
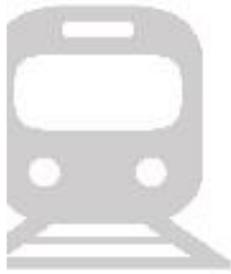


Fig. 15. Tranvia Lines and Population (1918)





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4.4 Observations

While graph-theoretic indices are useful in describing network connectivity, it should be emphasized that it does not account for all the factors that influenced the co-development between the tranvia lines and Manila's environs. For example, Santa Cruz had a high K despite it having the Plaza de Goiti central station. Similarly, some districts had significantly larger land areas which contributed to lower node density values. Graph theory usually does not take into account geographic factors and human activities but instead, it provides an initial idea of the degree of movement and accessibility within an area.

5. Summary and Conclusions

The findings and maps generated in this study attempted to describe the environs of historical Manila with respect to its streetcar system. Graph theoretic indices were calculated to describe the differences in movement and connectivity of districts within the area. As a consequence of implementing GIS, old administrative boundaries and the railways over time had been digitally reconstructed and georeferenced.

Intramuros and commercial districts had greater number of nodes despite their relatively smaller land areas compared to the peripheral districts. Their high node densities and the existence of several closed circuits in the graph indicate higher commuter traffic and higher propensity for movement starting from 1895 through 1945. The maximum nodal König index per district also correlates with the type of prevalent land use. Peripheral areas including nipa districts had higher König scores and low node density. These characteristics are associated with high residential population but low level of commercial activities. In turn, this correlates with the physical configuration of the historical tranvia network, wherein there is a compact and dense network at economic center and a thin radial pattern connecting the center to dormitory areas.

While graph-theoretic measures are simplified approximations, they happen to spatially correlate correctly with the characteristic of corresponding districts in terms of population, whether it was in a nipa district or not, and the extent of built-up areas. The method can be explored and tested further in mapping and in painting a picture of historical transport in urbanized areas.





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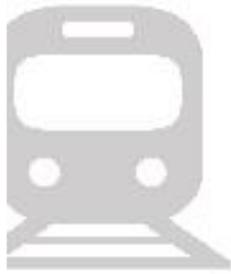
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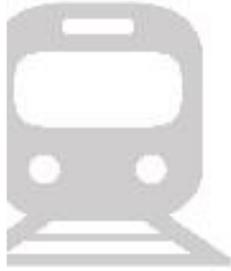
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