Journal of Community Medicine & Health Care

Open Access

Austin Publishing Group

Research Article

Mapping Public Health Disparities: The Subway Metaphor

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Received: July 06, 2026
Accepted: July 21, 2026
Published: July 28, 2026

Abstract

In 2004 Michael Marmot created The Subway Metaphor proposing a rapid decrease in longevity, stop by stop, along subway lines in New York, Washington, DC, and London, UK. To test the Metaphor, longevity and health disparities first were compared among all five boroughs. US census data then was assigned to individual subway stops along the approximately 8.5 miles of subway joining Bronx and Manhattan boroughs in New York City identified by Marmot. Graphically and statistically, the result demonstrates progressively decreasing longevity without, however, the consistent and radical rate of decent predicted. By imposing a Voronoi network with Thiessen polygons anchored by subway stops a clearer picture of decreased longevity and increased health inequalities predicted in the Metaphor was achieved. The result both adds to the literature of the Subway Metaphor and presents a new perspective with the Voronoi network of transit lines that better serves studies of urban health disparities.

Keywords: Health disparities; Longevity; Marmot; Subway metaphor.

Introduction

In contemporary public health, "The Subway Map" offers "one common metaphor for social and health disparities" [1]. It proposes a rapidly declining gradient of life years in populations living along subway lines traversing richer and then poorer urban neighbourhoods. Since it's introduction in 2004, it has served as a polemical tool focusing attention on pervasive health inequalities resulting in decreased longevity and lower general health in major cities like New York, London (UK), and Washington, DC [2].

"At a population level, no existing or conceivable medical intervention comes within an order of magnitude of the effect of place on health" [3]. Setting health *in* place emphasizes the broad gulf existing between richer and poorer, often contingent neighbourhoods. What makes the Metaphor so powerful is "the visualization of a geography in which transit is presented as a key axis of mortality" [4]. Life expectancy is a principal datum for those disparities, "a sort of X-ray machine that can see through the geography of a city to the bones of a neighborhood's distress" [5]. Stop by transit stop, one *sees* life years eroding and thus on those "bones" general health declining along subway lines serving densely settled cities. It is "not only the contrast between rich and poor, but the graded nature of the relation in between" that gives the metaphor its impact [6].

Like all metaphors, "The very systematicity that allow us to comprehend one aspect of a concept in terms of another … will necessarily hide other aspects of the concept" [7]. What is not clear is what is gained in public health, beyond the publicity and shock values, of data at this resolution. The specificity that gives the metaphor its power, focused upon a short section of transit, ignores disparities in both the individual boroughs and the city at large. It leaves open to question the longevity and health status of those living near but not at a specific subway stop. Finally, expected life years are not a simple datum but an outcome, the result of conditions affecting the general health or ill-health of populations. To understand the metaphor requires they be included in a study of the Metaphor's utility.

The metaphor

Michael Marmot introduced the metaphor in 2004, proposing a twenty-year gap in life expectancy along the Washington, DC subway from its southeast stations, perhaps Branch Avenue on the Green line northwest 19.6 miles to the Shady Grove stop on the Red Line [8]. He similarly described a loss of 15 year's life expectancy along approximately 8.1 miles of the New York City subway from mid-town Manhattan's Museum District, into the Bronx and its "slums of Harlem Life" [9]. More recently, Donald Berwick provocatively described a 10-year decline in life expectancy, or "six months for every minute on the subway" along those same subway tracts [10].

While originally proposed to draw attention to health disparities in US cities, the London Health Observatory [11], applied the Subway Metaphor to that city's famous underground (Figure 1). Along 11.2 kilometers on that city's Jubilee line, male life expectancy is calculated to drop approximately six months for every stop from Westminster Station to Canning Town [12]. This was assumed to reflect a more general, 19-year gap in life expectancy, "between the most and least affluent areas of the country" resulting from a "type of health difference that is closely linked with social, economic and/or environmental disadvantage" [13].

Citation: Koch T. Mapping Public Health Disparities: The Subway Metaphor. J Community Med Health Care. 2026; 11(1): 1080.

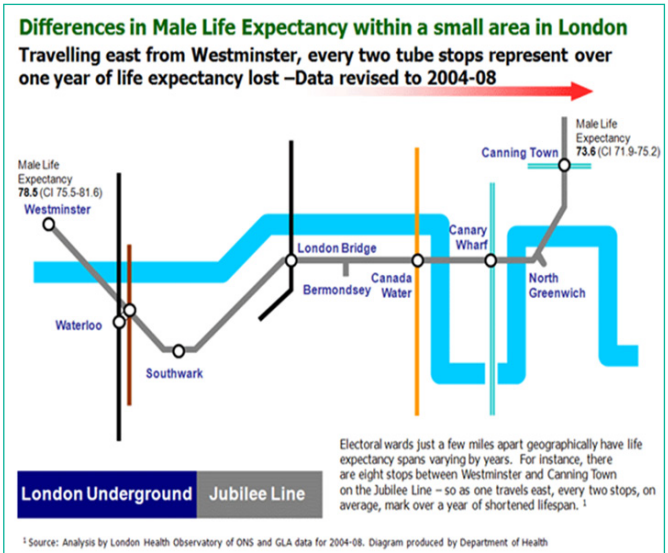


Figure 1: A map of the London Tube's Jubilee line and the gradient of diminishing life expectancy from Westminster to Canning Town stations. Courtesy the London Health Observatory (London Health Observatory 2012).

Geocoding

Geocoding mappable, health-related data has long been seen as a "'solution to the problem of how to monitor socioeconomic inequalities and their effect on health" [14]. Data for this project was collected from both US Census and official, city sources for all five New York City boroughs and then specifically for Bronx's and Manhattan's census tracts. While one might use data at census block, designated neighbourhood (for example "South Harlem"), or zip code resolutions, at least since 2005 census tracts have "increasingly been used to analyze inequities in access to health care, providing insight into the contribution of economic and geographic barriers to obtaining adequate care" [15]. While the US Census Bureau developed a limited set of census tracts for use in the 1910 census, it was not until 2000 that a complete set of tracts was completed for the entire United States. Each tract represents an average population of 4,000 people; each is an aggregation of smaller census blocks of approximately 1000 persons.

In 2004 Nancy Krieger and Harvard colleagues created The Public Health Disparities Geocoding Project, an online tutorial to facilitate the location and downloading of data on geographic disparities for population health studies [16]. For its part, the US Census Bureau provides a step-by-step online menu for locating and downloading a geographic, mappable framework (shape files, JSON, etc.) as well as health and socioeconomic census data (Figure 2). "Filters" permit a geography to be chosen (national, state, city, census tract, etc.) and then matched with desired subject files (for example, "race").

Today, data acquisition is facilitated through the use of Artificial Intelligence programs that can both search for data sources and write retrieval scripts for large datasets to be activated through one or another software programming environment. Data for this project was located through a search with Claude Sonnet 4.5 software and then downloaded using the analytic and programming software R. Health related data was identified at the US Census Bureau, its American Community Survey, and in the Centers for Disease Control's (CDC) U.S. Small Area Life Estimates Project (USALEEP). Federal health and socioeconomic data at borough and census tract resolutions was mirrored on the New York City Department of Planning's Resource

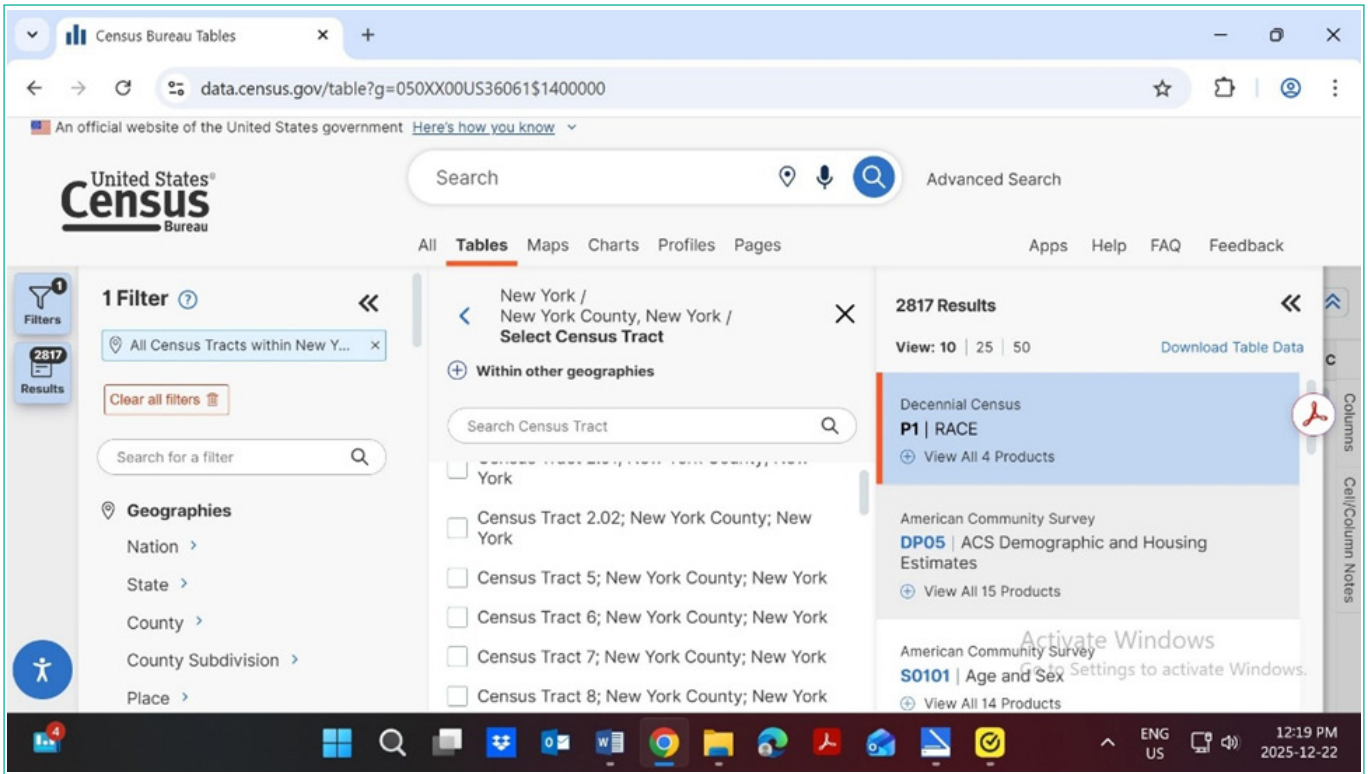
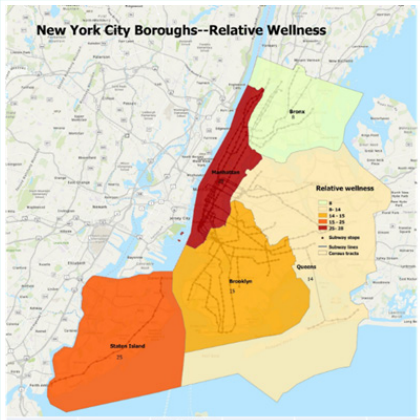


Figure 2: The US Census Bureau provides a step-by-step menu for retrieval of data at a range of scales (the nation) and resolutions (census tract). Data retrieved can then be joined with census tracts to map health and socioeconomic data in individual tracts.



Borough	Total score	median yrs. longevity	Median Income	% Infant mortality	% not employed	% without insurance	% families SNAP	% Black persons
Manhattan	28	84.7	$104,910	4.5	4.8	4.8	15	12.9
Staten Island	25	82.1	$89,800	4.2	5	5	12	9.5
Brooklyn	15	82.3	$66,900	5.2	6.2	6.2	22	31.9
Queens	14	81.3	$73,700	4.8	8.5	8.5	18	17.7
Bronx	8	80.7	$47,215	5.8	7.5	7.5	40	30.1

Figure 3: All five boroughs were rated with a cumulative index summing longevity and a set of socioeconomic factors contributing to it. Clearly Manhattan and then Staten Island had the greatest longevity followed by Brooklyn and Queens. The Bronx was by far the least advantage of all five boroughs.

page and stored in the official, New York City 'GitHub' repository. Files for geocoding subway lines and stops, located by the AI, were retrieved from the Department of Planning 's Open Data and data.ny.gov directories.

Besides average mortality (life years), data retrieved included criteria generally acknowledged to affect longevity: median household income; average number of persons with a high school education; average employment rate; percentage of persons with health insurance coverage, and percentage of persons receiving SNAP food benefits. Finally, because an estimated 26 million Americans lack health insurance [17], especially in non-Caucasian communities, race and health insurance data were also collected [18]. At every resolution—census tract, neighborhood, borough—the range for longevity was approximately 20 years.

Borough analysis

Mapping longevity and health disparities for all five New York City boroughs resulted in an image as stark as that promised by the Subway Metaphor for its localized transit section between Manhattan and the Bronx (Figure 3). Health and socioeconomic criterion retrieved for each borough was ranked on a scale of 1-5 with five being a "best" and one being the lowest returned for each variable. For example, Manhattan had the lowest percentage of persons receiving SNAP food supplements (thus a 5) and the highest percentage of persons with at least a high school education (again, a 5). These calculations then were summed to create a cumulative index of relative health security for each of the five boroughs. Not surprisingly, perhaps, Manhattan and the Bronx were respectively the richest and the poorest of the five boroughs and thus those with the highest and lowest life expectancies. With a population of approximately 1.7 million persons, Manhattan is the nation's principal financial centre and boasts the highest gross domestic product of any county in the United States. It is home to the ultra-wealthy "Billionaires' Row" of residential skyscrapers along 57th Street. South and Central Bronx, however, are "… characterized by high rates of poverty, large minority and immigrant populations, and low socioeconomic status, as indicated by education, employment, and homelessness rates" [19]. Clinically, they are, "medically unserved with a significant percentage of the population receiving health coverage, if at all, only through federal Medicare or Medicaid programs". One writer described the South Bronx as, "a cross-section of everything that is wrong with America" [20].

Clearly, Manhattan residents lived longer, presumably were in general healthier, and clearly more likely to be employed than their counterparts near and then beyond the Bronx border. Mean household income in Manhattan ($104.910) was more than double that of the Bronx ($45,000) where, predictably, unemployment was higher (10.58% versus 7.3%.). Not surprisingly, Bronx families were more than twice as likely to require SNAP food supplement benefits as were their counterparts in Manhattan (33.78% vs. 13.7%).

While the percentage of uninsured persons was relatively low in both boroughs, thanks to a range of federal programs (Medicare, Medicaid, Veterans assistance, etc.), its mean was higher in the Bronx (6.62% vs 4.10%). Demographically, only 12.9 percent of Manhattan residents were African American compared to approximately one-third of the Bronx population where also a larger percentage of Latin Americans resided, especially in "Spanish Harlem".

A Borough analysis is a summary that hides as much as it reveals. Manhattan's high relative score, for example, conceal lower rates of longevity and attendant socioeconomic indices on some streets in lower Manhattan near its Chinatown and then above 96th Street near the Bronx border Similarly, while Staten Island appears to be almost as healthy as Manhattan, a closer examination shows a sharp divide between northern and southern census areas. The US Census Bureau's American Community survey reports a lower longevity of between 74-78 years in upper Staten Island zip code areas with one reporting a longevity of only 69.1 years" [21]. By way of contrast longevity averages in the low to mid 80's with a high in one zip code in southern Staten Island of 85.1 years were reported. Analysis at the borough level hides those differences as well as those of contributing socioeconomic indices.

The metaphor

The genius of the Metaphor is the manner in which it anchors a study of health disparities in a local geography defined by transit stops, each typically less than a kilometer from the next. For an understanding of data at this resolution, census tract data on longevity and its socioeconomic contributors were transferred in the GIS to each of the 219 subway stops along relevant Bronx and Manhattan subway lines. From mid-town Manhattan across the Bronx longevity along subway lines ranged from a high of 89.1 years to a low of 74.9 years.

In the map (Figure 4) one *sees* the decent Marmot (2014) described from midtown Manhattan and then descending along the 14-block stretch from 96th Street to 110th Street—approximately 1.1 kilometers—into the South Bronx. From there longevity continues to a low of 74.4 years at 138th street before gradually increasing to stops in the northern Bronx by 165th Street. The gradient from midtown into

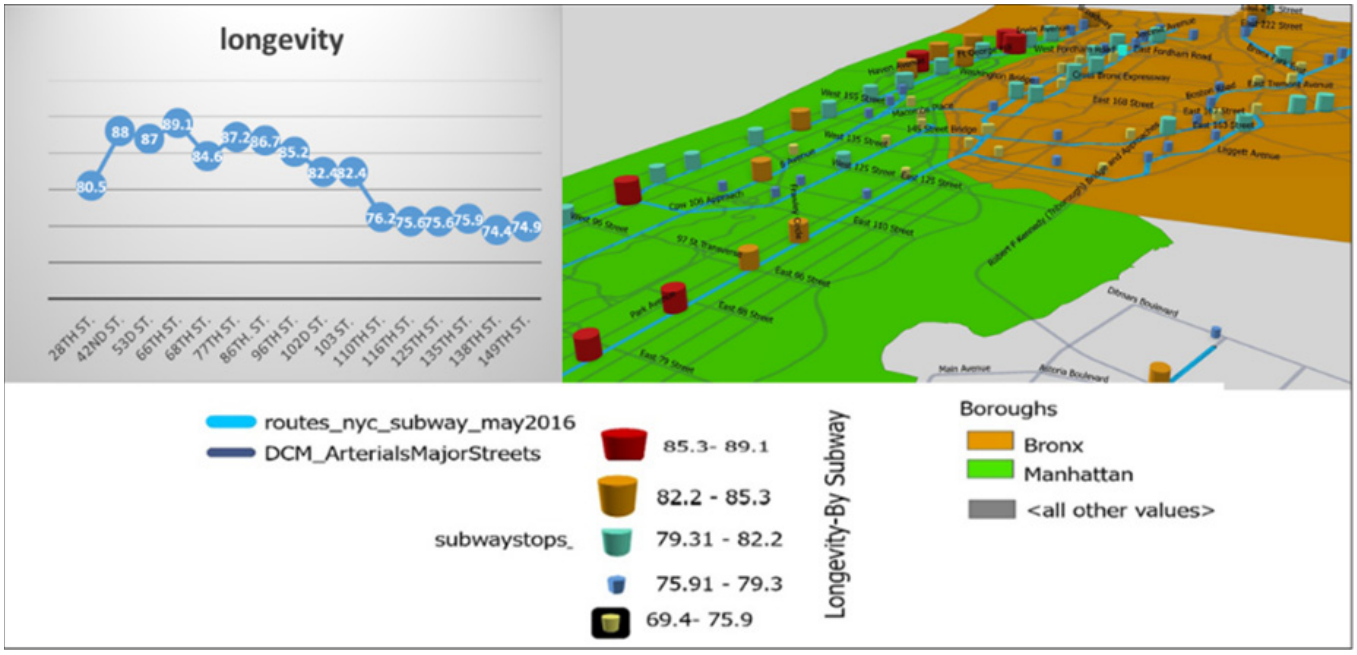


Figure 4: A map of longevity along New York City subway lines joining the Bronx (orange) and Manhattan (green) boroughs. Census tract data is assigned to each of the 217 subway stops along lines joining the two boroughs. Longevity declines gradually from 68th to 96th streets in central Manhattan and then more precipitously beginning at 96th Street.

and through the Bronx is not smooth, however, but rather stepwise. Stop by stop there are minimal changes with a sharp, step-wise decent from 86th Street to perhaps 102 Street and then to 110th. After that, longevity ratings almost level off until a low level at 138th street. After that it stabilizes and slowly increases into the northern borough. Longevity declines gradually from 68th to 96th streets in central Manhattan and then more precipitously beginning at 96th Street. A multiple regression analysis of not only stops linked to census tracts but of all census tracts for which full data was recorded (N=514), showed income (p-value 0.001) and race (White) (p-value 0.001) were dominant predictors of higher life expectancy. Poverty-related stress (SNAP) (p-value 0.002) and percentage of African American residents playing a meaningful role in decreasing life years. Other indices were less strongly associated with longevity resulted from multicollinearity, overlapping relationships between related socioeconomic predictors.

Nearest neighbour analysis

If a consideration of differences among all five boroughs was perhaps too general, obscuring differences along the border of the two boroughs, mapping census tract data assigned to subway stops was perhaps too specific. It is difficult to see the sharp decent predicted by Marmot along the line from midtown Manhattan into the Bronx, and beyond. And importantly, analysis and mapping of the total compliment of 219 subway stops based on proximate census tracts ignores potentially relevant data from the 398 remaining census tracts that lack attendant subway stops. To present a more efficient and potentially more complete application of the subway metaphor, subway stops were used to create a set of "nearest neighbor," transit-based, Thiessen polygons (Figure 5).

Named after nineteenth century mathematician Georgy Voronoy, the resulting Voronoi networks have a long history of use in health-related, retail, and transportation studies [22]. The result divides an area into regions based on proximity to a specific set of points. Each point in a set, in this case each subway stop, anchors one side of a polygon such that all points inside the resulting polygon are closer to its central point than to any other.

	Number of	Max. longevity	Min. Longevity
Census Tracts	671	93.3	71.2
Transit Stops	219	89.1	69.4
Thiessen polygons	231	93.3	77.6

In this transformation data on both longevity and contributing, socioeconomic factors were aggregated from the set of 617 census tracts into only 219 transit polygons. The result is at once more specific than that presented in the map of all boroughs (Figure 3) and more general (and perhaps more legible) than in the map of individual subway stops (Figure 4). Thus longevity for all census tracts ranged between 93.3 and 71.1 years; for all transit stops between 89.1 and 69.4 years. But the range for the set of 219 transit stops, anchored by the subway stops, was 93.3 and 77.6 years. With this approach, the predicted decent along the transit line from Manhattan into the Bronx was visibly clearer, giving weight to the metaphor's reality. Colors shift in a clear, lock step from mid-town Manhattan's dark brown to orange and then, with decreasing longevity, to the yellowed subway polygons in the Bronx. But note that the predicted decent from mid-town Manhattan into the South Bronx and then Harlem *begins* in Manhattan and only then increases in the Bronx.

Importantly, differences are revealed within each borough in a way obscured in other approaches. In Manhattan, for example, is a decreased longevity in transit neighbourhoods south of 57th Street and then again, below 34th Street in Manhattan, for example. Interestingly, longevity assigned to individual transit stops is in some cases different from that of the assigned transit neighbourhood. This occurs, for example, above Central Parkway; at 105th Street; near West 135th Street and St. Nicholas Avenue, and at West Fordham Road in the Bronx. This suggests the need for future investigation of the specific

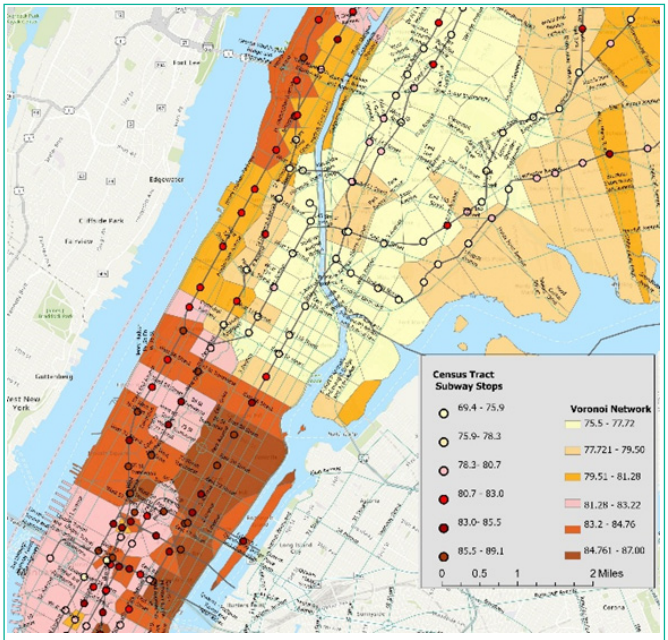


Figure 5: Nearest neighbour polygons anchored by subway stops defined by longevity at a proximate census tract. The result clearly shows sharp gradients in longevity between Northern Manhattan and the Bronx were longevity is diminished across the central borough, then increasing in its norther region.

census tract and its relation to those census tracts within a shared neighbourhood. What makes these census tracts, identified by the subway stop, different from others nearby?

Not surprisingly, multiple regression at the resolution of transit neighbourhoods (N=231) yielded returns roughly similar to those reported at the census tract level. Again, critical predictors indicating decreased longevity included the percentage of the population that was black (p-value 0.001) and those receiving SNAP (0.001). Percentage of persons unemployed was slightly above the normally accepted confidence threshold (0.057) with percentage of persons without health insurance significant at a p-value of 0.005. There was a strong degree of multicollinearity indicated by a high VIF (Variation Inflation Factor) between, the percentage of unemployed (VIF 9.51) and those without health insurance (VIF 9.08), as well as between those receiving food assistance (4.80) and race (5.38). Perhaps most interesting, and potentially useful to the public health analyst, are those subway stops where longevity is different from that of the surrounding polygon. Where the subway stop's longevity is greater than that of the polygon it suggests differences in services or socioeconomics that advantage the adjoining census tract from its neighbours. That would suggest the provision of them to other areas of the neighbourhood. Conversely, where census stops seem to have decreased longevity then programs of increased health and educational opportunities elsewhere available might be indicated.

Discussion

At least since the 1940's sociologists and geographers as well as public health researchers have investigated the relative inequalities affecting health and welfare across the United States at almost every scale—national to local to neighbourhood [23]. It thus is no surprise that longevity declines with income and employment where household value may be a surrogate for income and food assistance an indicator of relative poverty.

While the Subway Metaphor may serve less as a tool of public health investigation than as a polemical device, this work documents precisely the predicted decent in life years along transit lines traversing the city. The decline in longevity is clearest, and most complete with the neighbourhood resolution in the Voronoi network anchored by subway stops. Lost in the Metaphor but recovered in this approach were differences in life years across the entire city's five boroughs—the context of the metaphor—as well as within other boroughs like Staten Island where similarly differences are recorded.

A real and perhaps unique contribution of the Metaphor is its insistence on transit lines as a medium for the study of health disparities in urban settings. At the least, it offers a useful approach highlighting both the persistence of health disparities and the factors that affect them in specific urban geographies. A mapped interpretation at different resolutions—the city-at-large, along individual census tracts, and with neighbourhood polygons--permits a kind of spatial epidemiology encouraging statistical analyses in a cartographic environment.

Acknowledgement: The author gratefully acknowledges the assistance of University of Hawaii botany professor (retired) Kim Bridges in this paper's research and preparation

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