Health Impact Assessment and the Aging: A Mini-Review of Pollution and Public Health from Transport Infrastructure Proposals

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Abstract

It is a regulatory requirement in Australia that all three tiers of government must assess development applications using economic, social and environmental metrics. Health impact assessments (HIA) are poorly designed in practice in the case of transport proposals and fail to address the challenges of an aging population. Little is known about how environmental risks impact on individuals over time. A major challenge for health impact assessment is coping with the inter-related issues of environmental and health sustainability and population aging. This mini-review, limited to the authors’ research and consulting experience with the impacts of noise and air quality on public health that is briefly set out in the paper, proposes a conceptual mathematical model of fundamental interactions where the problem is to compute the integrated exposure as a sum of the individual products of the concentrations encountered by a person in a micro-environment and the time the person spends there. The implementation of the model for HIA requires extensive data collection.

1. Introduction

During the relatively uncomplicated world of transport infrastructure proposals and their assessment in the era post-Second World War - where there was a high degree of autonomy amongst the largely insular transport mode authorities - priorities were determined on the economic merits of projects. Founded on systems analysis by the RAND Corporation that arose from the civilian applications of operations research techniques honed during war-time [1, 2], cost-benefit analysis - first applied to the planning of water resources in the USA [3] and later to other infrastructure – became the fundamental tool for governments in deciding on what should be built. Assessment criteria for transport projects were expanded considerably following the Brundtland Commission report [4], when decision makers were required to add social and environmental factors to the economic ones. In Australia, for example, it is now mandatory for the three tiers of government [5] to consider economic, social and environmental factors when evaluating development applications submitted by the private and public sectors. The dominant environmental stressors from transport (roads, railways, sea ports and airports) are road traffic, ships in ports and aircraft noise that all have well-understood physical properties from the source of the sound waves together and trigger, or exacerbate, disease. There is good evidence that the impact of longer exposure to environmental pollution in aging population is more marked across a number of chronic diseases. These include cardiovascular disease [7], diabetes mellitus [8] and lung, breast and brain cancer [9-11]. It is the complexity of these emerging public health problems that present a major new challenge for sustainable development, well-being and the quality of life in cities for aging populations.

A major challenge for health impact assessment is coping with the inter-related issues of environmental and health sustainability and population aging. The research challenge is to establish this lifetime exposure (in different places and locations) to the environmental stressors from transport systems and their cumulative effects on health and wellbeing.

The significance of this line of research is that The World Health Organization’s (WHO) global strategy for age-friendly cities has charted the way towards sustainable solutions: how ‘active aging’ can be enhanced through outdoor spaces, transport, housing, and social participation and inclusion, and civic participation and employment strategies. This activity should take place ideally in non-polluted locations.

Little is known about how environmental risks impact on individuals over time. Little is known about location - the health differentials that are due to individuals’ accumulated exposures, differences in environmental stressors after internal migration (e.g., moves to and from the coast and rural areas), and selective mortality amongst individuals. Conceptually for HIA, we need to establish the lifetime exposure (in different places and locations) to environmental stressors from transport systems and their cumulative effects on health and wellbeing. To do this, we sketch out a simple example as a template for HIA to show how peoples’ travel patterns pass through “polluted” places as objects of investigation during their life histories as the body ages.

2. Main Text

“[D]ecreased efficiency in the blood-brain barrier and the cardiovascular, pulmonary, immune, musculoskeletal, hepatic, renal, and gastrointestinal systems can alter response to environmental agents, leading to heightened susceptibility to the toxic effects of air pollution, pesticides, and other exogenous threats to health” [12]

2.1. Authors’ Previous Relevant Research

This invited mini review is based on the authors’ experience of being chief investigators or principal investigators on trans-disciplinary research projects [13, 14] and consultancy advice to governments [15] that involve transport (all modes) and pollution (noise and atmospheric pollution) and environmental stressors on the health and well-being of the elderly [16-18]. The substantive themes have been the impact of pollutants on public health – specifically, lead in petrol and children’s intellectual development [19], aircraft noise and hypertension and elevated blood pressure amongst residents living near airports [20] and mitigation strategies to counter the effects of aircraft noise [21].
However, to advance the application of health impact assessment (that includes, explicitly, the elderly) and transport proposals, the following summary of completed research is of particular relevance. Environmental stressors clearly have both location and time-dimensions (duration by time of day, seasonality, trends over time). There is growing evidence that environmental stressors have a significant impact on long-term health conditions. Litt and colleagues [22] outline the lack of information on the role of environmental exposures in relation to the incidence of chronic diseases and other conditions including asthma, neurological disorders, diabetes and developmental disabilities. This is particularly relevant for aging populations because they have longer exposure to these pollutants in the environment.

As a preliminary attempt at this difficult empirical analysis [23] used geographic location as a proxy for exposure level. Analyses of all available waves (from 2001 to 2007) of the Australian HILDA survey were undertaken. HILDA is a comprehensive and nationally representative panel dataset that surveys both individuals and households. We selected all participants who were interviewed in the HILDA database. The non-interviewed members of the household were excluded. Participants aged 45 years or more at baseline (Wave 1, 2001) were included. To ensure adequate exposure to their local environment, we selected participants who had lived at their current urban, regional, rural or remote location for 20 or more years. The presence of long-term health condition was based on the HILDA interviewee confirming they had one or more of the following conditions: arthritis; asthma; any type of cancer; chronic with their health impacts on humans; and emissions from transport vehicles, where air quality and its impact on humans is further complicated by the technology of the fleet, atmospheric conditions and the diffusion of pollutants.

Despite these well-established casual links between environmental pollution and health we argue that the specific methodologies of health impact assessment [6] for infrastructure proposals are imperfectly and inconsistently applied especially for urban transport, not least because of the spatial and temporal dimension of pollution. Furthermore, when including the long-term effects of exposure to transport pollutants we suggest that the elderly be paid more attention in the analysis of health impacts on vulnerable groups. There is limited literature on the specific effect of living in cities on the aging compared with living in areas of high environmental quality. As our bodies age, the ability to defend against environmental pressures diminishes, and exposures can accelerate the aging process. Furthermore, there are increases in chronic diseases such as bronchitis or emphysema; Type II diabetes (adult onset); depression/anxiety; heart/coronary disease; high blood pressure/hypertension; and their circulatory conditions. Logistic regression was undertaken using SPSS version 16.0 with the presence of at least one long-term health condition as the outcome variable. Explanatory variables were included in the model if there was an association with a level of significance of .25. [24] Explanatory variables were considered significant in the logistic regression model with a level of significance of .05 and 95% confidence intervals for odds ratios. Survival was measured at each wave of the HILDA collection and defined as not reporting a long-term health condition occurring for the first time in that wave. Cox regression was used to determine predictors of survival. SPSS Version 16.0 was used for survival analyses with a level of significance of 0.05.

At baseline, there were 1312 HILDA interviewees aged 45 years or more who had lived at their current address for 20 years or more. Around two-thirds (63%) lived in a major city, 21% lived in inner regional areas, 14% in outer regional areas and 2% in remote areas. In 2001, one third (33%) of the interviewees had an existing long-term health condition as defined above. Increasing age, being male, living in major cities or inner urban areas, and living in an area with a lower socio-economic status (based on Socio-Economic Indicator for Area [25] increase the odds of having a long-term health condition.

A one-year increase in age increases the odds of having a long-term health condition by 1.04 (95% CI 1.03-1.05, p<.001). Males have 1.61 greater odds of having a long-term health condition (95% CI 1.26-2.04, p<.001). For people aged 45 years or more, living in a major city compared to a remote area increased the odds of having a long-term health condition by 6.51 (95% CI 1.48-28.59, p=0.013). Similarly, living in an inner regional area compared to a remote area increased the odds of having a long-term health condition (OR=7.19, 95% CI 1.63-31.67, p=.009). Living in the lowest decile of the index of relative socio-economic advantage/disadvantage compared to the highest decile increased the odds of having a long-term health condition by 3.92 (95% CI 2.25-6.82, p<.001).

This research reinforces the association between long-term exposure to environmental stressors, such as air pollution and noise, in large cities and in individuals developing long-term health conditions. The analysis at baseline demonstrated that urban and city dwellers were more likely to have one or more long-term health conditions. However, the odds of developing a long-term health condition in a cohort of aging Australians was not significantly higher in more densely populated areas compared to rural locations with its implicit superior environmental quality.

Of course, there is a major limitation in using geographic location as a proxy for levels or dosage of exposure to environmental stressors. Nevertheless, the results give support to the theoretical model that we propose in subsection 2.2. as a fundamental underpinning of HIA where residential zone r is designated as a “non-polluted” space, and that exposure to pollutants occurs in residential zone t. As noted in our conceptual model below, people living in the same location may have different exposure levels depending on their occupation and/or other lifestyle activities [26, 27].

2.2. HIA and Base-line Measurements

Contained within each uniquely defined geographical (spatial) entity, which here we call the “land-use/transport system”, there is a sub-set of locations and transport routes that are “polluted places”. What might constitute a “polluted” place in which environmental stressors are generated? Are these places continuously polluted? Or is there a time-dependent nature to this pollution? Whether or not a location is “polluted” is as much a political question (based on regulatory standards) as a scientific question. When transport infrastructure is proposed, the base-line measurements for health impact assessment (HIA) must account for the “locational life histories” of individuals and their health as they have aged, and how they move through these polluted places from cradle to grave through the mechanisms of migration and travel. There are long-term adverse health consequences (morbidity and mortalities) of this cumulative exposure to harmful pollutants.

A land use/transport system comprising of two zones and two routes has proved invaluable in explaining fundamental concepts for transport infrastructure planning [28, 29]. Here we add an additional residential zone (zone r) of high environmental quality to capture the migration dynamics and to lay the foundation of conducting a HIA. This zone is an “unpolluted place” where its residents’ enjoy healthy lifestyle choices of walking and cycling and a minimal amount of internal road traffic. This zone is in addition to the other residential zone (zone i) which generates a lot of car traffic and is connected to the employment centre (zone j) by a road system of two parallel routes (k=1; k=2).

For simplicity of exposition we can use the numerical worked example in [22, pp. 33-38] with equations and parameters that help explain fundamental concepts of traffic generation, the spatial pattern of traffic, transport mode and route choice, transport supply, and demonstrate the equilibrium flows of traffic of the road network. From vehicle emission models (or measured rates of tailpipe emissions), it is obvious that any properties along the main route (k=1) are located in a “polluted place”. Although the equations do not consider the internal traffic in zones i and j we can safely assume that these zones too are “polluted places” whereas zone r is not polluted – by definition.

The specific parameters chosen for the worked example gave the equilibrium traffic assignment in the peak one-hour,
And also showed how the equations of state could be applied to forecast peak-hour traffic under four different policy scenarios that represent alternative investment decisions [28].

It is straightforward (if tedious) to specify different parameters by time of day for the base case situation then project traffic forward for each day of the week, for each week of the year, and so one. An equally straightforward calculation is that of the pollutants from the traffic which can be integrated over time to give total accumulated dosages (in zone $i$, zone $j$ and along routes $k=1$ and $k=2$).

The problematic part of the analysis is to determine the population’s exposure to these “polluted places.” Let us take air pollution as an example. Air pollution epidemiology studies typically involve estimation of a statistical relationship between the frequency of a specific health outcome, observed in a study population in its normal place (location), and the air pollution concentration measured at that location (using a site-specific monitoring site as the proxy for individual locations). Typically, community-averaged outdoor pollution concentrations in the atmosphere are used in the statistical investigation of exposure-response relationships. The important point is that ambient monitoring at fixed locations does not reflect adequately, or accurately, total personal exposures to particulates and other pollutants [30]. The difficulty for our purposes is the highly time-dependent nature of the pollution phenomenon, primarily a function of the temporal traffic variation during 24 hours (including the imposition of legal curfews on the movement of aircraft or ships), and the time-dependent paths of individuals going about their activities – their time-space geographies.

The problem is to compute the integrated exposure as a sum of the individual products of the concentrations encountered by a person in a micro-environment and the time the person spends there. The integrated exposure permits computations of average exposure for any averaging period by dividing the integrated exposure by the duration of the averaging period. If the concentration within the micro-environment $j$ is assumed to be constant during the period that the person $i$ occupies micro-environment $j$, then the integrated exposure $E_i$ for person $i$ will be the sum of the product of the concentration $c_j$ in each micro-environment, and the time spent by the person $i$ in that micro-environment will be as follows,

$$E_i = \sum c_j \cdot t_{ij} \quad \text{(the summation is over all zones } J=1 \text{ to } n) \quad (1)$$

where,

- $E_i$ is the integrated exposure of person $i$ over the time period of interest;
- $c_j$ is the concentration experienced in micro-environment $j$;
- $t_{ij}$ is the time spent by person $i$ in micro-environment $j$; and
- $J$ is the total number of micro-environments.

To compute the integrated exposure $E_i$ for person $i$, it obviously is necessary to estimate both $c_j$ and $t_{ij}$. If $T$ is the averaging time, the average exposure $E_i$ of the person $i$ is obtained by dividing $T$; that is $E_i = E/T$.

To solve this problem it is necessary to determine the concentration outdoors, the dispersion in ambient air, penetration across building envelopes, and the exposure to the human respiratory tract. Human beings come in contact with pollutants of outdoor origin in many settings (micro-environments) including: ambient locations; indoors at home (in zone $j$); at work (zone $j$), or at school; in transit (along routes $k=1$ and $k=2$) while commuting or riding in a car or a bus. With particular reference to the worked example, we need specify a spatial model for aging in, and through, these “polluted spaces”. The total population comprises:

- Residents of zone $r$ who remain in “unpolluted spaces” in the analysis period $t_0$ to $t_n$.
- Residents of zone $r$ who migrate at time $t_m$ to re-locating in zone $i$ or along routes $k=1$ or $k=2$ and live there from time $t_m$ to $t_n$.
- Residents of zone $i$ who remain in “polluted spaces” in the analysis period $t_0$ to $t_n$.

Residents of zone $i$ or along routes $k=1$ or $k=2$ who migrate at time $t_m$ to re-locating in zone $r$ or and live there in “unpolluted spaces” from time $t_m$ to $t_n$.

Residents of zone $i$ who commute to zone $j$ along routes $k=1$ and $k=2$. Employees working in zone $j$ in the analysis period $t_0$ to $t_n$.

Employees of zone $j$ who re-locate a job at time $t_m$ by re-locating workplace to zone $r$ from time $t_m$ to $t_n$.

From a practical viewpoint in applying these concepts to HIA is to formulate two spatial models: one for the migration component of residents and jobs; another for the commuting component. Both models must specify the age of the person and the time at which the spatial interactions takes place – hence there is an explicit time dimension. Therefore, lifetime exposure $E$ from cradle $t_0$ to $t_n$ is a function of the location at (zones $= z$) at different times and where the population is at time $t=t_n$. This could be modelled using time-series analyses where demographics, such as age, sex and socio-economic status, are included in the model below:

$$E = F_{i}(t, t_n \text{demographics}) \quad (2)$$

3. Discussion

In relation to the practical application of HIA to transport infrastructure development applications where economic, social and environmental factors are of central importance, the core hypothesis is that there are long-term adverse health consequences (morbidity and mortality) of the cumulative exposure to harmful pollutants. We have demonstrated that the HILDA study data reinforces the association between long-term exposure to environmental stressors, such as air pollution, in large cities and in individuals developing long-term health conditions. The analysis at baseline demonstrates that urban and city dwellers were more likely to have one or more long-term health conditions. However, the odds of developing a long-term health condition in a cohort of aging Australians was not significantly higher in more densely populated areas compared to rural locations with its implicit superior environmental quality.

To address these limitations, a specifically designed HIA study should address the measurement of exposure to environmental stressors over the life-course of the aging populations, including accurate measurement of environmental stressors, such as ambient air quality and noise. Such a study should also include the diagnosis of non-infectious chronic disease by a health-care professional. Lifestyle choices that protect against, or are a risk for non-infectious chronic diseases, should be recorded in a systematic way. Notwithstanding the limitations of using a longitudinal database (HILDA) that was not specifically designed to measure environmental exposure our research has shown that aging Australians who live in urban areas are more likely to have a non-infectious chronic disease than those living more remotely (and implicitly in superior environmental conditions). Given that throughout the world there is increasing urbanisation, increasing aging of the population, and increasing levels of pollutants in the environment, there is an urgent need to address the impact of environment exposures on society especially for the cohorts of the elderly.

A major societal challenge is coping with environmental sustainability and population aging. The long-term research aims for improving HIA in the transport sector are to: analyse how environmental stressors impact on individuals over time and by location; to identify data; and to propose methodologies of dose-response over individual life-spans. As people age their ability to defend against environmental stressors, such as air pollution, diminishes. Such exposures can accelerate the aging process and trigger, or exacerbate, and the erosion of independence and wellbeing.

4. Conclusions

This mini-review has extended traditional spatial transport modelling through the inclusion of interactions between land use (with its demographic characteristics specified) and transport and public health (where health can be viewed as a central criterion for judging all human sustainability). The issues of pollution events (environmental stressors), time (from cradle to the grave) and place (locations, especially those with their own time-dependent variable of environmental stress) are the basis of what we propose as a new transport and epidemiological study.
As people age their ability to defend against environmental stressors diminishes, and such exposures can accelerate the ageing process and trigger, or exacerbate, disease and the erosion of independence and wellbeing.

We suggest an ambitious challenge would be the explicit recognition of time and spatial modelling in all research methodological phases in a HIA from problem definition, through to reviewing existing knowledge on the research problem, especially disciplinary and inter-disciplinary conceptualisations and explanations, designing the enquiry from research gaps; implementing the study of a transport infrastructure proposal, refining conceptual understandings and synthesising data sets; and specifying types of interventions (with stakeholders) and their costs and benefits. We need to establish the lifetime exposure (in different places and locations) to the environmental stressors from transport systems and their cumulative effects on health and wellbeing.

The methodological basis of a HIA could be time-space geography but with the additional complexity of locations and magnitudes of environmental stressors mapped “through which people on their journeys” are exposed. Researchers – currently familiar with spatial interaction models using cross sectional data – should turn their minds to the long-term dynamics of change and time series analyses as to how peoples’ travel patterns pass through “polluted” places as objects of investigation during their life histories as the body ages. We suggest that the issues of event (environmental stessor), time (from cradle to the grave), and place (locations, especially those with their own time-dependent variable of environmental stress) are the basis of a new type of epidemiological study to underpin health impact assessments (HIA) that give proper weight to impacts on the aging populations.

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Statement of Competing Interests
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References

