Probabilistic Estimates of Variability in Exposure to Traffic-related Air Pollution in the Greater Vancouver Regional District - A Spatial Perspective

by

Eleanor May Setton
B.A., University of British Columbia, 1994
M.Sc., University of Victoria, 1996

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Dr. C. Peter Keller, Supervisor
(Department of Geography)

Dr. Denise Cloutier-Fisher, Co-Supervisor
(Department of Geography)

Dr. Leslie Foster, Departmental Member
(Department of Geography)

Dr. Ray Copes, Outside Member
(Department of Health Care and Epidemiology, University of British Columbia)

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ABSTRACT

A probabilistic spatial exposure simulation model (SESM) was designed to investigate the effect of time spent at work and commuting on estimates of chronic exposure to traffic-related air pollution in large populations. The model produces distributions of exposure estimates in six microenvironments (*home indoor*, *work indoor*, *other indoor*, *outdoor*, *transit to work* and *transit other*) for workers and non-workers, using randomly sampled time-activity patterns from the Canadian Human Activity Pattern Survey and work flow data from Statistics Canada. The SESM incorporates geographic detail through the use of property assessment data, shortest route analysis, and the use of a geographic information system (GIS) to develop pollution concentration distributions. The SESM was implemented and tested using data for 382 census tracts in the Greater Vancouver Regional District of British Columbia.

Simulation results were found to be relatively insensitive to the choice of distance used to represent the typical range of non-work related trips; the use of a simple annual average pollution estimate versus a time-stratified annual average; and the use of different indoor/outdoor ratios representing the infiltration of ambient pollution into indoor locations. Substantial sensitivity was observed based on the use of different methods for producing spatial estimates of ambient air pollution.

The SESM was used to explore variability in annual total exposure of *workers* to traffic-related nitrogen dioxide (NO_2). Total exposure ranged from 8 $\mu g/m^3$ to 35 $\mu g/m^3$ of

annual average hourly NO_2 and was highest where ambient pollution levels are highest, reflecting the regional gradient of pollution in the study area and the relatively high percentage of time spent at home locations. Within census tract variation was observed in the partial exposure estimates associated with time spent at work locations, particularly in suburban areas where longer commuting distances are more prevalent. In these areas, some workers may have exposures 1.3 times higher than other workers residing in the same census tract. Exposures to NO_2 associated with the activity of commuting to work were negligible.

No statistically significant difference in total exposure estimates was found between female and male commuters, although there were small but observable differences at the upper end of the exposure distributions associated specifically with the *work indoor* microenvironment. These differences were highest in suburban areas (up to 3 $\mu g/m^3$ of annual hourly average NO_2 higher for female commuters, in relation to 99th percentile total exposures levels of approximately 37 $\mu g/m^3$), illustrating the impact of systematically different work locations for female compared to male commuters in these same census tracts.

Simulated exposures for *workers, non-workers,* and a base scenario where all time is spent at the *residence only* were compared. Statistically significant differences were found in the exposure distributions for *workers* versus *non-workers*, *workers* versus *residence only*, and *non-workers* versus *residence only*. Differences in exposure within census tracts were highest at the 10th and 90th percentiles, on the order of -5.4 to +6.5 $\mu g/m^3$ of annual average hourly NO_2 respectively for *workers* compared to *non-workers,* in relation to exposure estimates between 10 and 40 $\mu g/m^3$ of annual average hourly NO_2 on average.

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LIST OF ACRONYMS

APEX	Air Pollutants Exposure model
ASPEN	Assessment System for Population Exposure Nationwide
BAQS	Border Air Quality Study
BS	black smoke
CHAD	Consolidated Human Activity Database
CHAPS	Canadian Human Activity Pattern Survey
CMAQ	Community Multiscale Air Quality [model]
CO	carbon monoxide
E	total exposure
EVR	equivalent ventilation rate
EXPOLIS	Air Pollution Exposure Distributions of Adult Urban Populations in Europe
GIS	geographic information system
GVRD	Greater Vancouver Regional District
HAPEM	Hazardous Air Pollutant Exposure Model
HEEE	high-end exposure estimate
I/O	indoor/outdoor
IDW	inverse distance weighted
Km	kilometer
KS test	Kolmogorov-Smirnov goodness of fit test
LUR	land use regression
M	metre
ME	microenvironment
MEI	maximally exposed individual
MM5	mesoscale model 5
NAAQO	National Ambient Air Quality Objective
NAAQS	National Ambient Air Quality Standards
NEMS	NAAQS Exposure Models

NHAPS	National Human Activity Patterns Survey
NO_2	nitrogen dioxide
NOx	nitrogen oxide
O_3	ozone
$PM_{2.5}$	fine particulate matter
pNEMS	probabilistic NAAQS Exposure Models
SESM	Spatial Exposure Simulation Model
SHAPE	Simulation of Human Activity and Pollution Exposure model
SHEDS	Stochastic Human Exposure and Dose Simulation model
SMOKE	Sparse Matrix Operator Kernel Emissions [model]
SO_4^{2-}	sulfate
SO_x	sulfur oxides
UBC	University of British Columbia
US	United States
US EPA	United States Environmental Protection Agency
VOCs	volatile organic compounds
VR	ventilation rate
$\mu g/m^3$	micrograms per metre cubed

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1.0 INTRODUCTION

1.1 STUDY BACKGROUND AND DISSERTATION ORGANIZATION

Decades of epidemiological research show a clear association between exposure to ambient (outdoor) air pollution and a range of negative health effects, and do not give evidence that there is a demonstrable threshold for effects. These important studies inform air quality management policy internationally, nationally, and locally, which in turn can have wide-reaching impacts on environmental quality and economic development.

In 2004, Health Canada committed three years of funding to the Border Air Quality Study (BAQS), a multidisciplinary research effort led by Dr. Michael Brauer, Director of the School of Occupational and Environmental Hygiene, University of British Columbia, and conducted by researchers at the University of British Columbia, the University of Victoria, and the University of Washington. The focus of BAQS was on conducting epidemiological analyses of the associations between chronic (annual average) air pollution and negative birth outcomes, early childhood respiratory illnesses, and cardiovascular illnesses in people aged 45 and over in the Pacific Northwest. Of particular interest was air pollution associated with traffic and with wood-burning for residential heating.

The research presented in this dissertation was conducted as part of BAQS, at the University of Victoria's Spatial Sciences Research Lab (Dr. C. Peter Keller, Principal Investigator), with the overall goal of investigating methods for improving the exposure assessments employed in the BAQS epidemiological analyses. More specifically, this research focuses on traffic-related air pollution and the effects of commuting on exposure. The remainder of this introductory section is organized in the following manner. First, a detailed review of literature pertaining to health effects associated with exposure to air pollution in general, commonly used approaches for assessing exposure in epidemiological studies of air pollution, and the effect of individual mobility on air pollution exposure assessment are presented in Section 1.2. This review is intended to set the context for the research questions expressed subsequently in Section 1.3. Based on the research questions, the methodological approach adopted for the research presented here is described in Section 1.4. Finally, Section 1.5 describes the study area.

More generally, this dissertation is presented in a non-traditional format, and the following notes are intended to guide the reader by explaining the organization of the dissertation after Chapter 1.

- Chapter 2 provides an in-depth review of air pollution exposure simulation, the approach chosen for this research.
- Chapter 3 provides detailed information on the specification and testing of the spatial exposure simulation model (SESM), and development of the input data.

Following Chapter 3, three papers are presented. Each has been written as an independent document, and can be read separately, without having read any of the other material included in the dissertation. Each paper provides a pertinent literature review, description of methods, results, discussion, and references. As each paper is meant to stand alone, there are some areas of duplication between the papers and the chapters of the dissertation. A very similar description of methods is included in each paper, and represents a summary of the material in Chapter 3. Each paper also includes references, some of which are duplicated in the other papers and at the end of the dissertation. Readers could start with these papers first, if desired, in any order:

- Paper 1 presents SESM results that address the question of spatial patterns in exposure due to working and commuting.
- Paper 2 presents an analysis of how gender affects exposure for commuters.
- Paper 3 investigates how exposure differs if estimated for workers, non-workers, or for residential locations only.

Chapter 4 follows the three papers and provides conclusions about the results in general, the usefulness of the SESM, its strengths and weaknesses, and areas for future research.

1.2 LITERATURE ON HEALTH EFECTS OF AIR POLLUTION EXPOSURE, APROACHES FOR ASSESSING EXPOSURE, AND THE EFFECTS OF MOBILITY ON EXPOSURE

The purpose of this section is to provide a review of current and/or important studies and trends relating to the effects of air pollution on human health, exposure assessment for population-level epidemiological studies of air pollution, and the effects of mobility on exposure. These reviews are intended to provide context to support the research questions presented in Section 1.3.

1.2.1 Effects of outdoor pollution on health

A significant source of outdoor air pollution in urbanized areas is related to vehicle traffic. It is estimated that in the year 2000, the transportation sector in British Columbia was responsible for the emissions of approximately 9,500 tonnes of fine particulate matter ($PM_{2.5}$), 18,500 tonnes of sulphur oxides (SO_x), 84,750 tonnes of volatile organic carbons (VOCs), 206,116 tonnes of nitrogen oxides (NO_x), and 915,000 tonnes of carbon monoxide (CO)(Environment Canada 2006). In addition to these primary emissions, ozone (O_3) is formed by chemical reactions between nitrogen oxides and VOCs, particularly in the presence of sunlight.

Epidemiological studies have found associations between a range of health impacts in varied populations and exposure to outdoor air pollution in general. Numerous studies suggest these health impacts occur at typical ambient levels of pollution (i.e., are not associated with abnormally high air pollution episodes or exposures) and provide no evidence of a lower threshold below which health impacts do not occur (Pope 2000; Brauer, Brumm et al. 2002). In general, cardiovascular, cardiopulmonary and respiratory mortality and morbidity appear to increase with pollution levels both in the short term and long term, and lung function in children and adults may be affected. Table 1 provides additional detail, as summarized in several published comprehensive reviews.

Table 1. Examples of health effects associated with outdoor air pollution

Pollutant	**Effects**	**References**
Short term		
Carbon Monoxide	Exposure to high levels can be lethal, exposure to low levels may hasten the onset of angina in people with coronary artery disease and increase the incidence of cardiac effects	(HEI 2004)
Nitrogen Dioxide	There is considerable variability in responses, therefore no significant conclusions have been formed	(Bascom, Bromberg et al. 1996)
Ozone	Reduced lung function in some individuals, increased asthma attacks and hospitalizations, may also increase lung's reaction to allergens and other pollutants, some association with increased daily mortality; the number of respiratory admissions of all types show a relationship on a short term basis; increased emergency room visits	(Bascom, Bromberg et al. 1996); (Brunekreef and Holgate 2002); (HEI 2004);
Particulate Matter	Increased daily cardio-respiratory and respiratory morbidity and mortality; increased hospital admissions for acute respiratory and cardiovascular disease, increased hospital admissions for asthma and chronic obstructive pulmonary disease in people over age 65, increased emergency visits for acute asthma in children and adults, increased acute respiratory hospital admissions in children, school absences, decrements in peak flow rates in normal children, increased medicine use in children and adults with asthma, fluctuations in the pulmonary function of asthmatic children	(Bascom, Bromberg et al. 1996); (Brunekreef and Holgate 2002);
Sulfur Dioxide	Increased broncho-constriction in people with asthma, reductions in lung function, increased daily mortality and hospital admissions from respiratory and cardiovascular disease even at low levels	(HEI 2004)
Long term		
Nitrogen dioxide	Lung function in adults negatively affected in association with bronchitis, also associated with symptoms of bronchitis in children	(Brunekreef and Holgate 2002)
Ozone	Limited evidence of chronic health effects due to long term exposure (lung may develop tolerance)	(HEI 2004)
Outdoor air pollution	Increased total mortality and cardiopulmonary mortality in adults, strongest and most consistently with PM - especially $PM_{2.5}$	(HEI 2004)
Particulate matter	Increased mortality, lower survival in regions with higher pollution, increased prevalence of respiratory and cardiovascular disease in communities with higher pm, increased asthma prevalence and morbidity, decreased lung function in adults with bronchitis, associated with symptoms of bronchitis in children, decreased lung function in children	(Brunekreef and Holgate 2002); (Delfino 2002);
Sulfur Dioxide	Reduced pulmonary function and mortality from cardiovascular and respiratory disease, decreased lung function in adults with bronchitis, associated with symptoms of bronchitis in children	(Brunekreef and Holgate 2002); (HEI 2004)

1.2.2 Approaches to assigning exposure to traffic-related air pollution for epidemiological studies

Health impacts due to exposure to air pollution are measured in epidemiological studies using specific statistical methods. In general, the occurrence of a particular health outcome in a group of exposed people is compared to the occurrence in a group of unexposed (or less exposed) people, and the difference is measured statistically. It is important, therefore, that exposure is measured as accurately as possible; otherwise the real associations between exposure and health outcomes may be obscured.

Epidemiological studies specific to traffic-related air pollution vary in terms of study design, populations studied, health outcomes observed, and pollutants included, but generally use simplistic models of exposure. For example, time series models are regularly used to relate the change in mortality or morbidity in large populations to changes in air pollution levels on a day to day basis (i.e., (Burnett, Cakmak et al. 1998; Laden, Neas et al. 2000; Samet, Dominici et al. 2000; Ballester, Saez et al. 2002; Le Tertre, Medina et al. 2002; Filleul, Le Tertre et al. 2004)). The underlying exposure model employed in these studies is:

$$\mathbf{Exposure = C_{24h}\ (city\ of\ residence)}$$

C_{24h} is the 24 hour mean of hourly measures of ambient pollution at central site.

Similar exposure models are used by long-term studies of air pollution, as illustrated by the Harvard Six Cities prospective cohort study (Dockery, Pope et al. 1993), the results of which are widely cited. For the study, two methods were used to assign exposure. In the first case, study subjects were classified according to their city of residence. As the six cities included in the study were selected to represent a range of exposures (i.e., one city was less polluted than the others, the next more so, and so on), residence in a particular city indicated general exposure (low to high). In the second case, the mean hourly concentration of pollution over a fixed number of years, measured at a central site in each city, was assigned to the residents of each city. The two exposure models are, respectively:

Exposure = City of residence

and

Exposure = $C_{\text{mean of annual}}$ (city of residence)

$C_{\text{mean of annual}}$ is the mean hourly concentration for a fixed number of years at a central monitoring site.

In effect, these studies assume all residents of a particular city receive the same exposure; however, substantial evidence suggests that traffic-related air pollution levels can vary spatially and temporally over relatively short distances (Briggs, de Hoogh et al. 2000; Kousa, Monn et al. 2001; Gilbert, Woodhouse et al. 2003; Gilbert, Goldberg et al. 2005; Smargiassi, Baldwin et al. 2005).

More recent epidemiological studies of traffic-related air pollution attempt to incorporate this variation by using more detailed estimates of pollution. Buckeridge, Glazier et al (2002) use the following exposure model to assess the effects of vehicle emission on respiratory health of residents in southeast Toronto:

Exposure = C_d (census enumeration area of residence)

C_d is the average daily $PM_{2.5}$ emissions.

C_d was calculated using a GIS model of traffic volume and vehicle type for all major streets in the study area; these emissions were then apportioned to each census enumeration area. Study subjects were assigned the exposure level associated with the enumeration area in which they resided (Buckeridge, Glazier et al. 2002).

A study on the long-term effects of exposure to automobile exhaust on adult females undertaken in Japan used a different approach (Sekine, Shima et al. 2004). The exposure model employed for each study subject was:

Exposure = C_m (residential zone)

C_m is the five-year average NO_2 level measured in a residential zone.

Residential zones were defined by distance from heavy-traffic roads (less than 20m and 20m – 150m), and the pulmonary function of study subjects residing in each zone was compared between the two zones.

In a study of young children in Europe, the exposure model employed for each study subject was:

$$\textbf{Exposure} = \mathbf{C_{ma}}\ \textbf{(residential address)}$$

C_{ma} is the mean annual ambient concentration of NO_2.

This study related the mean annual ambient concentration at the residential address of each infant to childhood respiratory ailments (Best, Ickstadt et al. 2000). An innovative method of estimating C_{ma} was used, now commonly called the land use regression (LUR) approach (Briggs, Collins et al. 1997; Briggs, de Hoogh et al. 2000; Brauer, Hoek et al. 2003). The LUR method uses GIS-derived variables to predict pollutant levels for any point in a study area. For example, distance to high-traffic roads, residential density within a certain buffer, and hectares of industrial development within a certain buffer might be used as explanatory variables in a regression model to predict pollutant level at each study subject's residential location. Additional details on the LUR method are provided in Section 3.2.6.

Clearly there are numerous methods, from simple to sophisticated, for measuring or modelling the pollution levels needed for population-level exposure assessment[1]. These should not be confused, however, with the underlying exposure model, which has remained relatively simplistic over the past several decades of epidemiological research on traffic-related air pollution. In the examples given above, exposure is assumed to occur at the residential location, and nowhere else. Table 2 provides a summary of 28 additional recently published and/or highly cited population-level epidemiological studies of traffic-related air pollution. Notably, in the 2nd column of Table 2, the method used to assess exposure has been characterized as being an indicator (no actual measurement or estimate of pollution levels), measured (actual measures based on fixed-site monitoring), modelled (based on the application of spatial models to estimate pollution levels), or a combination of these. A description of the exposure metric used and the location of

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[1] Personal monitoring may also be used to directly measure an individual's exposure to airborne pollutants; however, logistical and cost constraints limit the application of personal monitoring to large populations. Section 1.4 provides additional discussion on this point.

exposure (i.e., residence, school, etc.) used in the assessment are included in columns 3 and 4. The remaining columns provide additional information about each study.

Of the 28 reviewed studies, eleven assessed exposure to be the same for all residents within specific zones (i.e., within a specified distance of a road, a monitor, a census area, or community), eight assessed exposure based on residential address on a particular date or year, and three assessed exposure at each residential address occupied by a study subject over the study period. In the remaining six studies, exposure was assessed based on pollutant levels for school locations (3 studies), at school and at home (1 study), or for multiple locations including school, home, outdoors, in cars, etc. (2 studies). Studies of pre-school aged children were not included in this review, as it is not expected that commuting to work or school will be as important in this population in relation to school aged children and working adults.

Table 2. Summary of population-level epidemiological studies on traffic-related air pollution (excluding time-series studies)

Author	Exposure Method	Exposure Metric	Exposure Location	Study Type	Study area	Health Outcome	Population	Pollutants
(Wjst, Reitmeir et al. 1993)	Indicator	highest volume of traffic within school district (115 districts)	school district	cross sectional	Munich, Germany	pulmonary function, respiratory symptoms	~4,600 school children	not specific
(Livingstone, Shaddick et al. 1996)	Indicator	shortest distance to road with 1000 vehicles an hour at peak times	residence specific	case control	London UK	asthma needing treatment	6,663 all ages	not specific
(Oosterlee, Drijver et al. 1996)	Indicator	dispersion model used to identify 'busy' streets and 'not busy' streets	residence within exposure zone	cross sectional / case control	Netherlands	chronic respiratory symptoms	1,485 adults 291 preschool and school children	NO_2
(Brunekreef, Janssen et al. 1997)	Combination: indicator and measured	distance to motorway (home and school), traffic density based on weekday counts, indoor NO_2 and black smoke at school	residence specific	cross sectional	Netherlands	lung function	1,200 school children	black smoke, NO_2 (indoors)
(Studnicka, Hackl et al. 1997)	Measured	3 year mean of central monitor in each city	city of residence	cross sectional	Austria (8 cities)	asthma and respiratory symptoms	842 school children	NO_2
(Ciccone, Forastiere et al. 1998)	Indicator	self-reported traffic near residences	residence specific	cross sectional	Italy	early respiratory disease (within first 2 years of life), current respiratory disorders (asthma, wheeze, cough, or phlegm within past year)	39,275 school children	not specific

Table 2. Continued

Author	Exposure Method	Exposure Metric	Exposure Location	Study Type	Study area	Health Outcome	Population	Pollutants
(Feychting, Svensson et al. 1998)	Modelled	Traffic model giving 99th percentile of 1 hour averages for year of diagnosis plus background NO_2 modelled on population density and usual wind force	residence specific	case control	Sweden	cancer - including leukemia and central nervous system tumor	710 preschool and school children	NO_2
(English, Neutra et al. 1999)	Indicator	distance from home to each street segment within 550m, average traffic volume for all streets, nearest street and highest volume street in buffer, also used quintiles of traffic flows	residence specific	case control	San Diego, US	medical diagnosis of asthma	8,280 preschool and school children	not specific
(Guo, Lin et al. 1999)	Measured	annual mean for monitor	school within 2km of monitoring station	ecological cross section	Taiwan	prevalence of physician-diagnosed asthma, wheezing, atopic exczema	1,000,000 school children	SO_2, NO_X, O_3, CO, PM_{10}
(Hirsch, Weiland et al. 1999)	Measured	annual mean and 95th percentile of closest monitoring site (1km x 1km grid of sites) in four geographical directions	residence specific for ages 5-7, time weighted average of residence and school specific for 9-11 years	cross sectional	Germany	wheezing, cough, doctor diagnosed asthma and bronchitis	5,421 school children	SO_2, NO_2, CO, O_3
(van der Zee, Hoek et al. 1999)	Measured	24 hour mean of monitor with up to 5 day lag	city of residence	panel	Netherlands	acute respiratory health in those with and without symptoms	633 school children	PM_{10}, black smoke, SO_4^{2-}, SO_2, NO_2
(Kramer, Koch et al. 2000)	Measured	direct measures of microenvironments: indoor at home, outdoor at home, outdoor near main roadways, indoor at school	total exposure based on four microenvironments and time activity diaries	cross sectional	West Germany	atopic sensitization, allergic symptoms, allergic diseases	317 school children	NO_2

Table 2. Continued

Author	Exposure Method	Exposure Metric	Exposure Location	Study Type	Study area	Health Outcome	Population	Pollutants
(Nyberg, Gustavsson et al. 2000)	Modelled	dispersion model expressed as annual average levels for each of thirty years	time weighted level at all residential addresses over 30 year study period	case control	Stockholm, Sweden	lung cancer	3,406 men aged 40-75	NO_X / NO_2, SO_2 (indicating traffic/heating respectively)
(Raaschou-Nielsen, Hertel et al. 2001)	Modelled	modified dispersion model expressed as hourly averages for time at residence	residence specific : time-weighted average of pollutant at each residential address throughout study period, as well as during mother's pregnancy	case control	Denmark	cancer (leukemia, tumour of the central nervous system, malignant lymphoma)	7,495 preschool and school children	benzene, NO_2
(Venn, Lewis et al. 2001)	Indicator	distance from home to nearest main road	residence specific	case control / cross sectional	Nottingham, UK	wheezing	6,147 primary school children 3,709 secondary school children	not specific
(Hoek, Meliefste et al. 2002)	Combination: modelled and indicator	regional (spatial interpolation of BS and NO_2), plus urban background (BS and NO_2 based on residential address density in postal code of residence), plus distance to road (50m, 100m)	residence specific	cohort	Netherlands	daily mortality, all causes, cardiovascular, respiratory, cardiopulmonary, lung cancer, non-cardiopulmonary, non-lung cancer	4,492 adults aged 55 – 69	black smoke, NO_2
(Lin, Munsie et al. 2002)	Indicator	residential distance in intervals (within 200m, 200 - 400 m, 400 - 600, and > 600m) from major state route, also indicators of traffic intensity (proportion of occurrence of any heavy trucks or trailers within 200m and 500m buffer; and vehicle	residence within exposure zone	case control	New York, US	hospital admissions for asthma	878 preschool and school children	not specific

Table 2. Continued

Author	Exposure Method	Exposure Metric	Exposure Location	Study Type	Study area	Health Outcome	Population	Pollutants
		miles travelled within 200 and 500 m buffers)						
(Scoggins, Kjellstrom et al. 2004)	Modelled	atmospheric model - 3km grid of hourly NO2 for one year, averaged to annual mean for each grid cell and assigned to census area unit (spatially weighted average where required)	residence within census area unit	ecological cross section	Auckland NZ	mortality	population	NO_2
(Yang, Chang et al. 2003)	Indicator	distance from freeways - within 500m, or 500-1500m	residence within exposure zone	cohort	Taiwan	pre-term delivery	6,521 women	not specific
(Finkelstein, Jerrett et al. 2004)	Indicator	within 100m of highway, within 50m of major urban roads	residence within exposure zone	cohort	Ontario, Canada	rate advancement of mortality from all natural causes	5,228 adults	not specific
(Kim, Smorodinsky et al. 2004)	Measured	Study period mean of measures taken at each school	school location	cross sectional	San Francisco US	bronchitis symptoms (current) and asthma	64 school children	particulate matter, black carbon, NO_X, NO_2
(Pedersen, Raaschou-Nielsen et al. 2004)	Modelled	dispersion model, expressed as hourly average concentrations, unknown if averaged to annual	Residence specific	cohort	Denmark	schizophrenia	7,455 adults	benzene, CO, NO_X, NO_2
(Peters, von Klot et al. 2004)	Indicator	self-reported time spent in cars, on public transportation, motorcycles, bicycles in four days prior to onset	time in microenvironment associated with traffic-related air pollution	case crossover	Germany	myocardial infarction	691 adults	not specific
(Yang, Chang et al. 2004)	Measured	24 hour mean of all monitors in city	city of residence	case crossover	Taiwan	daily mortality, respiratory, circulatory	population	SO_2, PM_{10}, NO_2, CO, O_3

Table 2. Continued

Author	Exposure Method	Exposure Metric	Exposure Location	Study Type	Study area	Health Outcome	Population	Pollutants
(Wilhelm and Ritz 2005)	Measured	Means of hourly measures at monitoring site for different periods through pregnancy; residence zones defined as 1 mile, 2 mile, and 4 mile buffers around monitoring site	residence within exposure zone	cohort	Los Angeles, US	low birth weight, pre-term birth	136,134 women (low birth weight) 106,483 women (preterm birth)	CO
(Gordian, Haneuse et al. 2006)	Indicator	traffic density (low, medium, or high) within 100m and 300m of cross street closest to residence	residence specific	cross sectional	Anchorage, US	diagnosed asthma	1,043 school children	not specific
(Nafstad, Haheim et al. 2003)	Combination: modelled and indicator	Dispersion model, expressed as annual mean concentrations for each of 15 years, plus additional exposure assigned if address on one of the 50 busiest streets in terms of traffic counts	residence specific : time-weighted average of pollutant at each residential address throughout study period	cohort	Norway	lung cancer	16,209 men aged 40 – 49	SO_2, NO_X
(Rich, Mittleman et al. 2006)	Measured	direct measures, 24 hour averages of hourly data from four to six sites in the study area	community (40 km radius study area)	case crossover	Boston, US	paroxysmal atrial fibrilation	203 adults	O_3, NO_2, SO_2, CO

1.2.3 Evidence of mobility-related effects on air pollution exposure assessment

Assigning exposure based on pollution levels only at residential locations has been recognized as a potential source of error in air pollution exposure models (Quackenboss, Spengler et al. 1986; Hoek, Brunekreef et al. 2002; Yang, Chang et al. 2003; Jerrett, Arain et al. 2005). Given that traffic-related air pollution can exhibit significant gradients over short distances, it is entirely possible that individuals experience a range of exposures throughout the day as they go to work, school, or shopping, and those exposures may be quite different than those at their residence. When more spatially detailed pollution estimates are used as a basis for exposure assessment in order to better reflect observed spatial variation in traffic-related air pollution, it becomes important to understand how spatio-temporal variation in the locations of study subjects affects their exposure.

Research on the effects of error in exposure assessment and personal monitoring studies provide enough evidence to suggest there may be quantifiable differences in exposure among individuals with different mobility patterns. The remainder of this section presents evidence that individual mobility may affect exposure assessments. First, a review of selected literature on theoretical investigations of exposure assessment error is provided, followed by a summary of evidence of exposure misclassification and measurement error derived from personal monitoring studies.

1.2.3.1 Exposure misclassification and measurement error investigations

The potential effect of individual movements on air pollution exposure assessment and subsequent epidemiological studies has been recognized for some time in the literature on exposure misclassification and measurement error.[2] Shy, Kleinbaum et al (1978) provide a theoretical analysis of exposure misclassification effects on the calculation of disease prevalence in association with air pollution and show that "non-differential misclassification biases the effect measure toward the null value, [while]

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[2] Exposure misclassification occurs when an individual is assigned to the wrong exposure class (i.e., high instead of moderate). Exposure measurement error occurs when a continuous numerical measure of exposure contains error.

differential misclassification (i.e., different magnitudes of disease misclassification in exposed and unexposed populations) can bias the effect measure toward or away from the null value relative to the true measure of association" (Shy, Kleinbaum et al. 1978). They also explicitly state that "ambient pollution at school and work, in the home, office, factory or automobile differs in kind and concentration from that represented by neighbourhood monitoring stations…Invariably, then, some individuals will be incorrectly classified as exposed or non-exposed when the results of a stationary neighbourhood air-monitoring station are used to estimate exposure status of a population" (Shy, Kleinbaum et al. 1978) pg. 1157.

Other studies suggest when multiple levels of exposure categories are used instead of a simple exposed/unexposed classification, analyses of study subjects in the highest level of exposure may produce results biased toward the null, but analyses of intermediate levels of exposure may produce relative ratios biased away from the null, even for non-differential misclassification (Birkett 1992). Similarly, non-differential misclassification in ecological studies may produce biases in either direction when using linear and log-linear regression (Brenner, Greenland et al. 1992). Shy, Kleinbaum et al. (1978) recommend that any studies employing indicators or surrogate measures of exposure also include personal monitoring of a representative sample of diseased and non-diseased subjects in order to allow for evaluation of exposure misclassification. Twenty-two years later, Huang and Batterman (2000), after a comprehensive review of 45 epidemiological studies published between 1981 and 1997 which used residential location as the site of exposure to air pollution, came to similar conclusions: "studies that use residence location as the only exposure estimator require follow-up, including monitoring, to quantify and confirm exposure estimates" (Huang and Batterman 2000), pg 82.

When continuous numerical measurements of exposure are used, as opposed to categorical indicators such as 'exposed' or 'unexposed', error can be of two types: Berkson or classical. Each has different effects on the linear, log linear or logistic regression coefficients, otherwise referred to as relative risk in this dissertation.

Berkson error occurs when study subjects are grouped and assigned the same numerical exposure measure (Zeger, Thomas et al. 2000). This would be the case if study subjects are assigned exposures based on the pollution levels measured at the nearest fixed-site monitor. All subjects living closest to a specific monitor would receive the same exposure measure. This approach has been commonly used for population level epidemiology studies of air pollution, particularly time-series studies looking at the effects of short-term exposure and that incorporate subjects in different cities (Burnett, Cakmak et al. 1998; Laden, Neas et al. 2000; Samet, Dominici et al. 2000; Ballester, Saez et al. 2002; Le Tertre, Medina et al. 2002; Filleul, Le Tertre et al. 2004). If present, Berkson error does not bias relative risk (Armstrong 1998).

Classical error occurs when a single measure is used to indicate average exposure. This would be the case if a single measure of exposure was taken to represent an individual’s average exposure over a given time period, rather than the average of a series of measurements over the time period of interest (Armstrong 1998). It is suggested here that classical error also occurs when the pollution level at single site (i.e. home address) is used to represent an individual’s average exposure, rather than a measure that includes the range of pollution levels encountered in typically visited locations away from home. Classical errors bias relative risk toward the null, i.e., the association between the outcome and the exposure is underestimated (Armstrong 1998). The underestimation of risk associated with exposure to air pollution could have important consequences, particularly when relative risk is used as a basis for the setting of air quality standards meant to be protective of human health (Jerrett, Burnett et al. 2005).

1.2.3.2 Evidence of exposure error based on personal monitoring

Empirical evidence that ambient air pollution levels at either centrally located monitors or residential locations do not adequately indicate personal exposure exists in a number of studies conducted for various traffic-related pollutants (Table 3). Measures of ambient manganese (Pellizzari, Clayton et al. 1999) and NO_2 (Kousa, Monn et al. 2001) at a central location explain only 32 percent and 29 percent respectively of concurrent measures at residential sites, suggesting there may be too much spatial variation in the ambient levels to be adequately measured by a central site.

Comparisons of 48 hour total personal exposure (measured with personal monitors) and ambient NO_2 levels at residential locations show that between 17 percent and 51 percent of the variation in personal exposure is predicted by ambient levels at residences (Spengler, Schwab et al. 1994; Levy 1998; Kousa, Monn et al. 2001; Lai, Kendall et al. 2004). These results indicate that 50 percent or more of personal exposures to NO_2 are occurring either away from home or possibly inside homes due to NO_2 generated by smoking or the use of gas cooking appliances. With longer monitoring periods (1 week), the percent of variation in total personal exposure explained by ambient NO_2 at residences ranged from 4 percent in the winter in Wisconsin (Quackenboss, Spengler et al. 1986) to 33 percent in a study conducted in Switzerland (Monn, Brandli et al. 1998). Measures of ambient bromine, lead, and manganese at residences explain 4 percent, 28 percent and 24 percent respectively of total personal exposure (Pellizzari, Clayton et al. 1999; Oglesby, Kunzli et al. 2000), suggesting that important exposures are occurring away from home since, unlike NO_2, there are no major residential indoor sources of bromine or lead (Oglesby, Kunzli et al. 2000), or manganese (Pellizzari, Clayton et al. 1999).

The level of agreement between personal monitoring and ambient levels measured at a central site are generally poor as well: central site ambient manganese explains 3 percent of the variation in personal exposure (Pellizzari, Clayton et al. 1999); central site ambient NO_2 explains between 0.9 and 19 percent of personal exposure (Gauvin, Le Moullec et al. 2001; Kousa, Monn et al. 2001); and central site ambient CO explains 11 to 59 percent of personal exposure (Georgoulis, Hanninen et al. 2002).

Of note, however, are results published for sulfur, which indicate that as much as 72 percent of the variation in total personal exposure is explained by ambient levels of sulfur (S) at residences, even when controlling for indoor sources (Oglesby, Kunzli et al. 2000). Similarly, 92 percent of the variation in personal exposure is explained by ambient levels of sulfate (SO_4^{2-}) measured at a central site (Ebelt, Petkau et al. 2000). Low spatial variability at a regional level and the lack of major indoor sources are identified as the key reasons for such high correlations between ambient and personal monitoring measures of exposure to sulfate (Ebelt, Petkau et al. 2000).

Although indoor sources of pollution in residences may be a major contributor to poor agreement between exposures measured with personal monitors and ambient outdoor measures (particularly in the case of NO_2), other factors have been identified. As noted above with reference to NO_2 and manganese, spatial variation in pollutant levels within a region impact the relationship between ambient levels at central sites and those at residential locations. Full-time work status, commute distance, gender, and working with or near gas furnaces, boilers, ovens, or flames were also found to be significant predictors of average total exposure to NO_2 (Quackenboss, Spengler et al. 1986).

Table 3. Summary of studies of traffic-related air pollution comparing ambient levels measured at residences, central sites and personal monitoring

Author	**Measure**	**Correlation coefficient (r)**	**Correlation coefficient squared (r^2)**
Ambient at residence versus ambient at central site			
(Pellizzari, Clayton et al. 1999)	72 hr manganese	**0.56**	0.32
(Kousa, Monn et al. 2001)	48 hour NO_2	0.54*	**0.29**
Personal monitoring versus ambient at residence			
(Spengler, Schwab et al. 1994)	48 hr NO_2	0.71*	**0.51**
(Levy 1998)	48 hr NO_2	**0.57**	0.33
(Kousa, Monn et al. 2001)	48 hr NO_2	0.61	**0.37**
(Lai, Kendall et al. 2004)	48 hr NO_2	**0.41**	0.17
(Quackenboss, Spengler et al. 1986)	1 week NO_2 summer	**0.47 - 0.55**	0.22 - 0.30
(Quackenboss, Spengler et al. 1986)	1 week NO_2 winter	**0.20 - 0.28**	0.04 - 0.08
(Monn, Brandli et al. 1998)	1 week NO_2	0.52 - 0.57*	**0.27 - 0.33**
(Oglesby, Kunzli et al. 2000)	48 hr bromine	**0.21**	0.04
(Oglesby, Kunzli et al. 2000)	48 hr lead	**-0.53**	0.28
(Pellizzari, Clayton et al. 1999)	72 hr manganese	**0.485**	0.24
(Oglesby, Kunzli et al. 2000)	48 hr sulfur	**0.85**	0.72
Personal monitoring versus ambient at central site			
(Georgoulis, Hanninen et al. 2002)	48 hr CO	**0.33 - 0.77**	0.11 - 0.59
(Pellizzari, Clayton et al. 1999)	72 hr manganese	**0.18**	0.03
(Kousa, Monn et al. 2001)	48 hr NO_2		**0.11 – 0.19**
(Gauvin, Le Moullec et al. 2001)	48 hr NO_2	0.09 - 0.20*	**0.009 - 0.02**
(Ebelt, Petkau et al. 2000)	24 hr SO_4^{2-}	**0.96**	0.92

Bold indicates published number, non-bold has been calculated by squaring or taking the square root of the published number

* assumed to be a positive correlation

Geographic location within a study region also has been identified as a possible influence on the relationship between personal exposure and ambient measures. Kousa, Monn et al. (2001) found that having a work place located ‘downtown’ was an important factor in exposure to NO_2 in three European cities (Basel, Helsinki, and Prague). Georgoulis, Hanninen et al (2002) reported that higher short-term (1 hour) exposures to CO during time spent in traffic had no significant impact on longer-term (48 hour) exposure, and that the

> “probable explanation for the obvious discrepancy between inconsistent impact on time spent in traffic on the long term exposures vs. the consistent increases in the short term exposures while in traffic, is that although the exposure levels are higher in traffic, those with longer commute times/distances mostly spend their leisure time in the more distant suburbs with cleaner air, and those with short commuting times/distances are more likely to both reside and work in the downtown area.” (Georgoulis, Hanninen et al. 2002) pg 972.

Finally, a recent and unique study conducted in California provides evidence of the importance of mobility with respect to exposure. Inhalation intake (a measure of exposure) was estimated using detailed spatial estimates of five pollutants for every hour over a period of one year, and an origin-destination survey giving geographic locations over a 24 hour period for approximately 29,000 person days (Marshall, Granvold et al. 2006). Inhalation intake was seen to increase when mobility was included in the calculation, compared to a base case without including mobility. The effect differed among the pollutants studied, with the lowest increase (+ 2 percent) seen for ozone, followed by benzene (+ 5 percent), diesel particulates (+ 8 percent), hexavalent chromium (+ 27 percent) and butadiene (+ 30 percent).

In summary, exposure misclassification or measurement error can have important effects on epidemiological analyses, resulting in either underestimating or overestimating the risk associated with exposure. Personal monitoring studies show that for pollutants with moderate to high spatial variability, such as NO_2, pollution levels measured at residences or at central monitors leave much of the total exposure unexplained, indicating that exposures occurring away from residences may be an important factor.

1.3 RESEARCH QUESTIONS

Accepting that people's daily travels away from home to work, school and other activities affect their exposure to traffic-related air pollution, it makes intuitive sense to hypothesize that there is a strong spatial pattern to exposure levels, driven in some part by urban form and geographic distance within the study area, and also by the spatial pattern of the pollution itself. Working people living in the suburbs commute along major transportation corridors to business centres where pollution levels may be higher, while non-working people may stay closer to home in general. People who live in rural areas may be too far from the central business areas to commute and may work in suburban areas. Gradients in traffic-related air pollution exist, not only at the micro-scale in terms of distance from roads, but also at the meso-scale in terms of distance from the business districts where traffic volume may be higher, and exposures may vary in an associated way. The research questions addressed by this dissertation are based on the hypothesis of a spatial pattern in pollution exposure that is influenced by time spent away from home. The dissertation hypotheses can be stated as follows:

- **Is there a spatial pattern in exposure to traffic-related air pollution due to the activities of working and commuting?**

- **Are there spatial differences in exposure to traffic-related air pollution based on gender?**

- **With respect to traffic-related air pollution, how might exposures for working people differ from non-working people, and how might these in turn differ from exposure measures that do not incorporate the mobility patterns of people in a region? If there are differences, what are the implications for population level epidemiological analyses of air pollution?**

1.4 STUDY APPROACH

The research questions stated above impose several criteria that the study design must meet in order to be successful. First, it must be possible to differentiate among populations at the neighbourhood level in urban, suburban and rural regions in the study area. Second, it must be possible to use fine resolution spatial surfaces of traffic-related air pollution that capture neighbourhood differences. Third, it must be possible to differentiate among populations of interest within each neighbourhood, particularly workers (defined here as anyone who is employed and regularly commutes to a work location) and non-workers.

Personal monitoring would provide empirical data on total personal exposures which inherently incorporate changes in pollution levels at each location a person visits during the monitoring period. Given the criteria above, however, each neighbourhood in the study area would have to be considered separately to allow for comparisons, and it would be possible to monitor only a representative sample of subjects for each population of interest. Based on sampling theory, the number of people needed to make up a representative sample can be estimated. Imagine that the goal is to estimate the mean exposure of the workers living in each of 400 neighbourhoods in a municipal jurisdiction, and that the expected standard deviation of exposure is 7 ug/m^3. In order to provide a result that is within 2.5 ug/m^3 percent of the true mean 95 percent of the time, 30 workers must be sampled in each neighbourhood, or 12,000 individuals in total. Add to this the requirement to monitor other populations of interest such as non-workers, and it is clear that an approach based on personal monitoring is beyond the scope of this study.

An alternative to using residential location only or directly monitoring each person in a study is offered with the indirect approach to exposure assessment. The indirect approach to exposure assessment conceptualizes total personal exposure as the sum of the time spent in each location multiplied by the pollution level at each location over the time period of interest (Duan 1982; Klepeis 1999), and so explicitly incorporates individual movements from location to location throughout the day. Instead of monitoring each person, pollution levels are measured in each location and a time-activity diary that records time spent in each location for each study subject is used to calculate total personal exposure.

There is reasonable agreement between exposure assessments conducted using personal monitoring and the indirect approach (Akland, Hartwell et al. 1985; Ott, Thomas et al. 1988; MacIntosh, Xue et al. 1995), but both methods have similar limitations. The number of individuals or unique locations that can be monitored is constrained by logistics and cost, and so cannot practically be applied to large populations. In addition, personal monitoring or the keeping of time-activity diaries have rarely been conducted for more than one or two consecutive days. As the size of the study population of interest increases, or the time period of interest moves from acute to chronic, researchers must use other measures of exposure, thus the prevalence of studies using residential location or other imperfect surrogates of exposure (as described in Section 1.2.2) that depend on some spatial estimation of air pollution levels.

Although the indirect approach shares the same limitations as personal monitoring in terms of monitoring requirements in different locations and the collection of time-activity diaries for each study subject, this approach can be adapted to apply at the population level. Instead of using direct measurements of pollution levels in each location a person might visit, a range of possible values for typical locations (i.e., indoors at home, outdoors, inside at work, and so on) can be substituted. The range of pollution values might come from limited monitoring in representative locations, or may be based on spatial models of pollution levels. Similarly, instead of collecting a unique time-activity diary for each subject, a set of representative time-activity diaries can be substituted. By randomly choosing a time-activity diary, and randomly selecting from the ranges of possible pollution values at typical locations, a *probable* exposure can be generated. With enough repetitions of this procedure, a distribution of probable exposures can be developed, i.e., simulated, and used to estimate the mean probable exposure, the 90th percentile exposure, and other meaningful statistics for comparison purposes. This adaptation of the indirect method of exposure assessment has been previously employed for large populations and is adopted here to conduct the research presented in this dissertation. Chapter 2 provides a more detailed method review. The development of the exposure simulation model and the input data used for this research are described in detail in Chapter 3.

1.5 STUDY AREA

The BAQS area includes populations in the Georgia Basin Puget Sound airshed, an area encompassing roughly 16 million hectares of urban, rural, remote and coastal environments (Figure 1). Approximately 6 million people live in the Georgia Basin Puget Sound airshed, the largest urban areas being Vancouver and Victoria in British Columbia, and Seattle and its surrounding suburbs in Washington State. The research presented in this dissertation encompasses the area included in the Greater Vancouver Regional District (GVRD) only.

As of 2004, the total population in the GVRD was 2,131,340, with 1,286,890 registered vehicles (0.6 vehicles per person)(Greater Vancouver Regional District 2006; Greater Vancouver Regional District 2006). Given forecasts that suggest the population of the GVRD will reach 2,437,500 by 2015 (Greater Vancouver Regional District 2006), at the current ratio of vehicles per capita there will be an additional 175,600 registered vehicles in the region (for a total of 1,462,500 vehicles) within the next ten years. Current estimates suggest about 3.5 million trips are made daily in the GVRD, about three quarters of these by private vehicle (Greater Vancouver Transportation Authority 2004). On average, 57 percent of commuters travel outside of their home municipality to work, although this percent is much lower near the downtown core and much higher in the near suburbs (Greater Vancouver Transportation Authority 2004), as shown in Figure 2. In addition to private vehicles, truck traffic forms a significant part of daily volume on regional roads, and “truck movements are expected to increase from around 16,000 in the peak hour today, to over 21,000 by 2013 – an increase of around 31%” (Greater Vancouver Transportation Authority 2004).

Unlike other regional districts in British Columbia, the GVRD exercises authority delegated by the province to manage air quality within its boundaries, and operates numerous monitoring stations throughout the region in order to adequately measure air quality and support associated planning and policy efforts. Figure 3 and Table 4 provide details on the air quality parameters monitored and fixed-site station locations.

Figure 1. General location of the study area and the Border Air Quality Study (BAQS) area

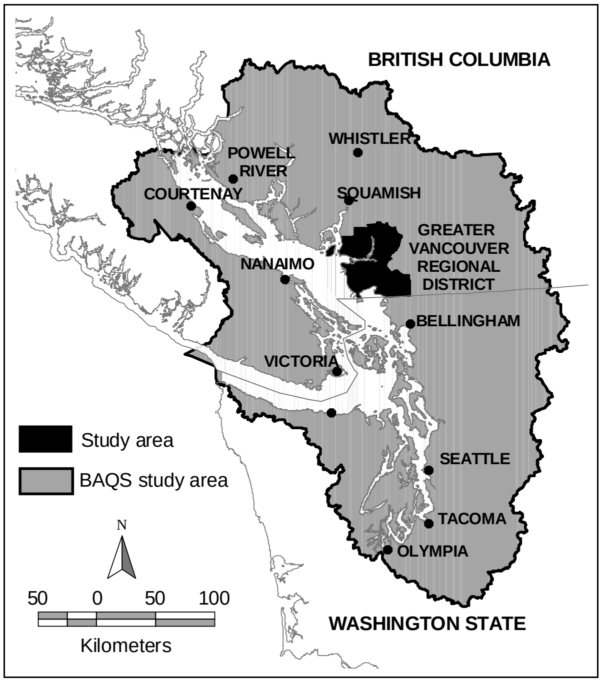
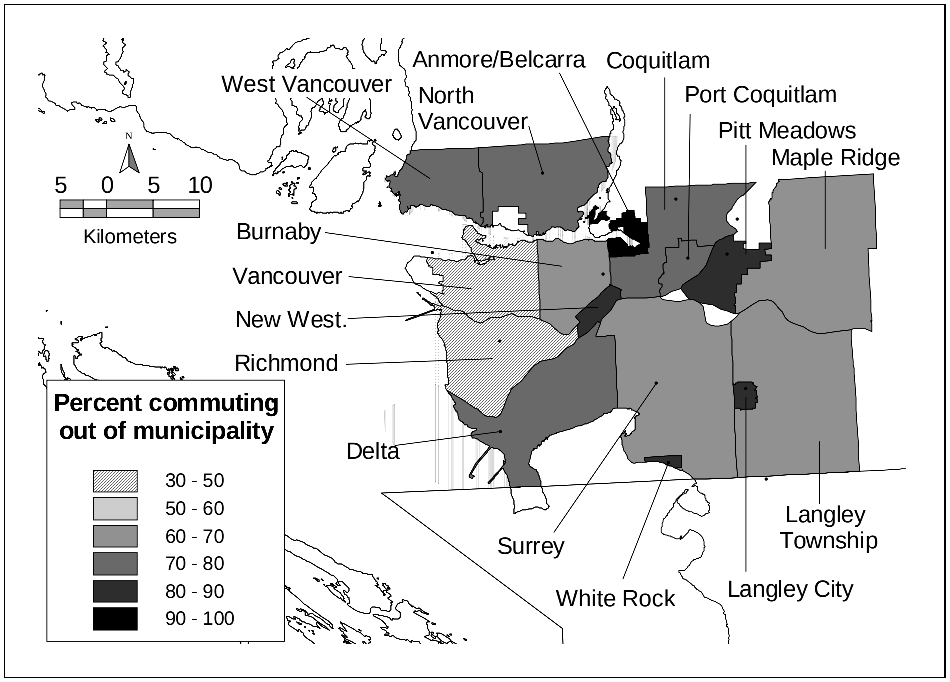


Figure 2. Percent of workers traveling away from their municipality of residence to work



Adapted from Greater Vancouver Transportation Authority (2004), based on 2001 Census data

Figure 3. Map of fixed-site monitoring station locations in the study area

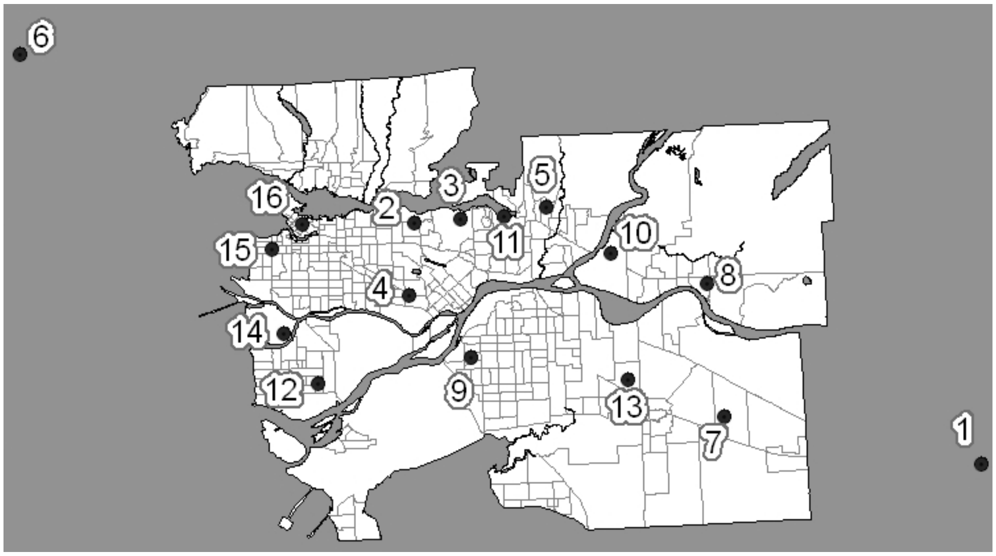


Table 4. Period on record for fixed-site monitoring stations in the study area

Map No.	Station Name	Station No.	Period on Record
1	Abbotsford Central	E238212	1998→
2	Burnaby Kensington Park	310177	1980→
3	Burnaby Mountain	E206270	1984 - 03
4	Burnaby South	E207418	1987→
5	Coquitlam Douglas College	E242892	2000→
6	Langdale Elementary	E222778	1996 →
7	Langley Central	E209178	1995→
8	Maple Ridge Golden Ears	E232245	1998→
9	North Delta	E207723	1988→
10	Pitt Meadows Meadowlands	E232244	1998→
11	Port Moody Rocky Point Park	310162	1980→
12	Richmond South	E207417	1986→
13	Surrey East	E206271	1984→
14	Vancouver International Airport #2	E232246	1998→
15	Vancouver Kitsilano	310175	1980→
16	Vancouver Robson Square	310174	1980→

Data Source: BC Ministry of Environment AIRQUIS, http://www.elp.gov.bc.ca:8000/pls/aqiis/aqiis.test

2.0 EXPOSURE SIMULATION

Exposure simulation has roots in the discipline of health risk assessment. The objective of this chapter is to provide a brief account of the development of exposure simulation, and to review it's applications to air pollution specifically.

2.1 EXPOSURE SIMULATION IN HEALTH RISK ASSESSMENT

Paustenbach (2002b) provides a succinct history of the development of health risk assessment, beginning with the recognition of the links between environment and health as early as 500 A.D., through the development of modern epidemiology as a response to the industrial revolution, to the establishment in the 1930s of the practice of risk assessment in order to establish permissible levels of exposure to toxic agents in the workplace (Paustenbach 2002). Since the 1930s, the discipline of health risk assessment has become more refined, and is commonly represented as having four key steps: 1) hazard identification, in which potentially hazardous contaminants in the environment are identified, the levels at which they are present are quantified, and their toxicity is determined; 2) dose-response assessment, in which a quantitative relationship between dose and toxic response is identified; 3) exposure assessment, in which the populations potentially exposed are identified, as well as the routes of exposure (inhalation, dermal absorption, and ingestion), and the magnitude, duration, and timing of doses; and 4) risk characterization, in which a qualitative or quantitative estimate is made of the likelihood that exposed people will experience any adverse effects due to exposure (Committee on Risk Assessment of Hazardous Air Pollutants, Board on Environmental Studies and Toxicology et al. 1994). Exposure assessment began to be identified as a specific component of health risk assessment in the 1970s (Moschandreas, Watson et al. 2002) and is more specifically defined as “ the process of measuring or estimating the intensity, frequency, and duration of human or other population exposures to risk agents” (Covello and Merkhofer 1993).

Health risk assessments for air pollutants most often have been conducted in the context of regulatory permitting for industrial developments in the US, and until relatively recently have relied on exposure assessments of the worst case scenario. In the 1970s and early 1980s, health risk assessments for proposed developments that would emit air pollutants were based on the 'maximally exposed individual' (MEI) in hopes of ensuring safety from pollution effects for the entire population of interest. The MEI was defined as "a person who lived for 70 years at the location deemed by [a] dispersion model to receive the heaviest annual average concentration, and that person stayed there 24 hours/day, and that there is no difference between outdoor and indoor concentrations" (Committee on Risk Assessment of Hazardous Air Pollutants, Board on Environmental Studies and Toxicology et al. 1994) pg 46. The product, then, of exposure assessment in this context was a single point estimate of the highest expected exposure.

By the mid-1980s, risk assessors began to employ Monte Carlo simulation techniques to produce exposure assessments that incorporated variability[3] and uncertainty[4], rather then relying on single point estimates of the worst case scenario (Paustenbach 2002). Monte Carlo techniques, also known as probabilistic techniques, were developed in the 1940s (Cullen and Frey 1998) and are based on calculating a deterministic equation many times, with different randomly sampled values for each term each time. Instead of calculating the exposure of the MEI, the probabilistic approach allowed for the simulation of many *possible* exposures based on the range of values indicating pollution concentrations, the range of values indicating the number of hours of exposure expected in a population, the range of values expected in typical indoor environments, and so on. Instead of a single point estimate of the highest exposure possible, a distribution of possible exposures was produced and could be used to identify the mean exposure of a population as well as the probability of exposures above and below the mean or at the upper and lower ends of the resulting distributions.

In the 1990s, the MEI was replaced in US EPA risk assessment guidelines with the high-end exposure estimate (HEEE), defined as " a plausible estimate of exposure of

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[3] "Individuals within a targeted group are likely to face different levels of exposure or dose due to differences in behavioral or dietary patterns (e.g., amount of time spent at work versus home or mass of home-grown tomatoes consumed each day), or physiological characteristics (e.g., breathing rates), or even over time. These differences lead to *variability* among individuals" (Cullen and Frey 1999, pg 1).

[4] "*Uncertainty* about exposure arises when there is a limited availability of empirical information, as well as imperfections in instruments, models, or techniques used to develop representations of complex physical, chemical, or biological processes" (Cullen and Frey 1999, pg 1).

the individual exposure of those persons at the upper end of an exposure distribution" and as "above the 90th percentile of the population distribution, but not higher than the individual in the population who has the highest exposure" (Committee on Risk Assessment of Hazardous Air Pollutants, Board on Environmental Studies and Toxicology et al. 1994). The HEEE, therefore, is a measure which can only be derived through the development of a distribution of exposures.

Exposure distributions suitable for use in health risk assessments can be developed using methods other than simulation. A representative sample of people can be recruited to wear personal monitors, as was done for carbon monoxide and a sample of 1,000 person-days (Akland, Hartwell et al. 1985); however, this approach has limits in terms of costs, logistics, and may require a large number of samples, depending on the number of populations of interest, as noted in Section 1.6. Similarly, a representative sample of pollution levels in each microenvironment can be used in conjunction with time-activity diaries for a representative sample of people, see for example, Freijer, Bloemen et al. (1998); Chau, Tu et al. (2002), but the same limitations apply in terms of costs and logistics when numerous populations and long time periods are of interest.

Simulating air pollution exposures requires a mathematical model (i.e., a deterministic equation) of exposure. The widely accepted and applied indirect model of exposure used for air pollution suggests that an individual's total exposure to air pollution can be calculated by multiplying the amount of time spent in a polluted location (called a microenvironment) by the concentration of pollution at that location, and in the case of multiple locations, the sum of these products provides total exposure. This has been expressed mathematically by (Ott 1985) as:

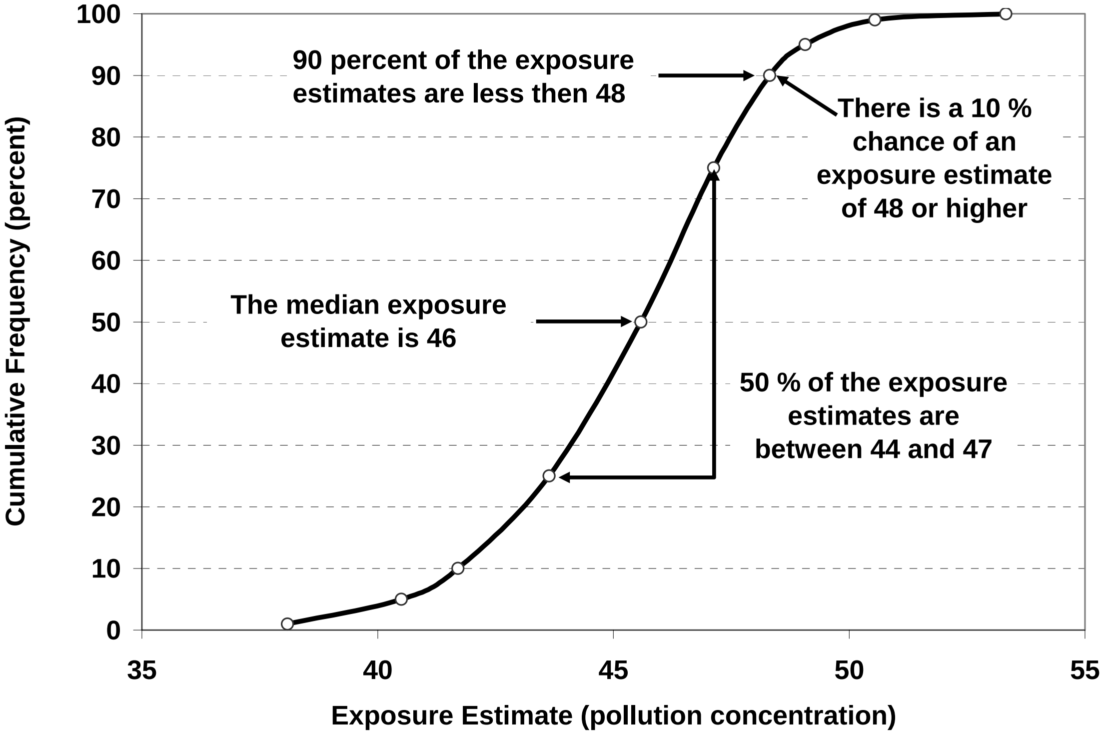
$$E_i = \sum_{j=1}^{J} C_j t_{ij} \tag{1}$$

where:

E_i = the integrated exposure of an individual (i) over the time period of interest
C_j = concentration of pollutant encountered in microenvironment j
t_{ij} = time spent by the individual (i) in microenvironment j
J = total number of microenvironments occupied by the individual (i) over the time period of interest.

In the absence of measured data for each study subject, probabilistic methods can be used to calculate exposures by randomly sampling from distributions of possible values for each variable term. When this procedure is repeated many times (i.e., several hundred or thousand repetitions are performed), the resulting calculated exposures can be plotted as a cumulative frequency distribution (Figure 4). Graphs of the cumulative frequency distributions can then be used to ascertain the probability of calculating an exposure of any particular magnitude, given the input data.

Figure 4. Example of a cumulative frequency distribution of exposure estimates



The exposures calculated in this way do not apply to any specific individual, but rather indicate the range of exposures possible, given the typical time-activity patterns of a group of people and pollution levels in the study area. Examples of applications of exposure simulation for air pollution based on the above model are reviewed in the next section.

2.2 AIR POLLUTION EXPOSURE SIMULATION

In a regulatory permitting context, exposure simulation is very useful for incorporating variability into predictive exposure assessments and assessing the associated uncertainty when faced with proposed industrial projects capable of polluting the air. Exposure simulation has also been used in the US, Europe and Canada to assess population level exposures associated with existing ambient air pollution such as is experienced by people living in most developed urban and suburban regions. Following are examples of the development of the latter, as they are more pertinent to the topic of traffic-related air pollution than examples specific to a single point source.

2.2.1 US Environmental Protection Agency

A variety of deterministic models to estimate population exposures to air pollution from mobile sources were developed by the US Environmental Protection Agency (US EPA) in the 1970s and 1980s, as described by Johnson (1995) and McCurdy (1995). These models were developed in support of establishing National Ambient Air Quality Standards (NAAQS) in the US, and were originally called NEMs (NAAQS Exposure Models). Early NEMs used in the 1970s and 1980s were deterministic and were developed for a range of pollutants including O_3, CO, and NO_2. Hourly pollution levels measured at fixed-site monitors provided the basis for developing pollution concentration estimates for each microenvironment. In addition to calculating exposure based on time spent in different microenvironments, ventilation rate (VR, defined as the amount of air inhaled in a specific time period), was also incorporated in some NEMs in order to estimate intake dose, as well as total exposure. Intake dose was calculated for each hour for the time period of interest and an exposure profile (dose versus time) was produced for a representative ‘person’ of a specified ‘cohort’. In this context, a cohort was defined as “a group of individuals of the same age/occupation classification that have the same work-commuting pattern and who live in the same type of home”(McCurdy 1995). Each cohort was represented by a single time-activity pattern consisting of a sequence of one-hour activities in a day, with different sequences for weekdays and weekends. For each cohort, a variety of useful measures were produced, including the area of the profile above a threshold of interest, and the frequency of and time between peaks above a threshold. In aggregate, the data for each cohort could provide a distribution of intake dose for the entire population of a study area given demographic data on the numbers of people in the study area within each cohort definition.

Around the same time, the Simulation of Human Activity and Pollutant Exposure model, also known as the SHAPE model, was being developed at the US EPA to estimate urban commuter exposures to CO (Ott, Thomas et al. 1988). In its original form, circa 1981, SHAPE simulated all possible variables, including the time-activity patterns, with the exception of air pollution levels. SHAPE was originally designed to allow for the use of air pollution levels by minute, but later implementations relied on hourly averages from fixed-site monitors in conjunction with data from pre-existing personal monitors. Distributions of average exposure (not intake dose) over a 24 hour period, as well as the maximum 1-hour average exposure and maximum moving 8 hour average based on Equation (1) were produced. SHAPE was later modified to use actual time-activity patterns collected for two days in a US EPA personal monitoring study in Denver, Colorado in 1982-83 to allow for the comparison of SHAPE results with empirical personal monitoring data. In this study, distributions of all microenvironmental levels of CO were developed from personal monitoring data collected on one day, and SHAPE used these distributions in conjunction with time-activity patterns from the following day to simulate exposures. Several methods for determining ambient CO were also evaluated, including the average hourly CO level measured at the fixed-site monitoring station nearest to participant locations.

Beginning in 1986, probabilistic methods were incorporated into the US EPA’s NEMs, in keeping with the periodic reviews of the NAAQS for each pollutant of interest. These newer models were called pNEMs (probabilistic NAAQS exposure models) to signify this change. Monte Carlo algorithms also were added to generate ‘equivalent ventilation rate’ (EVR, based on heart rate and its association with breathing rate), allowing EVR to vary based on the demographic group. Simulation routines were also incorporated into pNEM/CO in 1991 and pNEM/O_3 in 1992, as part of a newly included mass-balance equation employed to determine indoor pollutant concentration based on observed ambient levels (Johnson, Capel et al. 1996). Rather than using a fixed indoor/outdoor ratio, the indoor level varied according to randomly sampled values for air exchange rate, ambient outdoor (hourly), and indoor decay factor. Updates and refinements to the pNEM models continued to occur in the 1990s, and the capability to use an increasing number of databases on time-activity patterns, as they became available, was incorporated. Most recently, the US EPA has developed the Air Pollutants Exposure (APEX) model (also known as the $\text{TRIM.Expo}_{\text{inhalation}}$ model). Originally a personal computer version of pNEM/CO, this model has since been modified in a number of ways. APEX Version 2 moved away from the cohort simulation approach to a ‘personal’ profile approach, APEX Version 3 included additional output measures along with other improvements (U.S. Environmental Protection Agency 2005). APEX Version 4 is currently in use at the USEPA and incorporates more sophisticated methods for assigning ambient air pollution levels and compiling longitudinal activity patterns for simulated individuals.

A different approach was employed by US EPA researchers for the Stochastic Human Exposure and Dose Simulation (SHEDS) model for particulate matter, developed in the later 1990s. A detailed description is provided for the SHEDS-PM Version 1, tested using data from 1992-93 for Philadelphia (Burke, Zufall et al. 2001).[5] A fixed number of people are simulated for each census tract in the study area using time-activity data from the Consolidated Human Activity Database (CHAD); US Census demographic data giving the proportions of people of different age, gender, employment status and housing type in each census tract, and a 12-hour daytime average/12-hour nighttime average $PM_{2.5}$ level for each day of a full year, based on fixed-site monitors. By combining the exposures of the simulated people in each census tract, a population distribution was developed. Unlike the pNEM / APEX models, the SHEDS-PM model randomly chose one day of the year of interest for each person simulated, producing a measure of daily average exposure. The researchers are careful to note that:

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[5] A meeting abstract exists regarding the application of the prototype SHEDS model in Vancouver, B.C. Ozkaynak, H., M. Zufall, J. Burke, J. Xue and J. Zidek (1999). "A probabilistic population exposure model for PM10 and PM2.5." Epidemiology **10**(4): S79-S79., but no published results were found.

> “the resulting distribution represents a ‘cross-sectional’ distribution of PM exposures for the simulated population that corresponds to the time period of the ambient outdoor PM data used as input…since each individual is randomly assigned an ambient outdoor PM concentration from a particular date in the input data with equal proportions across all seasons. Therefore, SHEDS-PM simulates a different set of individuals for each date in the input data, whereas a longitudinal model would simulate the same individuals over time”(Burke, Zufall et al. 2001). pg 474.

Finally, the Hazardous Air Pollutant Exposure Model (HAPEM), first developed in 1985 to estimate exposure to non-reactive pollutants from mobile sources, deserves mention here. While numerous refinements have been made over the years, the current model, HAPEM4, is used to predict annual average exposure levels for each census tract in the US, and remains relatively simplistic in comparison to the other EPA simulation models described above. HAPEM4 is deterministic except in its treatment of time-activity patterns. For each of 10 pre-defined cohorts[6] in each census tract, HAPEM4 randomly selects daily activity patterns for a summer weekday, a non-summer weekday, and a weekend, then calculates a weighted average time activity pattern, with weights based on the number of summer weekdays, non-summer weekdays, and weekends per year. This is done 100 times for each demographic group in the census tract, and then 30 of these aggregated time-activity patterns are randomly selected to represent the population of the demographic group in that census tract (U.S. Environmental Protection Agency 2006). Although less complex than some other exposure simulation models, HAPEM4 does make use of the US Census Bureau data on work flows among census tracts to account for people who work in census tracts in which they do not reside, and uses the US EPA ‘Assessment System for Population Exposure Nationwide’ (ASPEN) dispersion-based model to estimate daily pollution levels for each census tract in the assessment, which are then aggregated into annual averages. Indoor concentrations associated with each census tract are derived using a penetration and a proximity factor.

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[6] A cohort in this case is the same as that used in the NEM and pNEM models: “a group of individuals of the same age/occupation classification that have the same work-commuting pattern and who live in the same type of home” (McCurdy 1995).

2.2.2 The Canadian Experience

To support setting National Ambient Air Quality Objectives (NAAQOs) in Canada, population exposures for particulate matter were simulated in the mid 1990s. The exact details of the simulation methodology used for particulate matter are contained in a report to Health Canada prepared under contract (Özkaynak, Macintosh et al. 1995). A copy of this report was not available to the author at the time of writing; however, a general description is provided in the Science Assessment Document associated with the NAAQO for particulate matter. The methodology is described as being “a Monte-Carlo based framework developed by Harvard researchers [and] applied to Canadian ambient PM_{10} measurements, demographics, and smoking rates by region” (CEPA/FPAC Working Group on Air Quality Objectives and Guidelines 1998). More specifically, daily (24 hour average) personal exposure distributions were simulated for populations living near one of 32 fixed-site monitoring stations across the country, and were grouped to represent five regions: the Maritimes/Atlantic, Quebec, Ontario, the Prairies, and British Columbia (CEPA/FPAC Working Group on Air Quality Objectives and Guidelines 1998). Time-activity patterns for the simulation were obtained from the US National Human Activity Pattern Survey (NHAPS). Hourly outdoor levels of particulate matter were obtained from the fixed-site monitors. Indoor concentrations were estimated by applying a physical model to account for air exchange and indoor sources. Time spent at work was not differentiated from time spent ‘indoors other than at home’.

A NAAQO for ground level ozone also was developed in the mid-1990s. The population exposure assessment conducted in support of setting the objective was accomplished with pNEM/O_3. Full details are provided in contract reports that were not available for review, i.e., (Johnson, Capel et al. 1994; Zhang 1996), but more general details are available in the Science Assessment Document. pNEM/O3 was used to simulate exposures over the ozone season (May 1 to September 30) in three cities – Montreal, Toronto, and Vancouver. Hourly ambient levels of O_3 were obtained from fixed-site monitors in each city. Population and commute data were not available at the census tract level apparently, so each city was divided into exposure districts based on census subdivision distance to nearest monitor (Federal-Provincial Working Group on Air Quality Objectives and Guidelines 1999).

2.2.3 The EXPOLIS project in Europe

In 1996, the EXPOLIS (Air Pollution Exposure Distributions of Adult Urban Populations in Europe) project started as part of the European Commission Research and Technological development Program. Personal monitoring was conducted in six European cities (Athens, Greece; Basel, Switzerland; Grenoble, France; Helsinki, Finland; Milan, Itlay; and Prague, Czech Republic) and provided a significant data set for the investigation of exposure to ambient $PM_{2.5}$, VOCs, CO, and NO_2. Within this larger project, a simulation method was developed to predict exposure distributions for European urban populations. Based on the indirect exposure model (Equation 1, in Section 2.1), the EXPOLIS simulation uses commercially available software (Microsoft Excel and Palisades @Risk Excel add-on software) to randomly sample from distributions of microenvironmental concentrations and time activity patterns (Kruize, Hanninen et al. 2003). Distributions of hourly pollution levels in microenvironments are based on personal monitoring results from EXPOLIS or on ambient concentrations from fixed-site air quality monitors in conjunction with effective penetration factors and contributions of indoor sources (both also expressed as distributions). Time spent in each microenvironment also is expressed as a distribution for different cohorts of ‘people’, i.e., different cohorts have different distributions. Applications of this method to $PM_{2.5}$ in Athens, Basel, Helsinki, and Prague, and to PM_{10} in the Netherlands are described in Kruize, Hanninen et al. (2003); an application to $PM_{2.5}$ in Helsinki is described in Hanninen, Kruize, et al. (2003); and an application to CO in Milan is described in Bruinen de Bruin, Hanninen et al. (2004).

2.2.4 Ambient air pollution levels and work flows in exposure simulation

Clearly, the simulation of exposures to air pollution has been of interest to government regulators and the research community for more than two decades. On a more technical note, a variety of methods have been employed to estimate air pollution levels in different microenvironments and to incorporate knowledge on work flow patterns in the study areas of interest. As these two aspects of the simulation models are of particular interest to this research, a brief summary of approaches used is provided here.

Simulating exposures to ambient air pollution requires some estimation of ambient pollution levels, and this requirement has been met in a variety of ways. The EPA’s APEX Version 4 model can incorporate high resolution spatial models of hourly ambient pollution, assigning census tract levels according to that modeled at the nearest grid point. The SHEDS-PM model used spatial interpolations based on fixed-site monitors (eight in Philadelphia) to estimate the ambient PM concentration at the centroid of each census tract for daytime and nighttime on each day in the time period of interest (May 1992 to September 1993 in Philadelphia)(Burke, Zufall et al. 2001). A more recent implementation of SHEDS was conducted under the MENTOR/SHEDS framework, again for Philadelphia, but this time using data for an acute pollution episode during a 14-day period in the summer of 1999 (Georgopoulos, Wang et al. 2005). A much more sophisticated method was used to estimate pollution concentrations in comparison to previous implementations - the EPAs Models-3/CMAQ numerical atmospheric model was used in conjunction with MM5 (modeled meteorological data) and SMOKE (emissions inventory model) to estimate hourly pollution levels for the study area (the spatial resolution of the output is not stated) and then used as the basis for interpolating ambient pollution levels for each census tract centroid in the study area. The HAPEM4 model is capable of using levels predicted by the ASPEN dispersion model to estimate ambient pollution for census tracts, but transforms the hourly estimates over the period of a year into single annual average levels for eight time periods (midnight to 3am, 3am to 6 am, 6am to 9am, etc.). Thus, HAPEM4 produces annual average exposure estimates based on time-stratified pollution estimates (Rosenbaum 2002). The EXPOLIS simulation model requires a distribution of ambient levels that can be derived in any method the user wishes, but which represent the entire study region rather than sub-areas (Kruize, Hanninen et al. 2003).

The methods by which time spent at work away from home is included in air pollution simulation models also vary. For some implementations of the pNEMs, US Census Bureau data for the number of persons in each census tract with one-way commute times reported to be in one of 12 commute duration ranges were used to identify home to work commute patterns. Given an average commuting speed, the straight-line distance traveled for each commute duration range was calculated, thereby allowing for the identification of all possible destination census tracts within driving distance (Johnson 1995). This method was employed in a 1996 use of pNEM/O_3, where the study area was divided into exposure districts consisting of contiguous census units associated with a fixed-site monitor. Work flows between exposure districts were developed by aggregating the home/work census tract information in each exposure district (Johnson, Capel et al. 1996; Whitfield, Biller et al. 1996). In 1998, pNEM/CO was updated to include more explicit work flow data available from the US Census Bureau, as well as to enhance simulation of indoor sources (gas stove use and passive smoking) and estimated ventilation rates. This new version of pNEM/CO was applied to Denver, CO, where 350 census tracts were aggregated into six exposure districts based on the nearest fixed-site monitor. Census data giving the number of workers in a census tract going to each destination census tract were available (versus commute time only), and for each exposure district, these Census data were aggregated to provide work flows between exposure districts (Johnson, Mihlan et al. 1999). Work flow data are apparently incorporated in the SHEDS-PM model (Graham 2006), but it is not clear if these are aggregated into exposure districts or if the relationships among each census tract and recorded work census tracts are maintained. APEX Version 4 is the model in use today for air pollution risk assessments at the US EPA, is based on census tracts (sectors), assigns ambient levels to each census tract according to distance from nearest fixed-site monitor or grid cell in a spatial air pollution model, and compiles work flow data for each sector using the Census data for each included census tract (U.S. Environmental Protection Agency 2006).

No differentiation between indoor at work and indoor at any other non-home location was made in the Canadian simulation of PM exposure (CEPA/FPAC Working Group on Air Quality Objectives and Guidelines 1998). The EXPOLIS model requires a single distribution of pollution levels for all indoor work locations in the study area, thereby implicitly assuming that all simulated people live and work in the same ‘zone’, in this case, a city (Kruize, Hanninen et al. 2003).

2.2.5 General limitations of exposure simulation models

Exposure simulation models have provided important information in terms of which microenvironments are associated with high exposures, probable exposure levels for vulnerable populations and general populations, and have been used to evaluate the change in exposure levels given a hypothetical increase or decrease in ambient pollution as a means of evaluating proposed policy changes; however, there are some inherent limitations that should be recognized. Firstly, the indirect exposure model which forms the basis of exposure simulation assumes a constant level of pollutant in each microenvironment for the increment of time used as a basis for the pollution estimate. For example, many models use one hour as the base time unit for the pollution estimate. In fact, microenvironment levels may fluctuate within that base time unit while a person is present. Theoretically, given pollution estimates on a second by second basis, this variability could be represented more accurately, but these kinds of estimates do not currently exist for areas with a large spatial extent, i.e. a city and its surrounding suburbs and rural areas, and would necessarily be subject to a large degree of uncertainty as per the limits of suitable data for modelling pollution levels. Additionally, time-activity data with the same temporal resolution would be required in order to take full advantage of such highly-resolved pollution estimates, if they existed.

Secondly, distributions of pollutant levels for microenvironments in the study area may not generally be available, requiring the use of addition modelling to estimate appropriate distributions, or the use of measurements available in published studies for similar microenvironments. Using models or distributions from studies conducted in geographic regions other than the one of interest may introduce additional error. Thirdly, there may be a small number of time-activity patterns available for input that are representative of the study population, and so inter-individual variability in time-activity patterns may not be adequately represented. These limitations are common to all applications of exposure simulation.

2.2.6 Evaluation of exposure simulation models

Exposure simulation models for CO have been evaluated several times. Ott (1988) reported that the mean of a simulated distribution of CO exposures in Denver was similar to the personal monitoring sample, but that there was more variability in the personal monitoring sample than in the simulation. The author suggested this discrepancy may have been due to the Monte Carlo algorithm, as it randomly sampled microenvironment levels hour to hour, thus potentially missing foreseeable situations where a person was exposed to high levels for multiple hours in a row. The personal monitoring data from Denver also was used to evaluate pNEM/CO (Law, Lioy et al. 1997). Comparisons of the simulated versus observed distributions of 1-hour daily maximum exposure and 8-hour daily maximum exposure in homes with and without gas stoves showed that the simulation consistently over-estimated low end exposures and under-estimated high-end exposures. Lower-end simulated exposures (5th percentile) were slightly higher than observed for both 1-hour and 8-hour exposures in homes without and with gas stoves, ranging from 1.7 to 3.8 ppm versus 0 to 2.5 ppm respectively. Larger differences were seen in the high-end exposures (95th percentile), where the simulated levels for 1-hour and 8-hour exposures in homes without and with gas stoves ranged from 11.9 to 28.7 ppm in comparison to observed levels which ranged from 17 to 42.5 ppm. Median values were slightly over- or underestimated depending on the scenario (presence or absence of a gas stove); variability was underestimated in all scenarios. The authors identified four possible reasons for the differences: 1) only two sources of indoor CO were included in the simulation, although there are other known sources; 2) randomly sampling throughout the simulated day and on each of two days to represent one person does not maintain the correlation within and between daily exposures likely to be found among real people; 3) activity patterns from cities other than Denver were included in the simulation (Cincinnati and Washington DC) and may not have been representative of Denver residents; and 4) the use of a single fixed value to represent secondary smoke likely did not capture the true variability.

An evaluation of an application of the EXPOLIS model to predict CO exposures among office workers in Milan suggests the resulting distributions, when compared to the actual personal monitoring data from that city predicted population exposures well. Still, the simulation tended to produce higher exposures in the 5th percentile range than observed, and to underestimate variation given different simulation formulations (Bruinen de Bruin, Hanninen et al. 2004).

The EXPOLIS model has also been evaluated for $PM_{2.5}$ using personal monitoring data for Helsinki, Basel, Prague, and Athens (Kruize, Hanninen et al. 2003); and for Helsinki alone (Hanninen, Kruize et al. 2003). In each of the four cities, the means of the simulated distributions were relatively close to observed means (i.e., 13 vs. 16; 25 vs 31; 37 vs. 35; and 43 vs 37 *u*g/m^3 in Helsinki, Basel, Prague and Athens respectively), but exposure levels were underestimated in Helsinki and Basel, and overestimated in Prague (with the exception of the 95th percentile) and Athens. Standard deviations of the simulated distributions were too high in Helsinki, Prague, and Athens, but too low in Basel, by as much as 50 percent. The authors suggest discrepancies are likely due to not fully capturing exposures to tobacco smoke, and to the use of Latin Hypercube random sampling, which produced a few extreme concentration values and thus had a large impact on the standard deviations. For the simulation of Helsinki alone, results for a non-tobacco-smoke-exposed population and the whole population were produced using concentration distributions cut off at the 99.9th percentile to avoid extreme levels. For the non-tobacco-smoke-exposed population, the simulation results were very similar to the observed data, with estimates of the distribution mean, standard deviation, 25th, 50th, 75th, 90th, and 95th percentiles all within 1 *u*g/m^3 of observed. Results for the whole population were also good, but did not agree quite as well. The simulated exposures were systematically lower than observed, with the differences increasing at higher levels of exposure to as much as 5 *u*g/m^3 (37.5 vs. 42.6, simulated and observed respectively, at the 95th percentile). The authors suggest this underestimation is due to the use of only two (home indoor and work indoor) or three (home indoor, work indoor, and other) microenvironments, which may not have captured exposure to tobacco smoke adequately.

2.3 CHAPTER SUMMARY

In summary, exposure simulation and the models and techniques it is based on have been in use for many decades, both in government regulatory and academic settings. There are a variety of approaches employed to develop the required input data and distributions in the context of simulating exposure to air pollution. In general, simulation results of the mean exposure correlate well with personal monitor measurements whereas simulation results of the lower and upper percentiles of the exposure distribution may be less accurate. The lack of agreement between simulation results and personal monitoring is attributed to model specification, limitations in data development or availability, but not to the conceptual validity of the indirect approach.

The next chapter describes the specification of an explicitly spatial exposure simulation model (SESM), designed to address the objectives of the research presented here. To the author's knowledge, this represents the first time geographic detail with high spatial resolution (i.e. neighbourhood scale) has been included in the simulation of population exposure to air pollution. This is accomplished through the incorporation of actual building locations and types based on property assessment data, and the identification of shortest-path routes between residential and work neighbourhoods. It should be noted, though, that the SESM as developed is not intended to produce similar results to previous simulation models, i.e., estimating exposures for an entire urban population. Rather, it has been designed to facilitate comparisons of distributions of exposure estimates among different population groups within and between neighbourhoods.

3.0 DEVELOPING A SPATIAL EXPOSURE SIMULATION MODEL

The objective of this research is to investigate the effect of time spent away from home on estimates of exposure with an explicitly spatial approach, in recognition of the existence of micro- and meso-scale pollution gradients and commuting patterns between neighbourhoods within an urban region. At present, no existing air pollution exposure simulation model can easily be adapted to simulate and produce output for each census tract in a study area, while incorporating geographic detail in terms of the actual locations of residential and commercial buildings and routes between home and work destinations. The spatial exposure simulation model (SESM) developed for this research presents a unique approach for accomplishing this analysis. The objective of this chapter is to describe the conceptual SESM, its general data requirements and outputs, then to provide detailed information on an implementation of the SESM, how the required data were acquired and processed prior to running the model, and results of testing the model's sensitivity to model parameters and data inputs. Finally, limitations of the model as implemented are discussed.

3.1 A SPATIAL EXPOSURE SIMULATION MODEL

The objective of this section is to provide a general description of the SESM, along with an explanation of how the SESM incorporates indoor/outdoor ratios to reflect lower levels of traffic-related air pollution in indoor microenvironments (MEs). Data requirements and SESM outputs are also discussed.

3.1.1 A general description of the SESM

The SESM is a probabilistic approach employing the indirect exposure model, with sets of representative time-activity patterns for several population groups and distributions of pollution levels in typical microenvironments. The exposure model is the same as that given previously (pg. 29) in Equation (1), but is expanded in Equation (2) to show the six microenvironments (MEs) included in the model. Total exposure (***E***) will be expressed in the concentration units of the pollution estimate (i.e., hourly, daily, or annual averages in *u*g/m^3). For any given neighbourhood, exposure is simulated for a particular population group using either four MEs (non-working people), or six MEs (working people). The model for working people can be mathematically expressed as:

$$\boldsymbol{E} = [(C_h \text{ x } t_h) + (C_w \text{ x } t_w) + (C_{oi} \text{ x } t_{oi}) + (C_o \text{ x } t_o) + (C_{tw} \text{ x } t_{tw}) + (C_{to} \text{ x } t_{to})] / T \quad (2)$$

$\boldsymbol{E}$ is a single exposure estimate associated with the group *workers*, expressed in pollution concentration units; C_h is the pollutant concentration at *home indoor*; C_w is the pollutant concentration at *work indoor*; C_{oi} is the pollutant concentration at *other indoor*; C_o is the pollutant concentration *outdoor*; C_{tw} is the pollutant concentration in *transit to work*; C_{to} is the pollutant concentration in *transit other*; t_{h}, t_{w}, t_{oi}, t_{o}, t_{tw} and t_{to} are the time spent in each respective microenvironment, based on the time-activity pattern; and T equals the duration of time activity pattern. For the non-working group, the *work indoor* and *transit to work* MEs are omitted. For this study, ***E*** is referred to as the total exposure estimate, and the value associated with each microenvironment variable as the partial exposure. As per Equation 2, there will be either four partial exposure estimates for non-working people, or six partial exposure estimates for working people, one for each microenvironment listed on the right hand side of the equation. Note that no mechanism for incorporating indoor sources of air pollutants is included in the SESM.

Sets of time-activity patterns for each population of interest (i.e., *workers* and *non-workers*) provide the amount of time spent in each microenvironment. Of particular note, the SESM uses these time-activity patterns differently than other exposure simulation models. All previous exposure simulation studies identified in the literature review conducted for this research produced a single distribution of exposures, meant to represent the entire population of the study area. In these applications, time-activity patterns are identified by gender, age, work status, and other characteristics, and demographic information (i.e., from a national census) provides the frequencies with which time-activity patterns are selected to match the characteristics of the simulated population. The SESM uses the same set of time activity patterns for a particular group (i.e. *workers* or *non-workers*) for every neighbourhood in the study area, and in this way controls for the effect of demographic variation in the results. Other factors then, such as the location of the residential neighbourhood in relation to urban development patterns, road networks, and work flow patterns are responsible for variation in the results, and it is these factors that are of interest to this research.

Distributions of possible pollution levels that are unique to each neighbourhood are included in the analysis and reflect the local gradient of pollution. This allows for the differentiation between exposures in home neighbourhoods versus work neighbourhoods when applicable. For each neighbourhood, a unique distribution of pollution levels for the *home indoor* ME is developed by estimating the pollution levels at each residence in the neighbourhood. Similarly, unique distributions of pollution levels at work are developed by estimating the pollution levels at every commercial location in a work neighbourhood (*work indoor* ME). Distributions for shopping and other indoor locations (*other indoor* ME) are developed using the estimated pollution levels at commercial locations within a reasonable distance from home neighbourhoods, and for outdoors, a distribution based on pollution estimates at regularly spaced points within a reasonable distance of home neighbourhoods is employed (*outdoor*ME). Pollution levels associated with commuting to work are associated with roads connecting home and work neighbourhoods (*transit to work* ME). Similarly, levels encountered when in transit for errands or leisure activities reflect those encountered on roads in the neighbourhoods where these activities are most likely to take place (*transit other* ME).

For a given home neighbourhood, the simulation for *workers* begins with the selection of an eligible work neighbourhood from a distribution based on the frequencies with which each possible work neighbourhood is visited from the home neighbourhood, followed by the random selection of a worker time-activity pattern and a pollution level from a distribution associated with each ME listed in the time-activity pattern. The time spent in each ME and the associated pollution level are then used in Equation (2) to calculate $\boldsymbol{E}$. The process is the same for *non-workers*, however no work neighbourhood is selected, and there is no time spent in the *work indoor* or *transit to work* MEs.

For each group (*workers* and *non-workers*) in each neighbourhood, multiple calculations of ***E*** are performed to produce a distribution of exposure estimates. The number of calculations performed has varied widely among existing exposure simulations. For evaluating the SHAPE model, 336 calculations were made, one for each 'individual' in the sample (Ott, Thomas et al. 1988). The pNEM/CO model makes one calculation for each 'cohort' – in one case, this was 1,860 (Johnson, Mihlan et al. 1999). APEX version 4 allows the user to set the 'sample' size; for the simulation of nine US cities, 35,000 individual calculations were made (U.S. Environmental Protection Agency 2005). In applications of the SHEDS-PM and MENTOR/SHEDS programs, 500 calculations per census tract were used to simulate the associated populations (Burke, Zufall et al. 2001; Georgopoulos, Wang et al. 2005). HAPEM4 makes 30 calculations for each census tract in the US (U.S. Environmental Protection Agency 2006). EXPOLIS has been applied in a number of European cities: 2,000 calculations were used to simulate urban adults in each of four cities – Helsinki, Basel, Prague, and Athens, and 40,000 were used to simulate the entire population of the Netherlands (Kruize, Hanninen et al. 2003); a simulation of Milan used both 500 and 2,000 calculations and compared the results (very similar) and also made 400,000 calculations to estimate the number of exceedences of a pre-set threshold in the population (Bruinen de Bruin, Hanninen et al. 2004); finally, 2,000 calculations were made to simulate the entire population of Helsinki, while 3,770 and 570 were used to represent the working and non-working populations respectively in Helsinki (Hanninen, Kruize et al. 2003).

The SESM differs from other air pollution exposure simulation models as it is designed to allow for the comparison of population groups within and between neighbourhoods, rather than for estimating the distribution of probable exposure for a demographically representative community population. For this reason, the number of calculations required in the SESM depends on the level of accuracy required of the estimates, rather than on demographic representation. Cullen and Frey (1998, pg. 214) provide guidance for choosing a sample size (i.e., the number of iterations) when random Monte Carlo simulation[7] is employed in the form of the following equation:

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[7] In random Monte Carlo simulation, one value from each input variable distribution is randomly chosen; all are substituted into the deterministic exposure equation and the result calculated. This is repeated many

$$m = p(1-p)\left(\frac{c}{\Delta p}\right)^2 \tag{3}$$

where:

m = sample size
p = percentile of interest
c = standard deviation of the standard normal distribution associated with the confidence level
Δp = percent change in percentile of interest

Table 5 provides the results of using equation (3) for 95% and 99% confidence levels for the 50th, 75th, 90th, and 99th percentiles of the results distribution.

For this research, 10,000 calculations are made for each population of interest in each neighbourhood, producing a confidence level of 95% that the value of the 50th percentile is contained within the range of the 49th and 51st percentile. The same level of confidence also applies to all other percentiles, given that fewer calculations are required as per Table 5.

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times over; the results provide a distribution of possible exposures. A common alternative approach is random Latin Hypercube sampling simulation, in which the input variable distributions are first divided into ranges of equal probability, and values for the deterministic exposure equation are randomly selected from each range an equal number of times. Fewer 'samples' (i.e., iterations) are required to produce a statistically stable distribution of results using random Latin Hypercube sampling simulation, but Cullen and Frey (1998) show that distributions derived using either approach converge at about 1,000 iterations.

Table 5. Iterations and associated confidence levels

Percentile of distribution	***m* (iterations)**
95 % confident that percentile is enclosed by 1% higher and 1% lower fractiles	
$c = 2$, $\Delta p = .01$	
50th ($p = 0.5$)	10,000
75th ($p = 0.75$)	7,500
90th ($p = 0.90$)	3,600
95th ($p = 0.95$)	1,900
99 % confident that percentile is enclosed by 1% higher and 1% lower fractiles	
$c = 3$, $\Delta p = .01$	
50th ($p = 0.5$)	22,500
75th ($p = 0.75$)	16,875
90th ($p = 0.90$)	8,100
95th ($p = 0.95$)	4,275

3.1.2. The use of indoor/outdoor ratios in the SESM

Not all ambient air pollution penetrates into indoor microenvironments, and the potential for lower levels of ambient-generated pollution in indoor microenvironments should be considered in the SESM. A range of approaches have been employed in simulation models to estimate the amount of ambient pollution infiltrating into indoor environments.

Regression models based on data collected for other studies have been used to predict indoor concentrations based on ambient levels measured for the study area of interest. Uncertainty about the model coefficients is allowed to vary according to a user-defined distribution (Burke, Zufall et al. 2001; Zidek, Meloche et al. 2003).

Alternatively, mass balance equations have been employed that relate indoor concentrations to ambient concentrations, the fraction of ambient air intercepted by the buildings, air exchange rates, indoor volumes, pollutant decay rates, deposition rates, flow rates through air cleaner filters (if used), the efficiency of the air cleaner (if used), and indoor generation rates (Burke, Zufall et al. 2001; Hanninen, Kruize et al. 2003; Kruize, Hanninen et al. 2003; Bruinen de Bruin, Hanninen et al. 2004; Georgopoulos, Wang et al. 2005; Zidek, Shaddick et al. 2005). Distributions of appropriate values for the mass balance equation parameters, based on empirical measures from studies reporting the results of concurrent indoor/outdoor measurements (i.e., (Murray and Burmaster 1995; Murray 1997)), are used as the basis for random sampling in order to allow for variation in the relationship between ambient and indoor levels. These models are not typically validated with monitoring when used in simulation models, for much the same reason that personal monitoring is not often used – costs would be very high and logistics very complex.

The US EPA’s HAPEM4 model uses a simpler approach. The concentration of air pollution in each microenvironment is based on the ambient level estimated for a census tract, a penetration factor (the indoor/outdoor ratio associated with the microenvironment), a proximity factor (meant to adjust for proximity to roadways or known point sources), and an additive factor (meant to represent indoor sources) (U.S. Environmental Protection Agency 2006). For each of five microenvironment groups (indoor at residence, indoor at other site, outdoors near a road, outdoors away from a road, and in a vehicle) a fixed value for the penetration factor is employed. The fixed values are based on a literature review, and set using the following criteria: 1) if a reviewed study reported an indoor/outdoor ratio with a median or mean less than or equal to 1, the median was used first, then the mean if that is all that was reported. If more than one study reported the median/mean, the average of the values was used; 2) If only the range of indoor/outdoor values was reported and the range extended below one, the difference between the minimum and 1 was split and the resulting value used; 3) when no indoor/outdoor ratios were reported as less than 1, 1 was used as a default, the idea being to exclude indoor sources from consideration (ICF Consulting and TRJ Environmental Inc. 2000).

The SESM has been designed to incorporate the literature review-based approach, but does not set specific criteria for integrating I/O ratios from different studies, such as are used for HAPEM 4. I/O ratios specific to different building types must be selected for the SESM and should be supported by a literature review. The I/O ratios are then used to adjust the pollution concentrations, a process described more completely in Section 3.2.7.

3.1.2 Data requirements

The SESM requires seven key datasets: 1) a spatial boundary file of neighbourhoods to be included in the study area; 2) representative time-activity patterns for each population of interest that provide the time spent in each of the microenvironments; 3) work flow data giving the percentage of workers in a neighbourhood who go to each associated work neighbourhood; 4) a detailed digital road network that supports the identification of shortest routes between home – work neighbourhoods; 5) spatial estimates of air pollution with a suitable resolution for capturing between neighbourhood variations in pollutant levels; 6) detailed information on building types to allow for the incorporation of geographic detail and the assignment of a suitable indoor/outdoor pollution ratio; and 7) microenvironment distributions unique to each neighbourhood. Detailed information on acquiring and processing the required data to support an implementation of the SESM is provided in Section 3.2 and the associated appendices.

3.1.3 Model outputs

The SESM provides for a new way of exploring the characteristics and differences among exposure estimate distributions by linking the descriptive statistics to their specific neighbourhoods, allowing for visual display via mapping and for the application of spatial analyses. Unique distributions of total and partial exposure estimates for the groups simulated in each neighbourhood in the study area are produced. A number of measures can be used to assess the differences among the distributions. Typically, descriptive statistics such as the 10th, 50th, and 90th percentile values of the distributions, as well as the range (i.e., 90th percentile value minus the 10th percentile value) and standard deviation are used to characterize a single distribution. The difference between these statistics for two distributions provides a simple method for making comparisons. Figures 5 and 6 show the model output comparison methods used in subsequent chapters.

Figure 5. Comparison methods for model outputs in a single neighbourhood

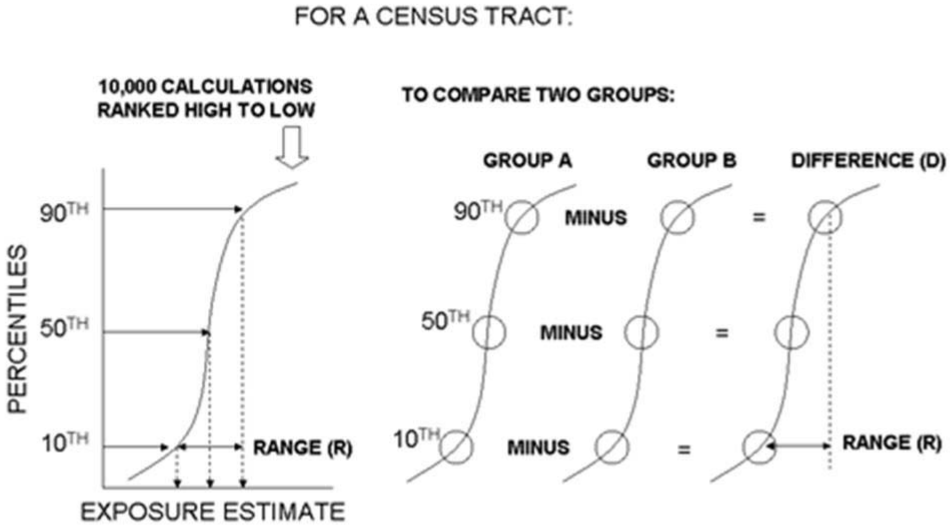
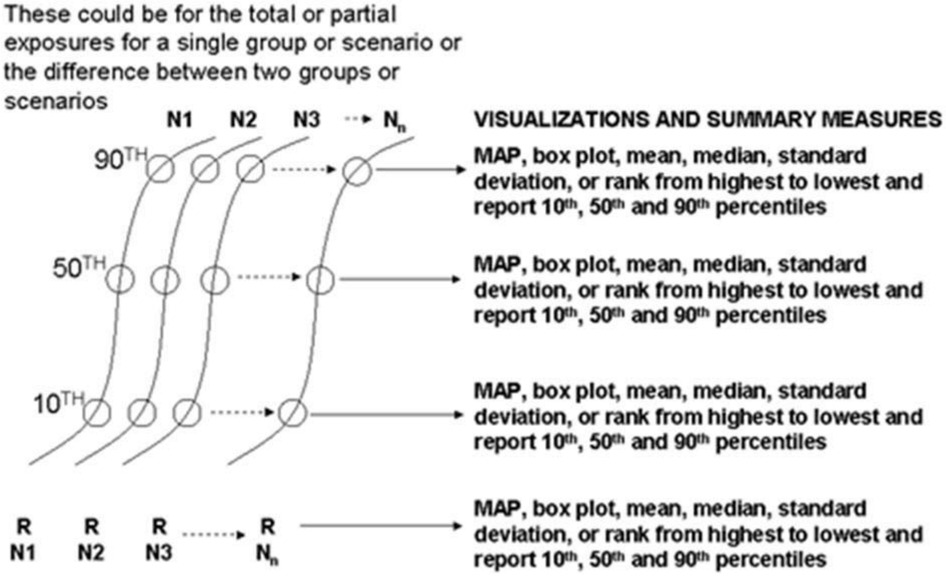


Figure 6. Comparison methods for model outputs in many neighbourhoods (N)



3.1.4 Model evaluation

Exposure simulation models can be evaluated when there is sufficient personal monitoring data for the same study area and time period (refer to Section 2.2.6 for examples). In the absence of these data, simulation results have been compared to distributions from personal monitoring studies in other regions. For example, Burke, Zufall et al. (2001) compare simulated $PM_{2.5}$ exposures for Philadelphia with published personal monitoring results for different populations from Toronto, Switzerland, Boston, Baltimore, and Fresno.

The study design of this research requires exposure estimates for a large number of distinct neighbourhood ‘populations’, making personal monitoring impractical. This is a limitation of the approach used for this research, but one that appears to be unavoidable. It is recommended that results produced using the SESM be compared only to each other, rather than to estimates of exposure based on the use of other models or personal monitoring. While this is a significant limitation in one way, the SESM is still useful in that numerous scenarios and groups can be simulated, allowing for the identification of similarities and differences based on the input data. The model outputs reflect the geographic position of each neighbourhood and its unique work flow patterns in relation to the spatial pattern of pollution, the road network, and commercial and residential development in the study area, thus allowing for an investigation of the effects of mobility on exposure.

3.2 IMPLEMENTATION, DATA ACQUISITION AND PROCESSING

Given the specific research questions (Section1.3) and the conceptual description of the SESM above, a custom software application was created to be used in conjunction with already existing software and suitable data. The objective of this section is to describe an implementation of the SESM, provide detailed information on the data acquired for this research, document processing steps undertaken to convert the data to appropriate formats, and discuss how the SESM is adjusted to simulate chronic (annual) exposure rather than single day exposures.

3.2.1 Hardware and software environment

Exposure simulation models have been implemented in various ways, often through the development of custom software programs installed on a mainframe computer (i.e., early simulation models used by the US EPA). In the last ten years or so, more exposure simulation models have been developed for use on personal computers, due to significant advances in computing speed and data storage capacity (Zidek, Shaddick et al. 2005). For this research, which employs a relatively simple exposure model in comparison, for example, to the SHEDS-PM and APEX4 models, for example, existing geographic information software (ESRI © ArcGIS 9.1) on a desktop computer running Windows XP was used to format and process all the spatial data required, and to produce all microenvironment distributions for each neighbourhood in the study area. With the aid of a programmer, a custom C++ program was developed to conduct the random sampling and perform calculations of total and partial exposure estimates. Copies of all custom scripts and programs are provided in Appendix A.

3.2.2 Neighbourhoods

The major consideration in choosing neighbourhood boundaries is the availability of other required data, particularly work flow information. In all existing air pollution exposure simulation models, work flow data come from the national census, and so census area boundaries are used as neighbourhood boundaries. This is the approach used in this research, as work flow information for the study area is available only from Statistics Canada for a range of official census areas.

Of interest to this research, which is focused on neighbourhoods, are the 2001 census dissemination areas and census tracts[8]. Dissemination areas are defined as “a small, relatively stable geographical unit composed of one or more blocks. It is the smallest standard geographic area for which all census data are disseminated”(Statistics Canada 2006). Typically, 400 to 700 persons reside in a dissemination area, so in dense urban places, dissemination areas may be quite small (sometimes encompassing one large

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[8] http://www12.statcan.ca/english/census01/Products/Reference/dict/geo013.htm

apartment building) while in less dense rural regions they may be much larger geographically. Census tracts are larger and are designed to include between 2,500 and 8,000 persons, with a preferred average of 4,000 persons, and to be as “homogeneous as possible in terms of socio-economic characteristics, such as similar economic status and social living conditions at the time” (Statistics Canada 2006).

In the study area, there are 3,332 dissemination areas within 382 census tracts. In both cases, the majority of areas (98 percent of dissemination areas and 87 percent of census tracts) are 5 square kilometers or less in size, equivalent to a 2.24 km x 2.24 km square, or a circle with diameter of 2.5 km, which is considered to be a reasonable neighbourhood size for this research (Table 6).

Table 6. Comparison of dissemination area and census tract sizes

	Dissemination areas		**Census tracts**	
Area (km^2)	**Number**	**Percent**	**Number**	**Percent**
2.5	3,222	97	246	64
5	39	1	88	23
7.5	16	0.5	9	2
10	12	0.4	7	2
12.5	17	0.5	0	0
15	5	<0.2	3	1
17.5	4	<0.2	3	1
20	4	< 0.2	6	2
25	5	< 0.2	6	2
50	6	0.2	6	2
100 or >	2	< 0.2	8	3
Total	**3,332**	**100**	**382**	**100**

Estimates received from Statistics Canada prior to the implementation of the SESM suggested that the number of unique residence/work pairs for dissemination areas in the study area could reach several million (all work dissemination areas associated with each of 3,332 residence dissemination areas) versus the approximately 35,000 that exist for the 382 census tracts in the study area. Given the more tractable number of possible work pairs for census tracts in the study area, and since most are 5 square kilometers or less in size, census tracts were chosen to represent neighbourhoods for the SESM. Digital boundary files for the 2001 census tracts were acquired via an academic research agreement with DMTI Spatial, an official commercial reseller of Census data.

3.2.3 Time-activity data

Time-activity data, providing the amount of time spent in each ME included in the SESM, were developed from the Canadian Human Activity Pattern Survey (CHAPS) database. CHAPS data were collected over a nine-month period in 1994/1995, using a 24-hour recall survey conducted by telephone, in Saint John NB, Toronto ON, Edmonton AB, and Vancouver BC. In total, 2,382 surveys are available (Leech, Wilby et al. 1997). Time spent in minutes for 91 different activity codes (ACT variables) and 83 unique location codes (WHERE variables) are provided, as well as numerous descriptive variables including age, gender, date of survey, and work status. General limitations of these data include potential biases due to the exclusion from the survey of persons without phones, non-English speakers, and those living in rural areas, as well as possible errors in recall by survey respondents (Leech, Wilby et al. 1997). Respondents also tended to have a higher socio-economic status than the Canadian population on average, as indicated by education level (Leech, Wilby et al. 1997). Access to the database was granted by the original researcher for CHAPS, Dr. Judy Leech, Medical Epidemiologist, Health Canada Air Quality Health Effects Research Section, and provided by Marc Smith-Doiron of the same department.

Five major processing steps were required to develop time-activity patterns suitable for use in the SESM, including: 1) selection of appropriate records, 2) calculating time spent in each ME; 3) removing anomalous records; 4) comparing time spent in MEs among the four cities included in the original survey; and 5) adjusting the time-activity patterns to allow for linking with specific times during the day. In Step 1, all records for people aged 15 and older were selected from CHAPS (1,852 records). A number of deletions were then made to remove unusual records, including those reporting time spent in travelling in an airplane (12 records), in boat travel (12 records), in other unspecified travel (15 records), with no gender reported (1 record), or those with weekend work hours (31 records), leaving 1,781 records remaining. In effect, these deletions restrict the SESM to producing exposure estimates for working and non-working groups whose members stay within the study area, and only for those who work on weekdays. In Step 2, times spent in specific activities and locations were grouped to produce a 24 hour time-activity pattern with each of the SESM MEs, as shown in Table 7. CHAPS WHERE codes were used primarily to identify appropriate locations for each ME, but because the WHERE codes do not differentiate working indoor from any other time indoor away from home, or time in transit for work from all transit, it was necessary to make two refinements. Time spent at work was available in two ACT codes; the times recorded for these activities were subtracted from the total time spent indoor not at home to produce time spent indoor at work, with the remaining time assigned to other indoor. Similarly, the times recorded for ACT 9 (travel to/from work) were subtracted from the total time spent in transit to produce transit to work and transit other. All CHAPS codes included in each microenvironment are listed in Appendix B.

Table 7. Development of time-activity patterns for SESM Microenvironments from CHAPS

Preliminary MEs	Examples of CHAPS variables	Adjust	Final MEs
Home Indoor (WHERE variables)	HOME-OTHER KITCHEN BEDROOM	→	**Home Indoor**
Work Indoor (ACT variables)	MAIN JOB SECOND JOB	→	**Work Indoor**
Not Home Indoor (WHERE variables)	OFFICE BLDG/BANK/POST OFFICE INDUSTRIAL PLANT/FACTORY GROCERY/CONVENIENCE STORE	Subtract Work Indoor from total	**Other Indoor**
Outdoor (WHERE variables)	IN YARD, POOL, PATIO WALKING, GOLF COURSE, PICNIC	→	**Outdoor**
Transit to Work (ACT Variables)	TRAVEL TO/FROM WORK	→	**Transit to Work**
All Transit (WHERE variables)	CAR TRUCK (PICK UP OR VAN) BUS	Subtract Transit to Work	**Transit Other**

Subtracting time spent at work and time spent in transit to work from the preliminary ‘not home indoor’ and ‘all transit’ categories resulted in negative values for some records in the final other indoor and other transit microenvironments, so in Step 3, these records (185) were removed prior to analysis, leaving 1,596 records remaining. In addition, 11 records that did not sum to 1,440 minutes (the number of minutes in 24 hours), and 9 records that showed less than 3 hours at home were deleted, leaving a total of 1,576 records.

Once the CHAPS data were summarized into the SESM MEs and all anomalous records removed, statistical comparisons were conducted in Step 4 to compare the time spent in each ME between surveyed cities (Toronto ON, St. John NB, Edmonton AB, and Vancouver BC). The time values in each ME were not normally distributed, so the nonparametric Kolmogorov-Smirnov goodness of fit test (KS test) was used to compare the distributions of time spent in each ME between cities. The results of the statistical tests showed no significant differences in the distributions for *home indoor, other indoor,* or *transit othe*r among the four cities surveyed. Significant differences were found, however, between cities for *work indoor* (Toronto was higher than Vancouver and St. John respectively), and *outdoor* (Toronto and Edmonton were lower than Vancouver and St. John). Table 8 gives the mean and standard deviation for the distribution of time spent in each ME in each city. Table 9 provides the significance levels of the KS tests for each microenvironment in each city-to-city comparison. Overall, no significant differences were found between any ME distributions in Vancouver BC and St. John NB, so only these records, a total of 776, were used in the final analyses for the study area.[9]

Table 8. Mean time spent in each microenvironment in CHAPS cities

	Mean time [standard deviation] in minutes			
MEs	**Toronto**	**Edmonton**	**St. John**	**Vancouver**
Home indoor	996 [284]	1,023 [261]	1,008 [290]	1,023 [275]
Other indoor	138 [179]	153 [170]	128 [169]	128 [171]
Work indoor	155 [232]	142 [231]	112 [205]	116 [211]
Outdoor	74 [163]	51 [105]	117 [192]	96 [165]
Transit to work	18 [31]	17 [31]	11 [24]	15 [30]
Transit other	59 [78]	55 [68]	64 [108]	63 [87]

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[9] Records for Toronto ON and Edmonton AB were dropped based on the advice of Thomas McCurdy, Exposure Modelling Research Branch, Human Exposure and Atmospheric Sciences Division, National Exposure Research Laboratory, US Environmental Protection Agency, personal communication, October 12, 2005. Dr. McCurdy suggested that pooling records from cities with significant differences is inadvisable.

Table 9. Significance of Kolmogorov-Smirnov test results comparing time-activity patterns among cities

Two-tailed significance values < 0.05 indicate a significant difference in the distribution of time spent in the microenvironment

Micro-environment	Vancouver St John	Vancouver Edmonton	Vancouver Toronto	Toronto St. John	Toronto Edmonton	Edmonton St John
Home indoor	0.613	0.995	0.266	0.539	0.554	0.809
Work indoor	0.808	0.718	**0.027**	**0.037**	0.494	0.509
Other indoor	0.535	0.099	0.885	0.471	0.257	0.084
Outdoor	0.143	**0.000**	**0.008**	**0.001**	**0.019**	**0.000**
Transit other	0.773	0.859	0.196	0.559	0.907	0.965
Transit work	0.725	0.718	**0.022**	**0.049**	0.667	0.633

bold indicates a significant difference

Vancouver	$n = 449$
St John	$n = 327$
Edmonton	$n = 249$
Toronto	$n = 511$

Using the pooled records for Vancouver BC and St. John NB, differences in the distributions of time spent in MEs by males and females, workers and non-workers, on weekdays and weekends, and in winter (September 23 to March 20) and summer (March 21 to September 22) were statistically tested. Significant differences in the distributions of time spent in *home indoor* and *outdoor* were found between females and males in general. No differences were found between male and female workers so these time-activity patterns were pooled for all subsequent analyses, with the exception of the analysis of gender-based difference in exposure presented in Paper 2. Significant differences in all MEs were found between workers and non-workers. The distribution of time spent in the *outdoor* ME was significantly different between female and male non-workers. Only the distributions of time spent in the *indoor other* ME on weekdays and weekends for non-working females were significantly different. All other ME distributions were not significantly different for non-working females or males when comparing weekdays to weekends. Finally, the distributions of time spent in *home indoor* and *outdoor* were significantly different between summer and winter for female non-workers, male non-workers, and workers, as were the distributions for time spent *indoor at work* for workers. Table 10 gives a summary of the differences found.

Table 10. Significance of Kolmogorov-Smirnov test results comparing females and males, workers and non-workers, weekdays and weekends, and summer and winter

Two-tailed significance values < 0.05 indicate a significant difference in the distribution of time spent in the microenvironment

	Microenvironment					
Comparison	**Home indoor**	**Work indoor**	**Other indoor**	**Outdoor**	**Transit other**	**Transit to work**
F (n = 416) M (n = 360)	**0.000**	0.997	0.051	**0.000**	0.284	1.000
NW (n = 598) W (n = 178)	**0.000**	n/a	**0.000**	**0.000**	**0.000**	n/a
FW (n = 94) MW (n = 84)	0.512	0.589	0.936	0.807	0.939	0.605
FNW (n = 322) MNW (n = 276)	**0.000**	n/a	**0.000**	0.168	**0.000**	n/a
MNW (n = 276) MW (n = 84)	**0.000**	n/a	**0.007**	**0.000**	n/a	**0.000**
FNW (n = 322) FW (n = 94)	**0.000**	n/a	**0.014**	0.075	n/a	**0.000**
W Summer (n = 108) W Winter (n = 70)	**0.001**	**0.039**	0.497	**0.000**	0.988	0.567
FNW Summer (n = 161) FNW Winter (n = 161)	**0.049**	n/a	0.545	**0.000**	0.143	n/a
MNW Summer (n = 159) MNW Winter (n = 117)	**0.000**	n/a	0.133	**0.000**	0.818	n/a
FNW Weekday (n = 211) FNW Weekend (n = 111)	0.081	n/a	**0.046**	0.318	0.641	n/a
MNW Weekday (n = 169) MNW Weekend (n = 107)	0.568	n/a	0.609	0.997	0.263	n/a

bold indicates significant difference

F = female
M = male
W = working
NW = nonworking

Based on the statistical test of the distributions of time spent in each ME, separate sets of time-activity patterns were created for non-working females summer (161), non-working females winter (161), non-working males summer (159), non-working males winter (117), workers summer (108) and workers winter (70). The numbers of unique time-activity patterns in each group are comparable to those used in other studies: Kruize, Hanninen et al, (2003) used 434, 322, 83, and 100 time-activity patterns to represent the total population of urban adults in Helsinki, Basel, Prague, and Athens respectively.

A second full set of time activity patterns were created for the groups listed above in Step 5. In this step, the time-activity patterns were adjusted to split *home indoor* into *home indoor night* and *home indoor day*, in order to support a secondary investigation of how the use of a simple daily average pollution level compares to using a time-stratified approach in which different pollution levels are associated with specific times of the day, such as is used in the HAPEM4 model. Using the latter approach, time spent in each ME can be linked more closely with pollution levels as they vary throughout the day. For example, ambient pollution concentrations for *home indoor night* can be estimated from pollution levels measured only at night. Similarly, ambient pollution concentrations for *transit to work* can be estimated from pollution levels measured during rush hours, and so on. *Home indoor* was split by assuming a minimum of 300 minutes (5 hours) for *home indoor night*, and any remaining time assigned to *home indoor day*. Examples of the time-activity patterns used in this research are shown in Tables 11 and 12. The time periods used for each ME for the time-stratified approach are provided in Section 3.2.6.

Table 11. Example of unadjusted time-activity data for workers

	Minutes					
Time-activity pattern	Home indoor	Work indoor	Other indoor	Outdoor	Transit to work	Transit other
1	880	450	0	0	110	0
2	905	495	0	0	40	0
3	790	420	150	0	80	0
4	1080	185	0	45	55	75
5	695	440	165	3	50	87
6	800	585	0	0	55	0
↓	↓	↓	↓	↓	↓	↓
n	690	480	150	0	90	30

Table 12. Example of adjusted time-activity data for workers, separating home indoor night and day

Time-activity pattern	Minutes						
	Home indoor night	Home indoor day	Work indoor	Other indoor	Outdoor	Transit to work	Transit other
1	300	580	450	0	0	110	0
2	300	605	495	0	0	40	0
3	300	490	420	150	0	80	0
4	300	780	185	0	45	55	75
5	300	395	440	165	3	50	87
6	300	500	585	0	0	55	0
↓	↓	↓	↓	↓	↓	↓	↓
n	300	390	480	150	0	90	30

3.2.4 Work flow data

Maintaining the spatial relationships among home census tracts and work census tracts is key to this research. Data for all workers aged 15 and over based on a 20 percent sample in each census tract on May 15th, 2001, were purchased from Statistics Canada. For each census tract, the number of workers going from the census tract of their residence to another census tract for work were used to develop frequency-weighted work pair lists for use in the SESM. Workers who had a place of employment within the census tract of their residence were excluded, under the assumption that commuting distance would be negligible, and the ambient pollution levels at home and work similar. In total, three separate datasets were developed, one for all workers, one for male workers, and one for female workers. Table 13 provides an example of the data. For each home census tract, a single work pair file was created with multiple entries for each work census tract according to the frequency given in the work flow data. For example, for home census tract 1, as shown in Table 13, the work pair file would contain 38 entries for work census tract 2, 10 entries for work census tract 4, and so on. During the simulation for home census tract 1, a work census tract is randomly chosen from the work pair file, with the probability of selection being associated with the number of entries for each work census tract.

Table 13. Example of work flow data for a single census tract

Home Census Tract	Work Census Tract	Frequency (number of people)
1	2	38
1	4	10
1	5	10
1	6	15
1	7	25
1	8	18
1	10	10
1	11	13
1	15	13
1	16	23
1	18	15
1	19	5

3.2.5 Road network

Pollution levels associated with travelling to work or for other non-work related errands need to be spatially consistent with the existing roads in the study area. A current digital road dataset was acquired for the study area from DMTI Spatial Inc. under an academic research agreement. This dataset was converted into a GIS network using ArcGIS 9.1, thereby allowing for the identification of the shortest route between two points while observing appropriate travel restrictions such as one way streets and speed limits. For every home census tract, the shortest route based on time for every work census tract listed in the work pair file (described above in section 3.2.4) was identified and saved as a unique GIS file using a specific identifier (i.e., originCT10_destinationCT_205) with attributes including total distance and total time associated with the route. All together, 34,782 unique GIS files were created, representing the shortest routes between each home census tract in the study area and all associated work census tracts. When used in conjunction with a pollution surface that differentiates between the level of pollution on roads and away from roads, using shortest routes between residence census tracts and work census tracts captures the elevated pollution levels associated with roads.

3.2.6 Ambient traffic-related air pollution data

Although the literature reviews presented previously (Section 1.2.1 and 1.2.2) include information on all traffic-related air pollutants, NO_2 was chosen as a focus for this implementation of the SESM because numerous health studies and field measurements suggest it is a good indicator of traffic-related air pollution. For example, the effect of particulate air pollution (PM_{10}) on cardiovascular diseases was investigated in eight European cities by Le Terte, Medina et al. (2002). In their study, the effects of PM_{10} on selected health outcomes was shown to disappear when NO_2 levels were included in the models or to be substantially reduced when black smoke (BS) was included, whereas the effects of BS on health outcomes was little affected when NO_2 was included in the models, leading the authors to conclude that “ the association of air pollution with cardiovascular hospital admissions is primarily attributable to traffic exhaust” (Le Tertre, Medina et al. 2002).

A study of school children in the Netherlands found that measured personal and outdoor NO_2 levels were significantly higher for children living near a very busy highway compared to those living near a non-busy highway (Rijnders, Janssen et al. 2001). Similarly, outdoor NO_2 measured at homes was found to be correlated with an index of traffic volume nearby in a study of school children in West Germany (Pearson correlation 0.70, n = 294) (Kramer, Koch et al. 2000).[10] Another study of school children in the Netherlands measured NO_2 and black smoke (BS) (identified specifically with heavy vehicle/diesel traffic) inside schools near major roadways and found a high correlation between the two pollutants (>0.70) (Brunekreef, Janssen et al. 1997).

In the East Bay Children’s Respiratory Health Study in the US, measurements of black carbon, NO_x and NO_2 were highly correlated at 10 schools over 19 weeks ($r^2 = 0.90$), and concentrations of black carbon (BC), NOx, NO, and NO_2 were higher at schools located within 300m downwind of a freeway compared to concentrations at

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[10] Interestingly, Kramer, Koch et al. 2000 also found that personal NO_2 measures were up to 50 percent lower than and not well correlated with outdoor NO_2 levels at home, but were correlated with NO_2 levels estimated using a microenvironmental model including NO_2 concentrations measured at school locations. This suggests that movements in and out of residential neighbourhoods can have a large impact on total personal exposure to NO_2.

school upwind or further away from major traffic sources (Kim, Smorodinsky et al. 2004).

A number of studies have specifically measured the gradient of NO_2 with distance from roadways. In the Netherlands, NO_2 was measured at four distances (50, 100, 150, and 300 metres) from a roadside in two city districts, and levels were found to decrease with distance from the road (Roorda-Knape, Janssen et al. 1998). Measurements of NO_2 were taken for a seven-day period at varying distances from a busy highway in Montreal, Canada and clearly showed a decreasing gradient in NO_2 levels as distance from the highway increased, with the sharpest decrease observed between zero and 200 metres (Gilbert, Woodhouse et al. 2003). Similar results were obtained in Sapporo, Japan, where decreasing gradients in NO_2 were observed in relation to distance from intersections over a two-week period (Maruo, Ogawa et al. 2003). A more recent study conducted in Montreal, Canada found NO_2 levels decreased as the amount of local traffic decreased (Smargiassi, Baldwin et al. 2005).

Given NO_2 as an indicator for traffic-related air pollution, two types of estimated ambient pollution levels were employed for this research. First, a series of surfaces based on spatial interpolation employing the often used inverse distance weighted algorithm (IDW) and data from fixed-site monitors for one year (2001) were developed. Second, a single spatial surface representing annual average pollution levels, developed by UBC researchers using the land use regression method (LUR) and data measured from temporary monitors used in 2003, was used.

The IDW surfaces were developed based on either the average of a full year of monitored hourly data (2001 to match the year of the Statistics Canada work flow survey date), or annual hourly averages stratified by time periods (similar to the HAPEM 4 model) using the ArcMap 9.1 IDW tool with settings of 2 (power), 12 (the number of points to include in search radius), and 50 (metres resolution of output raster). These distinct spatial surfaces (listed in Table 14) allow for an investigation of the effects of using different pollution data averaging methods on the SESM results.

Table 14. Methods and metrics used to create spatial pollution surfaces with IDW

Method	Microenvironments	Metric based on pollution monitor data
Average		
Nonworkers	All →	Annual average of all hourly measures
Workers	All →	Annual average of all hourly measures
Stratified		
Nonworkers	Indoor home night→	Annual avg. of hourly measures 8pm to 8am
	All others →	Annual avg. of hourly measures 7am to 9pm
Workers	Home indoor night →	Annual avg. of hourly measures 8pm to 8am
	Transit to work →	Annual avg. of hourly measures 7-9am + 4-6pm
	Indoor work →	Annual avg. of hourly measures 8am to 6pm
	Indoor other, transit other →	Annual avg. of hourly measures 4pm to 10pm

The LUR estimate was developed by researchers at the University of British Columbia and made available for this research. Full details on the method used to develop this surface are presented in (Henderson, Beckerman et al. 2007). Briefly, linear stepwise multiple regression is used to develop a model for predicting pollution levels at any given point in a study area based on data collected from temporary monitors and independent variables developed from the land use surrounding each temporary monitor. Typically, independent variables include traffic density or volume, length of roads, percentage of land in commercial or residential use, and so on, within specific distances from the temporary monitor (Briggs, Collins et al. 1997; Briggs, de Hoogh et al. 2000; Brauer, Henderson et al. 2005; Jerrett, Arain et al. 2005; Ross, English et al. 2006). The LUR model used for this research, noted below, produces an R^2 of 0.52, which is typical for this method.

$$\begin{aligned} NO_2(ppb) = {} & 12.1176 + 9.6810(RD1.100) + 0.2486(RD1.1000) + 4.4293(RD2.200) \\ & + 0.1024(EAP.2500) + -0.0234(ELEV) + 0.1328(COMM.750) \end{aligned} \qquad \text{(Eq 4)}$$

Where:

RD1.100 = length of freeways and highways within 100m
RD1.1000 = length of freeways and highways within 1000m
RD2.200 = length of major roads within 200m
EAP.2500 = population density within 2500m
ELEV = elevation in metres at sample site
COMM.750 = hectares of commercially zoned land within 750m

Section 3.2.8 describes how these surfaces were used to develop pollution concentration distributions for each ME in each neighbourhood. Section 3.2.9 describes how the CHAPS time-activity patterns were used in conjunction with the pollution concentration distributions to produce different simulations of total exposure in the SESM. Section 3.3 contains results of sensitivity testing based on the use of different averaging methods for IDW and on the differences between IDW and LUR.

Other methods for developing spatial surfaces of pollution could be used with the SESM, such as kriging or dispersion modelling. Kriging was evaluated for use in this research, but pollution surfaces produced were identical to those produced using IDW because of the limited pollution monitoring network in the study area. Ideally, 50 to 100 sample points are required to produce a stable variogram, a critical component of kriging (Burrough and McDonnell 1998). Data from only 16 monitoring stations were available for the study area. More importantly, in order to use kriging effectively for the SESM, the pollution sampling points would have to be spatially dense enough to capture both the regional and neighbourhood gradients in NO_2, which would require an inordinately large number of sampling points in the study area. Dispersion modelling could be used to create high resolution estimates for the SESM, but was not evaluated for this research.

All of the methods described above rely on some kind of measured concentration of ambient NO_2, and it should be recognized that sources of NO_2 other than traffic may contribute to ambient levels. For the purposes of this research, NO_2 in the study area is assumed to be primarily associated with traffic, rather than non-traffic related sources.

3.2.7 Data for residences and commercial buildings and associated indoor/outdoor ratios

Detailed data on all properties for which taxes are assessed in the study area were acquired in 2004/2005 from the provincial tax assessor, BC Assessment (attribute data), and from 16 municipal jurisdictions[11] (spatial property parcel data). Based on a unique parcel identifier used by both BC Assessment and the municipal jurisdictions, attribute data were joined to the spatial parcel data in ArcGIS 9.1©, allowing for the identification of the primary building type on each property. The attribute data included an ‘actual use

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[11] Burnaby, Coquitlam, Delta, District of North Vancouver, Langley City, Langley Township, Maple Ridge, North Vancouver, New Westminster, Pitt Meadows, Port Coquitlam, Port Moody, Richmond, Surrey, Vancouver, and West Vancouver

code', relating to approximately 200 unique building types. Properties were divided into 'residential' and 'commercial' categories based on the actual use code (see Appendix C for the full list of actual use codes and the category assigned). Buildings were assumed to be located at the centroid of each associated property parcel; these centroid points were used as inputs to the SESM, as described in Section 3.2.8. In total, there are 427,514 residential and 80,282 commercial buildings in the study area.

A literature review was conducted to identify appropriate indoor/outdoor ratios for different building types, and revealed a wide range, depending on the season and differences in heating/cooling practices associated with the local climate and whether or not indoor sources of NO_2 were excluded. For example, I/O ratios for residences range from 0.40 to 0.98 when considering both winter and summer, and when gas stoves, the major indoor source of NO_2, are excluded. Few studies publishing I/O ratios for buildings other than residences were found, but again, a wide range was observed depending on the location and ventilation system – from 0.19 (summer, air conditioned offices) to 1.0. The studies reviewed (Table 15) were difficult to compare due to the differing geographic locations, sample sizes, time periods and seasons measured, and treatment of indoor sources. Additionally, none of the reviewed studies measured NO_2 for longer than two weeks, so estimates of annual I/O ratios were not available.

Due to the variability of I/O ratios and the general lack of comprehensive data, I/O ratios loosely based on the literature review were applied according to building type under two scenarios, as listed in Table 16, and the results tested for sensitivity to changing the I/O ratios used. Theoretically, if the I/O ratio is set too high, exposures will be overestimated, and if the I/O ratio is set too low, exposures will be underestimated. For the 'moderate' scenario, all residences were assigned an annual average I/O of 0.7, based on Quackenboss, Spengler, et al (1986), and commercial buildings were assigned one of three I/O ratios – 0.35 for large office buildings and hotels, 0.50 for civic institutions, schools, industry and manufacturing, and 0.70 for small commercial buildings with a high likelihood of frequent door opening and people moving in and out. These I/O ratios are then used as multipliers for the ambient pollution estimate, and act to reduce pollution concentrations in indoor MEs. A plausible 'worst case' scenario was also developed, designed to maximize the difference between residential buildings and commercial buildings, and therefore the difference between *non-workers* and *workers*. All residential buildings received an annual average I/O ratio of 0.75, while most commercial buildings were assigned 0.35, small neighbourhood stores, car lots and fast food restaurants being the exceptions. In this way, time spent in the *work indoor* ME would provide a relatively high protective effect (i.e., pollution concentrations are the most reduced), while the pollution concentrations for the *home indoor* ME would be minimally reduced. The effect of using different I/O ratios on SESM results is described in Section 3.3.

Table 15. Indoor/Outdoor (I/O) ratios for NO_2 from existing monitoring studies

Study and location	Measurement period	Site description	Number of measurements	Duration	Equipment	Summary of I/O	Notes
(Quackenboss, Spengler et al. 1986) Wisconsin, US	1981-1982 Summer and winter	47 residences	2 seasonal at each location	7 days	Palmes tubes	median I/O summer = 0.80 median I/O winter = 0.60	Gas stoves excluded
(Spengler, Schwab et al. 1994) Los Angeles, US	May 1987 – May 1998	682 residences	Once at each location	2 days	Palmes tubes	Mean I / mean O = 0.71 all seasons including homes with gas stoves	Gas stoves included
						Slope for homes with out pilot light or electric, all seasons = 0.40	Gas stove with pilot lights excluded
(Lee, Yanagisawa et al. 1995) Boston, US	November 1984 – October 1986	Unknown number of residences (estimated at ~ 100, or 28% of 345 total measured in summer)	At least once in each of three seasons (winter, summer, and fall)	2 weeks	Palmes tubes	Summer: Mean I/O kitchen = 0.81 Mean I/O living room = 0.81 Mean I/O bedroom = 0.77 Mean of above = 0.80	Gas stoves excluded
(Lee, Yanagisawa et al. 1996) Boson, US	November 1984 – October 1986	192 single unit 207 small multi unit 131 large multi unit	At least once in each of three seasons (winter, summer, and fall)	2 weeks	Palmes tubes	Mean for winter, fall, summer: Single unit: 1.08, 0.97, 1.16 Small multi unit: 1.29, 1.28, 1.18 Large multi unit: 1.54, 0.97, 1.03	Gas stoves included
(Hagenbjork-Gustafsson, Forsberg et al. 1996) Umea, Sweden	1994 Jan - March	23 residences in urban area, 20 residences in suburban/rural area	twice per home, at least 8 days apart	1 day	Willems badge	urban homes winter = 0.44 rural homes winter = 0.67 urban apartments winter = 0.49, urban detached homes winter = 0.41	Gas stoves excluded
(Monn, Fuchs et al. 1997) Switzerland	1996 (?) winter - two homes, 15 in spring/summer	5 residences	not clear	not stated	Palmes tubes	winter = 0.40 and 0.46 spring/summer = 0.69, 0.74, 0.98	Gas stoves excluded, all naturally ventilated
(Levy 1998) 18 cities in 15 countries	1996 February or March	227 residences in 18 cities	one each	2 days	Filter badges	Overall winter = 0.69	Gas stoves excluded

Table 15. Continued

Study and location	Measurement period	Site description	Number of measurements	Duration	Equipment	Summary of I/O	Notes
(Monn, Brandli et al. 1998) Eight European cities (SAPALDIA study)	December 1993 – December 1994	1,501 monitoring events at residences in total	3 times over the year	1 week	Palmes tubes	Slope of linear regression = 0.47 (could be considered 'best fit' I/O ratio, but r2 is low – 0.37)	Gas stove and smokers included
		943 monitoring events at residences without gas stoves or smokers				Slope of linear regression = 0.40 (could be considered 'best fit' I/O, but r2 is low – 0.34)	Gas stoves and smokers excluded
(Chao and Law 2000) Hong Kong	May – June 1997	12 residences with air conditioning systems, non-smokers, gas stoves	Once	1 week	Gradko passive samplers	I/O ratios: 0.71, 0.53, 1.04, 0.93, 0.79, 0.94, 0.61, 0.30, 0.98, 0.67, 0.95, 0.98 Mean I/O = 0.79 Mean I/O with no cooking = 0.50 Mean I/O with cooking = 0.89	Gas stoves included Air conditioners were not used in all residences
(Lai, Kendall et al. 2004) Oxford, UK	December 1998 – February 2000	39 (?) residences	Once	2 days	Gradko passive samplers	Mean (?) I/O = 0.9 Nonsmokers mean I/O = 1.0 Smokers mean I/O = 1.5	Gas stoves included
(Ekberg 1995) Goteborg, Sweden	Not stated	3 office buildings with mechanical ventilation		4 days	Physics ALD 700	ratio of exhaust air/supply air = 0.90, 0.72, 0.73 (24 hours); 0.85, 0.70, 0.67 (working hours), 0.73, 0.65, 0.65 (max 1 hour avg.)	No indoor sources assumed
(Liao, Bacon-shone et al. 1991)Hong Kong	1990 July, August, September	35 small firms and large modern offices, all above ground level, 9 with window unit air conditioning and 26 with central air	1 at each location	4 to 12 hours	Filter badges	Mean I/O summer = 0.19	Not controlled for indoor sources (but assumed indoor source unlikely)

Table 15. Continued

Study and location	Measurement period	Site description	Number of measurements	Duration	Equipment	Summary of I/O	Notes
(Partti-Pellinen, Marttila et al. 2000) Imatra, Finland	1998 Season not stated	1 daycare facility	2 under different filtration conditions, on weekend, weekday, and high event	6 to 7 days, 2 times	Horiba Apna 360 analyzer	Exhaust fan and mechanical filter : 0.6, 0.78, 0.50 Intake and exhaust fans, 2 mechanical filters: 0.95, 1.09, 0.78 Intake and exhaust fan, 2 mechanical filters and a chemical filter, 20% air recirculation: 0.49, 0.53, 0.35	No indoor sources
(Blondeau, Iordache et al. 2005) La Rochelle, France		8 schools, mechanically or naturally ventilated	2 at each location, one in spring or summer, one in winter	2 weeks	AC31m analyzer	I/O ranged from 0.88 to 1.0 with no correlation with building permeability	No indoor sources
(Liao, Bacon-shone et al. 1991) Hong Kong	1990 July, August, September	35 ground level shops, usually door open during business hours, 4 with natural ventilation, 14 with central air, 17 with window unit air	1 at each location	4 to 12 hours	Filter badges	Shops, summer: ratio of mean I/mean O = 0.82, ratio of median I/median O = 0.86	Not controlled for indoor sources
(Guo, Lee et al. 2004) Hong Kong	2001 / 2002 September - January	3 non-air conditioned markets, 2 air conditioned markets	one at each location	bag samples (1 hour)	Tedlar bag with pump	The I/O ratios were close to 1 at all markets, no significant difference between non-air conditioned and air conditioned	Not controlled for indoor sources, but well ventilated
(Lee, Chan et al. 1999) Hong Kong	1996 / 1997 October 1996 - March 1997	3 restaurants with gas stoves, 2 libraries, 2 recreation places, 3 shopping malls, 2 sport centres, 1 car park, all with mechanical ventilation	one at each location	bag sample (1 hour)	Teflon bags	restaurants = 0.70 libraries = 0.72 recreation places = 0.72 shopping malls = 1.03 sport centres = 0.53 car park = 0.69 overall average = 0.75	Not controlled for indoor sources

Table 16. Indoor/Outdoor ratios employed in the SESM for annual simulations for two scenarios

Micro-environment	Type	I/O ‘moderate’	I/O ‘worst case’
Indoor Home	All residential dwelling types	0.70	0.75
Indoor Work and Shopping	Office buildings (primary use), hotels	0.35	0.35
	Neighbourhood stores, car sales, fast food	0.70	0.75
	All other stores, services, entertainment	0.70	0.35
	Civic and institutional offices, industrial and manufacturing	0.50	0.35

3.2.8 Microenvironment distributions

A key component of exposure simulation is the use of distributions to represent the range of possible pollution levels encountered in each ME included in the simulation. Depending on the particular ME of interest, various methods for identifying distributions of appropriate values have been employed for the SESM.

Like other simulation models, ME distributions for the SESM depend on ambient levels of pollution, however, the SESM incorporates geographic detail through the use of several key datasets: spatial property assessment data providing locations and building details for all taxed properties in the study area; and a digital road network providing road locations and types. The following describes the methods used to develop ME distributions for the SESM and the approach used to adjust ambient levels for indoor MEs.

3.2.8.1 Home indoor

For each census tract in the study area, a single pollution value is extracted for the centroid of each residential building parcel and multiplied by the appropriate I/O ratio. This produces a distribution of all possible indoor pollution values at residential locations within the census tract.

3.2.8.2 Work indoor

For each census tract in the study area, a single pollution value is extracted for the centroid of each commercial building parcel and multiplied by the appropriate I/O ratio. This produces a distribution of all possible indoor pollution levels at commercial locations within the census tract.

3.2.8.3 Other indoor

For each census tract in the study area, a single pollution value is extracted for the centroid of each commercial buildings within a specified distance and multiplied by the appropriate I/O ratio. This produces a distribution of all possible indoor pollution levels at commercial locations within the chosen distance.

3.2.8.4 Transit to work

Given a list of all residence–work census tract pairs, GIS is used to determine the route taking the shortest time between pairs. The route is then overlayed on the spatial pollution surface and broken into individual segments with unique pollution values. A single length-weighted average value is calculated by summing the product of each segment length and the associated pollution value, then dividing the sum by the total length of the route. An I/O ratio of 1.00 is assumed.

3.2.8.5 Transit other

For each census tract in the study area, all roads within a specified distance from the census tract centroid are converted into points (50 metre resolution); pollutions values for each point are extracted and averaged. The average then acts as a fixed value for ambient pollution associated with other transit for that particular census tract. An I/O ratio of 1.00 is assumed.

3.2.8.6 Outdoor

For each census tract in the study area, a single pollution value is extracted for a grid of points with 200 meter resolution within a specified distance of the centroid of the census tract. This produces a distribution of possible ambient pollution levels within the chosen distance. I/O ratios are not applicable.

The GIS procedures described above produce distributions (*home indoor*, *work indoor, other indoor,* and *outdoor*) or fixed values *(transit to work* and *transit other*) of ambient air pollution for each census tract for each ME in the SESM. The shape of each distribution varies among MEs in the same census tract, and among the same MEs in different census tracts, thus incorporating the spatial characteristics of the pollution surface. For example, in areas where pollution levels are fairly homogeneous within the census tract and nearby, the ME distributions produced will be flatter. In areas with large spatial gradients in pollution, ME distributions will exhibit more variation. Unlike other simulation models, the SESM does not require the user to choose a specific distribution shape to characterize pollution levels for an ME. Instead, the values are 'sampled' directly from the pollution surface, based on the actual locations of residential buildings, commercial buildings, and roads, providing the distributions.

For *other indoor*, *transit other*, and *outdoor* ME distributions, a specific distance must be chosen that represents the maximum distance a resident travels to other indoor locations or outdoors. Sensitivity tests were conducted to evaluate the effect of choosing different distances for this parameter on the SESM results, and are presented in Section 3.3.

3.2.9 Simulating annual average exposures

This research is part of a larger study investigating the effects of chronic exposure to air pollution on a range of health outcomes, so the interest is mainly in annual average exposure rather than single day exposures. The SESM therefore must be capable of producing these longer-term simulations. More sophisticated exposure simulation models, such as the US EPA's APEX4 model, simulate individuals hour by hour, day by day for long time periods (i.e., a year) by creating longitudinal series of time activity patterns that are ranked and scored for similarity/correlation between some key variable (or composite of variables) such as time spent in a car or outdoors (U.S. Environmental Protection Agency 2006). The SESM has more in common with the HAPEM 4 model, as it has been implemented to simulate a single year, using pollution estimates representing annual average levels rather than simulating consecutive days and then averaging to produce an annual estimate. In this regard, the SESM as implemented is limited to producing only an average annual exposure, and estimates cannot be used to simulate the maximum hourly (or 8 hour) exposure level, or the number of times a selected threshold is exceeded over a given time period.

The CHAPS time-activity patterns provide the amount of time spent in each ME for a 24 hour period rather than for an entire year, so some generalizations must be made in order to simulate annual average exposure. The following assumptions have been made about *workers*[12] and *non-workers* behaviour: 1) a working individual has the same daily time-activity pattern every workday in a year; 2) a working individual works 52 weeks per year; 3) a working individual has a different daily time-activity pattern every non-working day; and 4) a non-working individual has a different daily time-activity pattern every day of the year. These assumptions are reflected in the mathematical models employed in the SESM.

For *non-workers*, the calculation of annual average exposure is based on the random selection of a time-activity pattern for each day in summer and each day in winter, which provides the times spent in each microenvironment, and the subsequent random selection of a pollution values from the distributions associated with the census tract:

$$\boldsymbol{E_{nw}} = [(W_s * 0.50) + (W_w * 0.50) \qquad (5)$$

where:

$\boldsymbol{E_{nw}}$ = a single estimate of annual average exposure for *non-workers* in a census tract
W_s = exposure during summer
W_w = exposure during winter
0.50 = the weight given to the each season

and

$$W_s = [\sum_{n=183} \{(T_h * P_h) + (T_{oth} * P_{oth}) + (T_{out} * P_{out}) + (T_{tro} * P_{tro}) /\text{total time}\}] / 183 \qquad (6)$$

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[12] In this dissertation, *workers* and *non-workers* are italicized to note they are simulated groups.

where:
W_s = exposure during summer (183 days per season)
T_h = time spent at home indoor from the summer time-activity pattern
P_h = pollution concentration at home indoor
T_{oth} = time spent at other indoor from the summer time-activity pattern
P_{oth} = pollution concentration at other indoor
T_{out} = time spent outdoor from the summer time-activity pattern
P_{out} = pollution concentration outdoor
T_{tro} = time spent in transit other from the summer time-activity pattern
P_{tro} = pollution concentration in transit other

The calculation for W_w is the same as Equation (6), but T_h, T_{oth}, T_{out}, and T_{tro} are drawn from winter time-activity patterns. Summer is defined as all days between March 22st and September 21st; winter is defined as all days between September 22nd and March 21st.

For *workers*, the equation is more complex, in order to incorporate the differences in time-activity patterns on weekends, summer and winter. First, an eligible work census tract is selected from the work pair file, and a single work time-activity pattern is selected to represent all weekdays in the year. The exposure associated with weekend days in the summer is calculated by randomly choosing 53 non-worker summer time-activity patterns and taking the average of each result. The same is done for weekend days in the winter. In addition, there is no guarantee that the time reported for transit to work in the randomly selected time-activity pattern will match the time calculated to travel the shortest route to the randomly selected work census tract, so the round trip time associated with the shortest route is substituted into the time-activity pattern, and the time spent at indoor home is increased of decreased accordingly:

$$\boldsymbol{E_w} = [\{(W_a * 0.72) + (W_{ws} * 0.28)\} * 0.50] + [\{(W_a * 0.72) + (W_{ww} * 0.28)\} * 0.50] \qquad (7)$$

where:

$\boldsymbol{E_w}$ = a single estimate of annual average exposure for *workers* in a census tract
W_a = exposure during weekdays
W_{ws} = exposure during summer weekends
W_{ww} = exposure during winter weekends
0.72 = the weight given to weekdays
0.28 = the weigh given to weekend days
0.50 = the weight given to each season

and:

$$W_a = [\{(T_h - T_{adj}) * P_h\} + (T_w * P_w) + (T_{oth} * P_{oth}) + (T_{out} * P_{out}) + (T_{tro} * P_{tro}) + (R_{trw} * P_{trw})] / TA_{time} \qquad (8)$$

where:

W_a = exposure during weekdays
T_h = time spent at home indoor from the worker time-activity pattern
T_{adj} = adjustment to reconcile with shortest route time of work census tract
P_h = pollution concentration at home indoor
T_w = time spent at work indoor from the worker time-activity pattern
P_w = pollution concentration at work indoor
T_{oth} = time spent at other indoor from the worker time-activity pattern
P_{oth} = pollution concentration at other indoor
T_{out} = time spent outdoor from the worker time-activity pattern
P_{out} = pollution concentration outdoor
T_{tro} = time spent in transit other from the worker time-activity pattern
P_{tro} = pollution concentration in transit other
R_{trw} = time associated with shortest route to work census tract
P_{trw} = pollution concentration for shortest route to work census tract
TA_{time} = total time in units of time-activity pattern

and:

$$W_{ws} = [\sum_{n=53} \{(T_h * P_h) + (T_{oth} * P_{oth}) + (T_{out} * P_{out}) + (T_{tro} * P_{tro}) /\text{total time}\}] / 53 \qquad (9)$$

where:
W_{ws} = exposure during summer weekends (53 weekend days per season)
T_h = time spent at home indoor from the summer time-activity pattern
P_h = pollution concentration at home indoor
T_{oth} = time spent at other indoor from the summer time-activity pattern
P_{oth} = pollution concentration at other indoor
T_{out} = time spent outdoor from the summer time-activity pattern
P_{out} = pollution concentration outdoor
T_{tro} = time spent in transit other from the summer time-activity pattern
P_{tro} = pollution concentration in transit other

W_{ww} is calculated using Equation (9), using winter time-activity patterns
The simulation consists of 10,000 calculations of total exposure and the associated partial exposures, producing a confidence level of 95% that the value of the 50th percentile of the distribution is contained within the values of the 49th and 51st percentile (Cullen and Frey 1998).

The SESM as designed and implemented can use any spatial estimate of pollution levels, and provides an opportunity to evaluate how the use of different estimates affects the model outputs. Table 17 provides a description of the calculation of total exposure to annual average NO_2 ($\mu g/m^3$) for *workers* and *non-workers* using the IDW surfaces created for summer weekdays/weekends and winter weekdays/weekends. In general, unique distributions for each microenvironment (*home indoor*, *work indoor*, *other indoor*, *outdoor*, *transit to work* and *transit other*) are produced for each surface (summer weekday, summer weekend, winter weekday and winter weekend). The amount of time spent in each microenvironment is provided by time activity patterns for male *non-workers* summer/winter, female *non-workers* summer/winter, and *workers* summer/winter. Total exposure (annual) is an average of 365 interim total exposure calculations for summer weekdays, summer weekends, winter weekdays and winter weekends, weighted by the number of weekday days and weekend days, and seasons. Other important features to note include the use of non-worker time activity patterns for workers on weekends.

Additional IDW surfaces are also employed to further differentiate between pollution levels associated with night, rush hour, day and evening. For example, for *workers*, summer and winter weekday is split into IDW surfaces based on averages of monitoring data from 8pm and 8am, 7am to 9am plus 4pm to 6pm (rush hours), 8am to 6pm (workday), and 4pm to 10pm (evening) in each season. These surfaces are used to produce unique distributions for *home indoor night*, *transit to work*, *work indoor,* and *indoor other*/*transit other* respectively. For *non-workers* and weekends, only night (8pm to 8am) and day (7am to 9pm) are differentiated.

Annual simulations using the LUR surface employ the same algorithm; however, the distributions for MEs are exactly the same for summer and winter, weekdays and weekends, all being derived from the single LUR surface.

Table 17. Example of total exposure calculations for a single census tract, based on annual average IDW surfaces for summer weekday, summer weekend, winter weekday and winter weekend

POLLUTION ESTIMATE	***Non-worker* Male (NWM)**	***Non-worker* Female (NWF)**	***Worker* Male (WM)**	***Worker* Female (WF)**
Summer weekday	Home indoor, other indoor, transit other, outdoor based on 133 random nonworking summer male T/A patterns, averaged → NWM**(a)**	Home indoor, other indoor, transit other, outdoor based on 133 random nonworking summer female T/A patterns, averaged → NWF**(a)**	Home indoor, work indoor, other indoor, transit work and transit other based on 1 worker T/A pattern → WM**(a)**	Home indoor, work indoor, other indoor, transit work and transit other based on 1 worker T/A pattern → WF**(a)**
Summer weekend	Home indoor, other indoor, transit other, outdoor based on 53 random nonworking summer male T/A patterns, averaged → NWM**(b)**	Home indoor, other indoor, transit other, outdoor based on 53 random nonworking summer female T/A patterns, averaged → NWF**(b)**	Home indoor, other indoor, transit other, outdoor based on 53 random nonworking male summer patterns, averaged → WM**(b)**	Home indoor, other indoor, transit other, outdoor based on 53 random nonworking female summer patterns, averaged → WF**(b)**
Winter weekday	Home indoor, other indoor, transit other, outdoor based on 128 random nonworking winter male T/A patterns, averaged → NWM**(c)**	Home indoor, other indoor, transit other, outdoor based on 128 random nonworking winter female T/A patterns, averaged → NWF**(c)**	Home indoor, work indoor, other indoor, transit work and transit other based on the above worker T/A pattern → WM**(c)**	Home indoor, work indoor, other indoor, transit work and transit other based on the above worker T/A pattern → WF**(c)**
Winter weekend	Home indoor, other indoor, transit other, outdoor based on 51 random nonworking winter male T/A patterns, averaged → NWM**(d)**	Home indoor, other indoor, transit other, outdoor based on 51 random nonworking winter female T/A patterns, averaged → NWF**(d)**	Home indoor, other indoor, transit other, outdoor based on 51 random nonworking male winter patterns, averaged → WM**(d)**	Home indoor, other indoor, transit other, outdoor based on 51 random nonworking female winter patterns, averaged → WF**(d)**

$$E = [\mathbf{(a)}*0.72 + \mathbf{(b)}*0.28]*0.50 + [\mathbf{(c)}*0.72 + \mathbf{(d)}*0.28]*0.50$$

0.72 = proportion of weekday days (same for summer and winter)
0.28 = proportion of weekend days (same for summer and winter)
0.50 = seasonal weight, equal for summer and winter

3.2.10 Temporal characteristics of the data inputs

Input data for the SESM were collected at different times. The time-activity patterns in CHAPS were collected in 1994/1995 (Leech, Wilby et al. 1997). The work flow data from Statistics Canada are based on a survey conducted on May 15th, 2001. The pollution estimates are based on data from 2001 (the IDW estimates) and 2003 (the LUR estimate). Property assessment and parcel data were collected in 2004/2005. With respect to the work flow data, more current data are not available. It is unlikely, however, that overall urban and residential development patterns have changed enough between 2001 and 2004/2005 (the date of the property-related data) to affect the SESM results. Similarly, it is unlikely that the spatial patterns of traffic-related pollution changed dramatically between 2001 (the work flow data date), 2003 (the LUR estimate date) and 2004/2005(the property-related data date). This leaves only the currency of the CHAPS time-activity data in question.

Studies which reported time spent in microenvironments analogous to those used in the SESM were reviewed and the results are reported in Table 18. Only data for working and nonworking adults are presented. No clear trend is obvious with respect to changes in the amount of time spent in different microenvironments over time, although different geographic locations and city sizes creates difficulty in making comparisons. Unfortunately, no time-activity surveys for the same population at different times were found during the conduct of this review. Still, the general proportions of time spent in each microenvironment are similar in magnitude across cities and over time. For the SESM, it is assumed that the time-activity patterns collected for CHAPS in 1994/1995 remain relevant for 2001, the date of the work flow survey.

Table 18. Summary of time spent in microenvironments for a range of locations and years

Authors and Location	Date of survey	Percent of day spent in microenvironments home indoor	outdoor	transit (all)	work indoor	other indoor
(Quackenboss, Spengler et al. 1986) Portage WI	1981 - 1982	71	7.6	5.0	9.3	7.0
(Akland, Hartwell et al. 1985) Washington DC	1982 - 1983	73		9.0	30.0	
(Akland, Hartwell et al. 1985) Denver	1982 - 1983	68		9.5	33.0	
(Clench-Aas, Bartonova et al. 1999) Norway	~ 1990	68	9.1		12.8	
(Kruize, Hanninen et al. 2003) Netherlands	1994/1995	69	13.5	4.5		12.5
SESM	**1994/1995**	**66**	**5.0**	**8.0**	**16.0**	**8.0**
(Bruinen de Bruin, Hanninen et al. 2004) Milan	1997-1998	56	1.7	7.5	30.0	5.1
(Chau, Tu et al. 2002) Hong Kong	1998	58	4.0	7.0	31.0	
(Lai, Kendall et al. 2004) Oxford UK	1998 - 2000	69	3.8	6.7	17.5	3.4

3.3 SESM SENSITIVITY TESTS

The SESM developed for this research relies on the choice of: 1) a specific distance parameter; 2) a spatial estimate of ambient pollution levels; and 3) indoor/outdoor ratios to represent indoor levels of pollution from ambient sources. The sensitivity of SESM results to each of these choices is described in the following sections. Differences between results for selected percentiles of the total exposure estimate distributions given different parameter choices are described using Pearson's r which gives the correlation between alternate results for the 382 census tracts in the study area. The t-test for paired samples was not used, given that the relatively large *n* (382) leads to the finding of significant differences even when the differences are inconsequential in terms of annual average exposure (i.e. on the order of 0.05 *u*g/m^3 for inputs with a range of 10 to 35 *u*g/m^3). Sensitivity is also described in terms of the magnitude of the difference between different percentiles of the total exposure distributions produced by alternate results, and visualized using box plots and/or maps.

3.3.1 Sensitivity to choice of distance parameter

The SESM requires the choice of a distance from the centroid of each residential census tract, within which commercial locations, roads and outdoor ambient values are used to construct unique distributions of NO_2 levels for the *indoor other, transit other,* and *outdoor* MEs respectively.

In the following analysis, distances of 2.5 km, 5.0 km, and 7.5 kilometres (km) were used to generate distributions of *non-worker* total exposure estimates using the annual average IDW surfaces. *Non-workers* were chosen for this sensitivity test, as they would be the most affected by changes in the distance parameter given that more time is spent in the *indoor other, transit other,* and *outdoor* MEs that are based on the use of a distance parameter in the development of the associated NO_2 distributions. Distances chosen for evaluation were based on a review of the few studies found which have published either typical times or distances for non-work related daily trips away from home (Table 19), and which suggest non-work trips are, on average, in the range of 2 to 8 km from residences.

The SESM results were found generally to be insensitive to the choice of distance up to 7.5 km, with correlations of ~ 1.0 in all comparisons of the 10th, 50th and 90th percentile of total exposure distributions for each distance. Figure 7, containing box plots for each comparison shows that the range in differences is generally within +/- 1 *u*g/m^3, with the widest ranges associated with the differences between the 2.5 and 7.5 distances for all percentiles. Given the total exposure estimates range from between 15 and 40

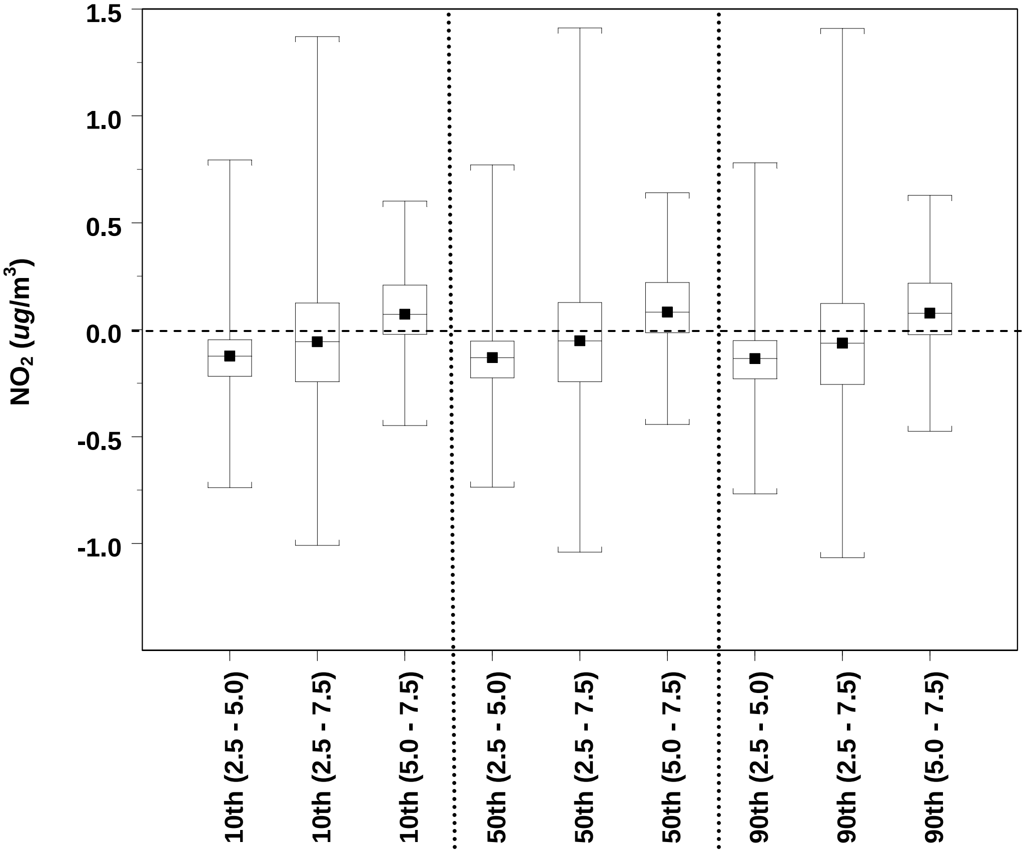
ug/m^3, differences on the order of +/- 1 ug/m^3 are not considered here to be significant in terms differentiating among the choices of distance.

Table 19. Typical distances and time for non-work related trips away from home

Study	Trip type	Mean distance travelled (km)
(Handy 1996) San Francisco (*n* not stated)*		
Mountain View residents	Super market trips	2.8
Junior College residents		2.6
Sunnyvale residents		2.6
Rincon Valley residents		3.2
Average		**2.8**
Mountain View residents	Regional shopping centres	4.5
Junior College residents		2.3
Sunnyvale residents		5.4
Rincon Valley residents		7.1
Average		**4.8**
(Crane and Crepeau 1998) San Diego		
Grid neighbourhood form (number or trips = 644)	Non-work	7.6
Cul-de-sac neighbourhood form (number of trips = 2,010)		9.2
Mixed neighbourhood form (number of trips = 1,525)		7.3
Total all neighbourhood forms (number of trips = 4,199)		8.3
Average		**8.1**
(Janelle, Goodchild et al. 1988) Halifax - survey 1971/72		
All residents (n ~ 2,000)	Usual shopping location	3.0
Females (n = 675)		3.0
Males (n = 532)		2.9
Female, employed, married, no children (n = 71)		2.7
Female, unemployed, married, no children (n = 66)		3.0
Female, employed, married, children (n = 104)		3.7
Female, unemployed, married, children (n = 236)		3.4
Female, employed, single, no children (n = 105)		2.7
Female, employed, single, children (33)		2.4
Male, employed, married, no children (n = 97)		3.0
Male, employed, married, children (n = 264)		2.0
Male, unemployed, married, children (n = 22)		4.5
Male, employed, single, no children (n = 57)		2.6
Male, employed, single, children (n = 26)		2.4
Male, unemployed, single, children (n = 23)		1.6
Average		**2.9**

***** Distance calculated for this table based on published times (minutes) and an assumed speed of 50 km/h.

Figure 7. Box plots* of differences in non-workers exposure distributions at the 10th, 50th and 90th percentiles for distances of 2.5, 5.0 and 7.5 km



*Plots show the minimum and maximum values (lower and upper horizontal bars), the median (black square) and the 25th and 75th percentile values (lower and upper bounds of the box).

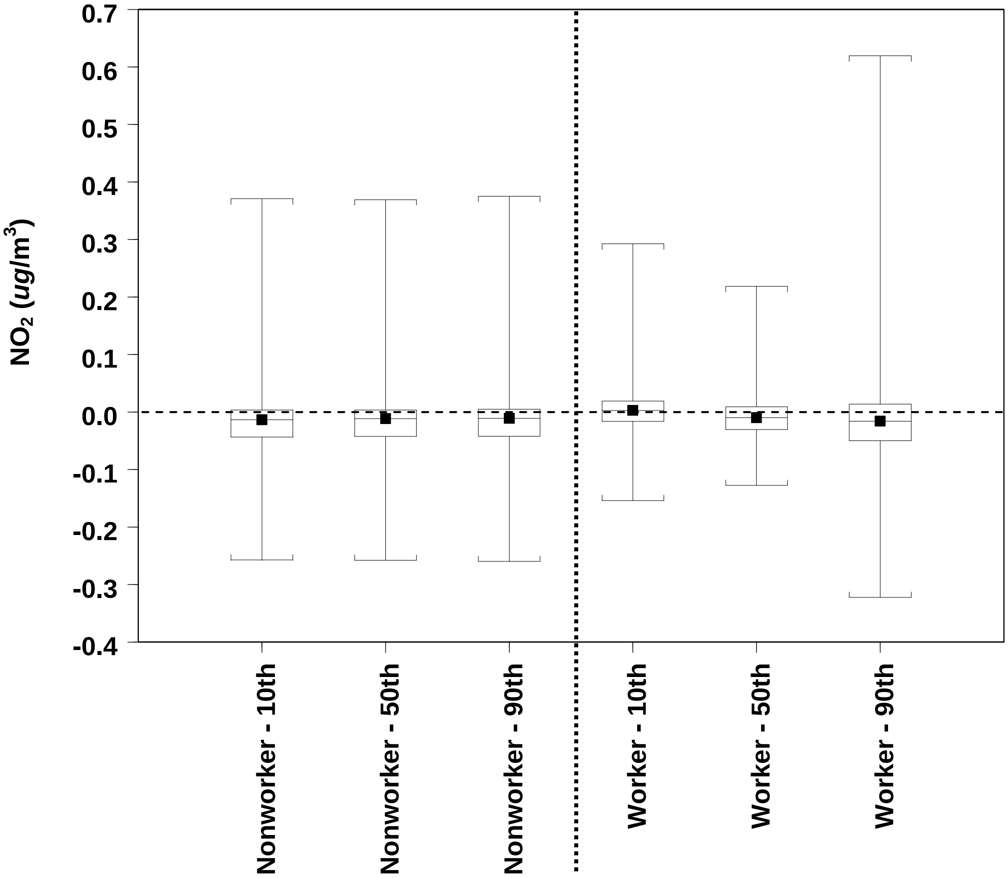
In part, this lack of sensitivity is dependent on the spatial pollution estimate; however, a very steep gradient in pollution would be required to create an observable difference due to the use of random sampling of locations within these distances. For example, much higher pollution levels would have to exist systematically within the 2.5 to 5 km distance to make an observable difference between the 2.5 km and 5 km results. In practice, this would be a ‘doughnut’ of high pollution around a low pollution centre, a condition unlikely to occur naturally or in any modeled pollution estimate for many census tracts in the study area. Along the same line of reasoning, a single ‘hot spot’ within the selected distance would be unlikely to have an observable effect as it would not be randomly selected in every iteration, and so the effect would be averaged away in most cases. Instead, the use of increasing distances has the effect of smoothing out differences in the pollution distributions used for the *indoor other*, *transit other*, and *outdoor* MEs between census tracts, rather than creating substantial differences in the total exposure distributions in the same census tract. At the extreme case, if pollution distributions for *indoor other*, *transit other*, and *outdoor* were developed for the entire study area (i.e., using a very large buffer distance), instead of limiting them to a specified distance from each home census tract, the distributions of the pollution levels calculated for these MEs would be the same for every census tract, and thereby ignore any potential spatial variation due to regional and local gradients in the pollution levels.

3.3.2 Sensitivity to method of pollution measurement aggregation method: time-stratified versus simple average

For long-term simulations of exposure to air pollution, different approaches exist with respect to the pollution metric used and how it is aggregated or accumulated over time. The more complex US EPA models such as APEX.4 simulate each day based on hourly air pollution estimates for an entire year. HAPEM4, the less complex screening-level model, uses pollution levels from a dispersion model (ASPEN) to calculate annual average pollution levels stratified into eight 3-hour time blocks (i.e., the hourly measures between midnight and 3 am for each day in the year are averaged to provided the annual average for that time block, etc.)(Rosenbaum 2002). The SESM was implemented using two strategies: the HAPEM 4 approach (although different time blocks were used, see Section 3.2.6), and a simple annual average. Results for the two strategies are compared to investigate the sensitivity of the SESM results to the choice of pollution metric.

The SESM results for both *workers* and *non-workers*, based on IDW surfaces, were found to be insensitive to the use of a simple annual average compared to a stratified annual average. Correlations between 10th, 50th and 90th percentile of the total exposure distributions based on the annual average versus the stratified annual average were all approximately 1.0. Differences were found to be approximately +/- 0.7 *u*g/m^3, as shown in the box plots in Figure 8. This comparison suggests that, in the SESM at least, the use of a simple annual average produces essentially the same results as the use of the more complicated stratified annual average, which is intended to include the effect of systematic diurnal variations in pollution levels.

Figure 8. Box plots of differences in total exposure distributions between a stratified annual average and an annual average for non-workers and workers



3.3.3 Sensitivity to method used to develop spatial estimate of pollution

The SESM is designed to take advantage of reasonably high resolution spatial estimates of pollution levels, such as those produced using LUR. Advantages of using the LUR approach include the capture of higher pollution levels on roadways and the local gradients in pollution as distance from roads increased. Disadvantages include the necessity of conducting field sampling for at least two weeks in a year (timed to occur when the ambient levels are near that of the annual average) with a reasonable number of locations sampled to allow for the construction of a useful regression model. The LUR surface used for this research was developed with data from 116 temporary monitoring sites (Henderson, Beckerman et al. 2007). In the absence of these data, spatial interpolation, such as IDW or kriging, or data from permanent monitoring stations can be used, resulting in somewhat less detailed surfaces (i.e., pollution levels are not higher along or nearby roads). SESM results based on the use of the available LUR estimate of annual average hourly NO_2 and the annual average hourly NO_2 estimates using the IDW approach described earlier were compared to assess how the choice of method might affect the results. The LUR surface used was developed by researchers at UBC and is described in Section 3.2.6. The IDW surface used for this analysis is based on the annual average hourly values measured at 16 permanent monitoring locations in the study area (see Section 1.7) and is also described more fully in Section 3.2.6.

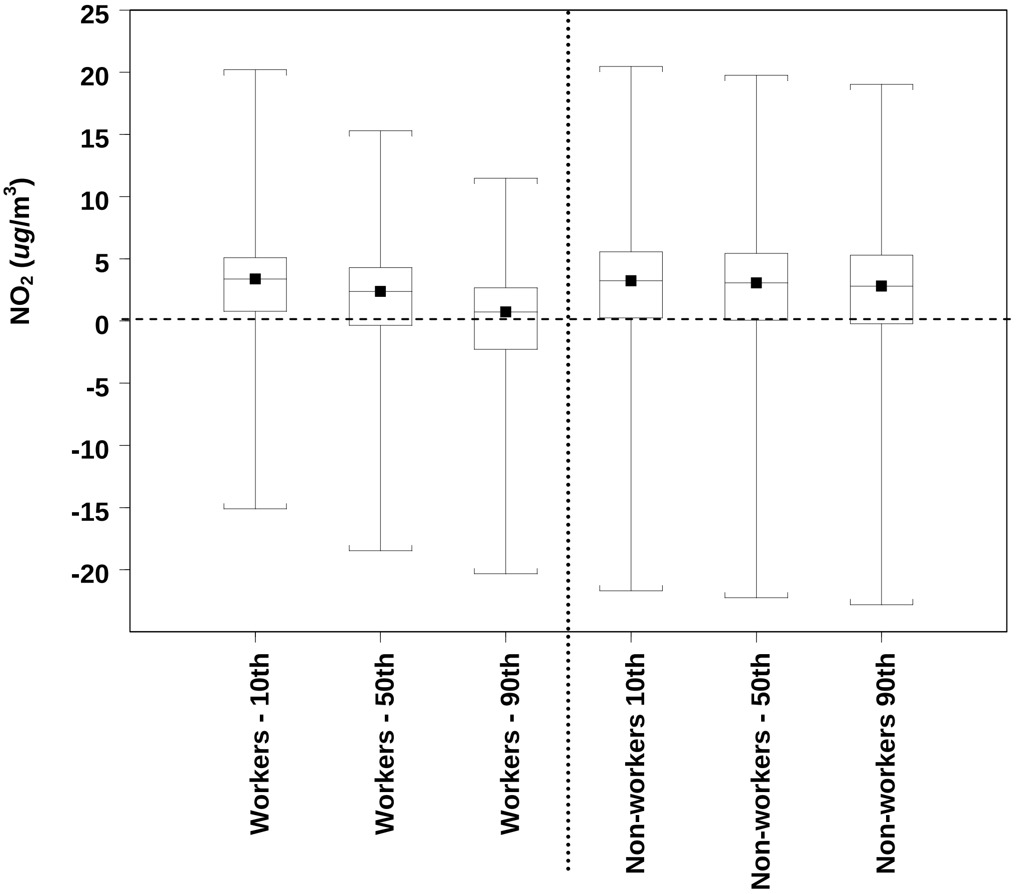
SESM results were found to be sensitive to the method used to produce the average annual hourly NO_2 estimate. In this limited comparison, the correlations between 10th, 50th, and 90th percentiles of the distributions of total exposure for *workers* and *non-workers*, based on IDW versus LUR, were moderate, ranging from approximately 0.60 to 0.71 (Table 20). Box plots of the differences in the distributions (IDW-based minus LUR-based) for both *workers* and *non-workers* (Figure 9) suggest that the IDW surface produces total exposures higher than, but generally within 5 $\mu g/m^3$ of the total exposures produced using the LUR surface, other than for *workers* at the 90th percentile. Still, minimum and maximum differences between the distributions can be greater than +/- 20 $\mu g/m^3$.

Table 20. Correlations between 10th, 50th and 90th percentiles of total exposure distributions based on IDW and LUR surfaces

Percentile	Workers (IDW – LUR)	Nonworkers (IDW – LUR)
10th	0.71	0.65
50th	0.67	0.64
90th	0.60	0.63

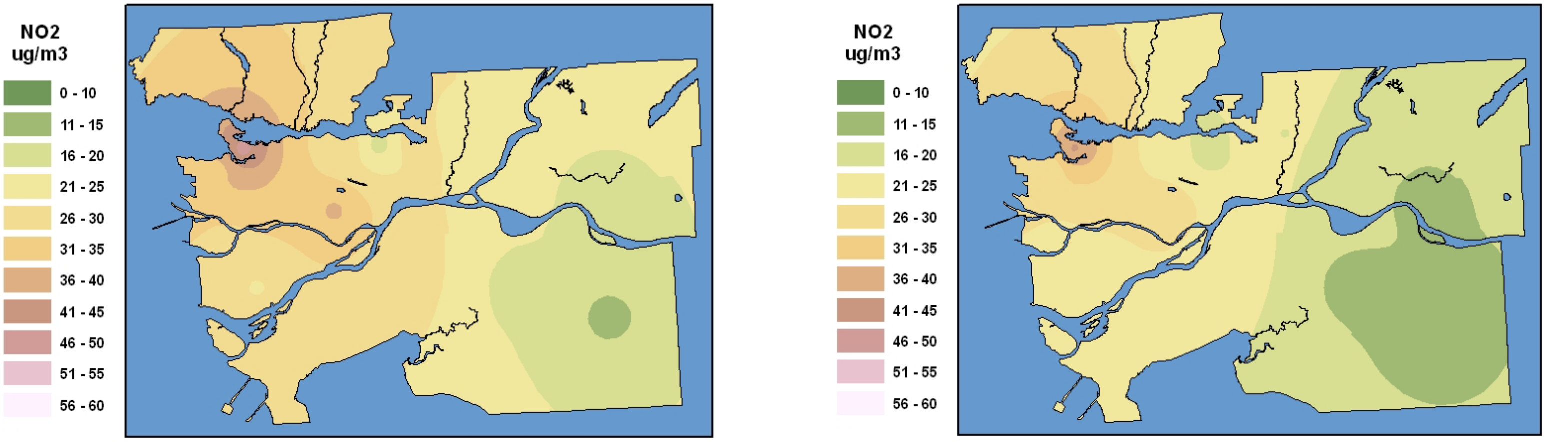
These results are not surprising, given the different spatial patterns of pollution produced by the different methods (Figures 10 and 11). In some areas, such as near the urban core, the IDW method produces uniformly high NO_2 levels while the LUR method produces much greater variability due to the configuration of the road network, population density patterns, and the presence of commercial properties. Similarly, in suburban areas, the IDW method produces uniformly lower levels while the LUR method produces ‘hotspots’ associated with commercial nodes and regional highways. These differences between the two surfaces create substantial differences in the SESM results.

Figure 9. Boxplots of differences in total exposure distributions between IDW and LUR pollution surfaces for non-workers and workers at the 10th, 50th and 90th percentiles



In the absence of measured data allowing for the evaluation of the accuracy of either pollution estimate, no recommendation is made here in terms of which produces a ‘better’ result. The LUR method, however, does produce a pollution surface that appears to capture, at least partially, the phenomenon of local gradients in traffic-related air pollution associated with roadways, as well as the urban to rural gradient observed in the fixed-site monitoring data in the study area. SESM results based on the LUR surface therefore may be a more realistic representation of the spatial patterns of exposures in the study area.

Figure 10. Maps of NO_2 levels produced using IDW for the simulation of average annual exposures


(a) Summer average weekday

(b) Summer average weekend

(c)Winter average weekday

(d) Winter average weekend

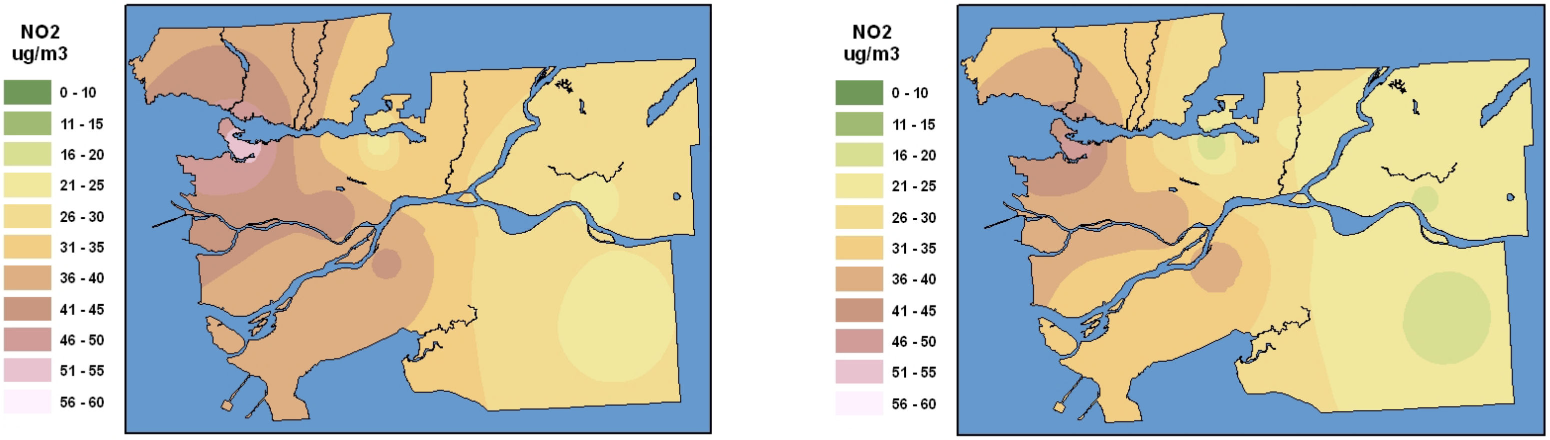
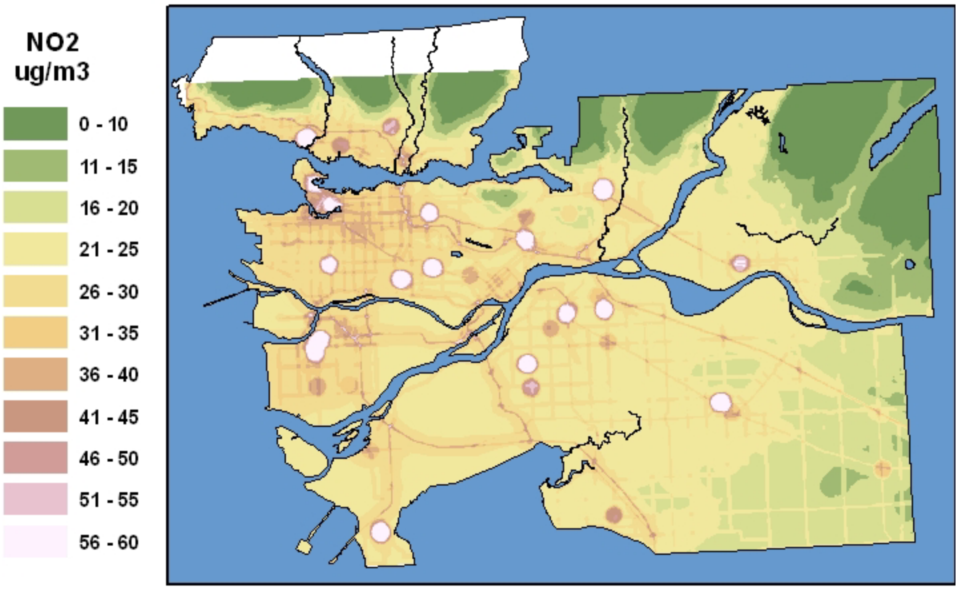


Figure 11. Map of NO_2 levels produced using LUR for the simulation of average annual exposures



3.3.4 Sensitivity to the choice of different indoor/outdoor ratios

The SESM employs indoor/outdoor ratios to account for lower levels of ambient-generated pollution in indoor MEs. Results produced under three scenarios have been used to investigate the effects of using different I/O ratios. In the first scenario, no I/O ratios are employed. These results represent the commonly used approach of using ambient pollution at residential locations to indicate exposure. The second scenario represents a moderate case, where a 'reasonable' range of annual average I/O ratios have been assigned according to building type (described in Section 3.2.7). The third scenario represents a plausible 'worst case' situation, where there is relatively high infiltration of ambient pollution to residences (annual average I/O = 0.75), and relatively low infiltration to commercial buildings (0.35 for most). The use of the worst case scenario should maximize differences between *worker*s and *non-workers*.

The SESM results produced under the three different I/O scenarios with the LUR NO_2 estimate are highly correlated (r = 1), no matter which scenarios are compared for *non-workers* or *workers* (Table 21). This suggests that any differences due to the use of different I/O ratios are systematic throughout the study area and therefore would not affect the overall spatial patterns of exposure. More interestingly, however, are box plots of the differences among scenarios (Figures 12 and 13), which provide a better picture of the effects. The use of I/O ratios, whether under the moderate or worst case scenarios, lowers total exposure estimates by between 5 and 10 *ug*/m^3 at least, and in some cases by as much as 12 to 15 *ug*/m^3, when compared to results produced using no I/O ratios. Also notable is the lack of sensitivity between the moderate and worst case I/O scenarios. The box plots in Figures 18 and 19 show that the differences in the distributions of total exposures between *workers* and *non-workers* when comparing the moderate to the worst case scenarios are in the range of only a few *ug*/m^3 plus or minus. So, while there are substantial differences in the magnitude of total exposures, the extremely high correlations suggest that the change is systematic across all census tracts in the study area.

Table 21. Correlations (r) between *non-worker* and *worker* total exposure distributions for three indoor/outdoor ratio scenarios

10th percentile	**Non-worker**		**Worker**	
Scenario	Moderate I/O	Worst Case I/O	Moderate I/O	Worst Case I/O
No I/O	0.999	0.998	0.998	0.998
Moderate I/O	-	0.998	-	0.996
50th percentile				
Scenario	Moderate I/O	Worst Case I/O	Moderate I/O	Worst Case I/O
No I/O	0.999	0.998	0.998	0.996
Moderate I/O	-	0.998	-	0.996
90th percentile				
Scenario	Moderate I/O	Worst Case I/O	Moderate I/O	Worst Case I/O
No I/O	0.999	0.998	0.997	0.997
Moderate I/O	-	0.998	-	0.994

Figure 12. Box plots of differences in *non-worker* total exposure distributions based on three I/O scenarios (none, moderate, and worst case)

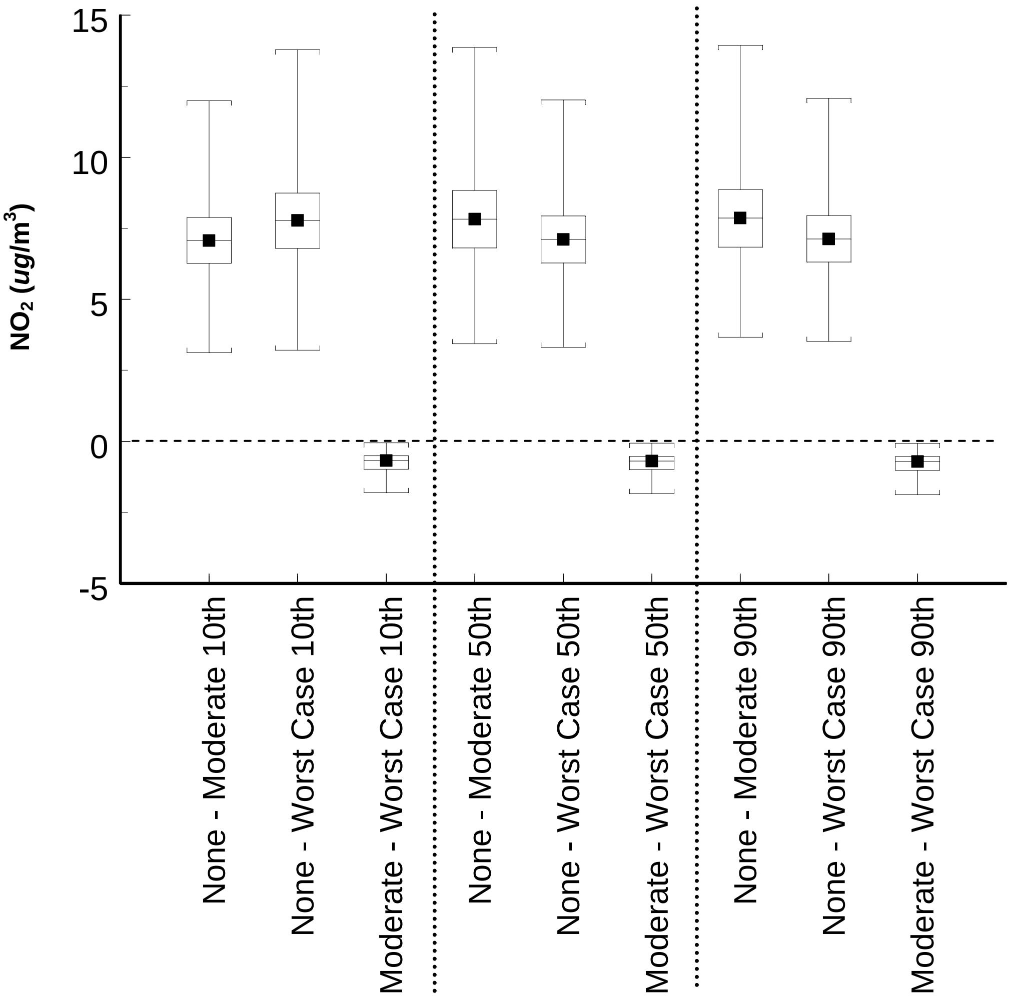
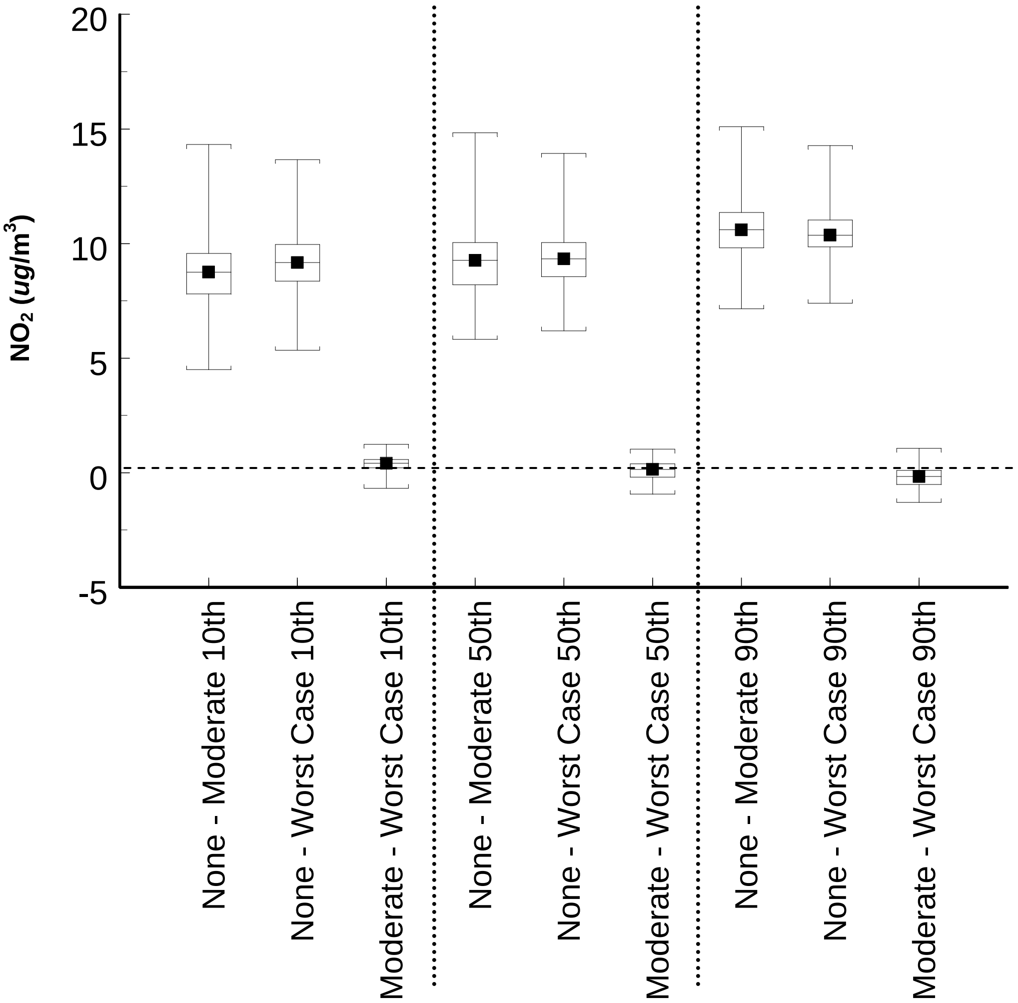


Figure 13. Box plots of differences in *worker* total exposure distributions based on three I/O scenarios (none, moderate, and worst case)



3.4 SESM STRENGTHS AND LIMITATIONS

The SESM was developed for the specific purpose of addressing the following research questions:

- **Is there a spatial pattern in exposure to traffic-related air pollution due to the activities of working and commuting?**

- **Are there spatial differences in exposure to traffic-related air pollution based on gender?**

- **With respect to traffic-related air pollution, how might exposures for working people differ from non-working people, and how might these in turn differ from exposure measures that do not incorporate the mobility patterns of people in a region? If there are differences, what are the implications for population-level epidemiological analyses of air pollution?**

Given the purpose of the SESM, its design and implementation are unique, and present a variety of strengths and limitations with respect to answering the research questions posed and in comparison to other air pollution simulation models.

The most important conceptual strength of the SESM is the explicit incorporation of geographic detail in the model, and the simulation of groups within census tracts. Geographic detail is incorporated through the use of spatial datasets including a road network with information on flow direction, speed limits and connectivity allowing for the identification of shortest routes between home and work census tracts; and geographic coordinates and descriptions of every residential and commercial building in the study area. The SESM is therefore constrained to simulating movements along actual roadways, and using pollution levels at actual building locations in the study area. This approach allows for the maintenance of associations between time spent in each microenvironment, real geographic locations, and the pollution levels estimated at those locations. In contrast, other simulation models use either ambient levels at residential locations as a basis for all microenvironments other than work, or a simplified representations of time spent in transit, such as an average ambient level based on residential and work location. The simulation of groups within census tracts is unique to the SESM and allows for the comparison of variation in exposure between groups at a fine spatial scale. Other simulation models produce exposure distributions for the entire population in a study area, and thus do not support this kind of detailed analysis.

However, the SESM shares a number of limitations with other air pollution exposure simulation models. Time-activity patterns are a key component in exposure simulation models, but little empirical data are available, and it must be assumed that the time-activity patterns used for simulation are truly representative, both geographically and temporally of the population simulated. For the SESM, time-activity patterns from the study area and another area found to be statistically the same were used, but these were collected in 1994/95 and may no longer be fully representative of current time-activity patterns of people in the study area. Constant levels of pollution are assumed within microenvironments for the duration of the time spent there, when in reality there may be fluctuations. How important these fluctuations may be is unknown.

Perhaps the greatest limitation of the SESM (and other air pollution simulation models) is the difficulty in evaluating the simulation results. Only data from personal monitoring are truly useful for evaluating simulation results, and some models have been evaluated in this way (see Section 2.2.5); however, the SESM was designed to investigate differences among neighbourhoods, and so an unreasonably large number of representative personal monitoring information would be required for every neighbourhood. In the absence of evaluation, careful interpretation of the SESM results is required and should be limited in general to comparisons among SESM results for different groups, rather than to other studies or populations.

PAPER 1. VARIABILITY IN ESTIMATED CHRONIC EXPOSURE TO TRAFFIC-RELATED AIR POLLUTION IN COMMUTING POPULATIONS – A SIMULATION

PAPER 1

SPATIAL VARIATIONS IN ESTIMATED CHRONIC EXPOSURE TO TRAFFIC-RELATED AIR POLLUTION IN COMMUTING POPULATIONS – A SIMULATION

Abstract

A spatial exposure simulation model is used to explore variations in the annual total exposure to traffic-related nitrogen dioxide (NO_2) in 382 census tracts in the Greater Vancouver Regional District of British Columbia. Partial exposure associated with each of six microenvironments (*home indoor*, *work indoor*, *other indoor*, *outdoor*, *transit to work* and *transit other*) is also explored. Two sources of variability were observed. First, total exposure ranges from 8 $\mu g/m^3$ to 35 $\mu g/m^3$ of annual average hourly NO_2 and is highest where ambient pollution levels are highest. This reflects the regional gradient of pollution in the study area and the relatively high percentage of time spent at home locations. Second, within census tract variations were observed in the partial exposure associated with time spent at work locations, particularly in suburban areas where longer commuting distances are more prevalent. In these areas, some workers may have exposures 1.3 times higher than other workers residing in the same census tract, due to time spent at work locations. Importantly, exposure associated with the activity of commuting to work was negligible, based on the relatively short amount of time spent in transit compared to other locations, but this may not be the case for other pollutants not studied here. These results represent the first time spatially disaggregated variations in exposure to traffic-related air pollution within a community have been estimated and reported, and the first time local geographic detail in the form of property types and locations, and shortest path routes between residential and work destinations have been incorporated in air pollution exposure simulation modelling.

Introduction

Chronic exposure to traffic-related air pollution is associated with a variety of health impacts in adults, and recent studies show that some residents in a community may be more exposed than others. The objectives of this study are to (1) investigate the magnitude and spatial pattern of variation in chronic (annual average hourly) exposure to nitrogen dioxide (NO_2) for workers in the Greater Vancouver Regional District of British Columbia; and (2) demonstrate how geographic detail can be included in simulating exposure to traffic-related air pollution. Specifically, a spatial exposure simulation model (SESM) which incorporates six microenvironments (*home indoor, work indoor, other indoor, outdoor, transit to work* and *transit other*) is described and used to estimate the distributions of total exposure as well as partial exposure associated with each microenvironment for working people in each of 382 census tracts in the study area. Summary statistics relating to the distributions of the estimated exposures are compared visually through mapping and observed variations are explained through analyses of the model inputs. Nitrogen dioxide was chosen for study as it is recognized to be an indicator of traffic-related air pollution (Brunekreef, Janssen et al. 1997; Roorda-Knape, Janssen et al. 1998; Kramer, Koch et al. 2000; Janssen, van Vliet et al. 2001; Le Tertre, Medina et al. 2002; Gilbert, Woodhouse et al. 2003; Maruo, Ogawa et al. 2003; Kim, Smorodinsky et al. 2004; Smargiassi, Baldwin et al. 2005).

Background

Epidemiological studies specific to traffic-related air pollution show that living in proximity to busy roads increases the risk of health effects in adults. For example, the prevalence of preterm birth in women living within 500m of a freeway in Taiwan was higher than that for women living between 500m and 1,500m away, after controlling for maternal age, season, marital status, education, and infant gender (Yang, Chang et al. 2003). The adjusted odds ratio was reported to be 1.30 (95 % confidence interval 1.03, 1.65). Another study of birth outcomes in Los Angeles, which also controlled for a variety of individual and socioeconomic factors, mapped residential addresses and assigned exposure based on a distance-weighted measure of traffic density. The risk of preterm birth for those in the highest quintile of exposure was 1.08 (95% confidence interval 1.01, 1.15). Risks were higher for women who's last trimester was in the fall or winter, when levels of some traffic-related air pollutants are higher than in other seasons, being 1.39 (95 % confidence interval 1.16, 1.67) for full term but low birth weight; 1.2 (95 % confidence interval 1.03, 1.48) for preterm and low birth weight; and 1.15 (95 % confidence interval 1.05, 1.26) for all preterm births (Wilhelm and Ritz 2003).

Cardiopulmonary mortality was found to be higher in a cohort of adults in the Netherlands based on where they lived in relation to roadways. Subjects were considered to be exposed if they lived within 50m of a major urban road or within 100m of a freeway. The relative risk of death associated with traffic exposure was 1.41 (95 % confidence interval 0.94, 2.12) while the risk of non-cardiopulmonary, non-lung cancer deaths was 1.03 (95% confidence interval 0.54, 1.96) (Hoek, Brunekreef et al. 2002). Socioeconomic variables controlled for included education and occupation at the individual level as well as regional poverty indicators of income distribution, and use of social security. Individual level variables controlled for included smoking, diet, age, height and weight, and alcohol consumption.

In Canada, the rate advancement of mortality due to exposure to traffic was estimated for an adult population in Hamilton, Ontario. Chronic exposure was indicated based on residence within 50m of a major urban roadway or 100m of a freeway, as was done in Hoek, Brunekreef et al. (2002). A rate advancement period of 2.5 years (95% confidence interval 0.2, 4.8) was found to be associated with traffic exposure, and the number of excess deaths was calculated to be 0.4, 1.6, 4.4, and 10.9 per 1,000/year, for populations aged 40, 50, 60 and 70 years, respectively (Finkelstein, Jerrett et al. 2004).

As a final example, a study of healthy Japanese women found higher prevalence rates of respiratory symptoms (persistent cough, asthma, wheeze, and breathlessness) in those who lived in higher pollution areas within 20m of a trunk road compared to those living in lower pollution areas. A larger decrease in forced expiratory volume in 1 second (FEV_1) in the women from high pollution areas compared to those living in lower pollution areas was also observed (Sekine, Shima et al. 2004).

Other sources of variation in exposure may also exist due to systematically higher pollution levels in some types of locations. Monitoring studies of NO_2 provide evidence that consistently higher levels can be observed in urban areas and in transit-related environments. For example, short-term monitoring of NO_2 in Helsinki showed that personal exposures for those participants who lived downtown were 23 percent higher than those for participants living in suburban areas, a difference of approximately 7 $\mu g/m^3$ (Rotko, Kousa et al. 2001). Measured levels of NO_2 in Hong Kong suggest that short-term concentrations are as much as 17 times higher in transit environments (bus, truck, van or car) than ambient outdoor levels (Chau, Tu et al. 2002), and a study conducted in North Carolina focusing on cars specifically found levels of NO_2 inside cars, averaged over the course of several hours driving, to be about 1.4 times higher compared to levels measured concurrently at an ambient monitoring site (Riediker, Williams et al. 2003).

These studies provide evidence that exposure to traffic-related air pollution can affect population health, and that within-community spatial variations exist in exposure. Understanding where, and by how much, people may be exposed to traffic-related air pollution is important in determining the best approaches for reducing exposures. For this study, exposure is considered to be due to inhalation only and equivalent to the level of pollution in the air near a person, not the amount inhaled or absorbed in the body. This research marks the first time such spatially disaggregated estimates of within-community variability in exposure have been produced via simulation modelling and subsequently mapped. It also is the first example of incorporating geographic details into air pollution simulation modelling through the use of a geographic information system and data sets with high spatial resolution.

Methods

The following provides a brief overview of the study area and model used for this research; and is similarly described in Chapters 5 and 6. A detailed description is available in Chapter 3.

Study area. This research was conducted as part of the Border Air Quality Study (BAQS), funded by Health Canada, using data for the Greater Vancouver Regional District (GVRD), located in southern British Columbia on the west coast of Canada. As of 2004, the total population of the GVRD was approximately 2.1 million people (Greater Vancouver Regional District 2006). Nearly 3.5 million trips are made daily in the GVRD, with about 75 percent of these made by private vehicle. On average, 57 percent of commuters travel outside of their home municipality to work, although this percent is lower near the downtown core and higher in the near suburbs (Greater Vancouver Transportation Authority 2004).

Approach. Exposure simulation is used to estimate variability in chronic exposure to NO_2. This approach is based on the indirect method of exposure assessment, in which total exposure is equivalent to a time-weighted average of the concentrations of pollutants in various microenvironments (MEs) encountered throughout a day (Duan 1982; Ott 1985; Klepeis 1999). In theory, given the amount of time a person spends in each ME (i.e., indoor at home, indoor at work, commuting, shopping, and so on) and the associated pollution concentrations, the calculation of total exposure is straightforward, as shown in Ott (1985):

$$E_i = \sum_{j=1}^{J} C_j t_{ij} \tag{1}$$

E_i = the integrated exposure of person i over the time period of interest; C_j = the concentration of pollutant encountered in microenvironment j; t_{ij} = time spent by person i in microenvironment j; J = total number of microenvironments occupied by person i over the time period of interest. Dividing E_i by the total time period provides an estimate of exposure expressed in the units of the pollution estimate (i.e., parts per billion, or micrograms per cubic metre).

In reality, these kinds of data are not readily available for large populations. Instead, simulation is used to estimate a range of *probable* exposures based on randomly sampling from representative time-activity patterns and distributions of possible pollution concentrations (Ozkaynak, Zufall et al. 1999; Kruize, Hanninen et al. 2003). This approach has been used extensively by the US Environmental Protection Agency (US

EPA) in support of setting air quality management objectives and standards (Johnson 1995; McCurdy 1995; Burke, Zufall et al. 2001; U.S. Environmental Protection Agency 2005a; U.S. Environmental Protection Agency 2005b). For this research, the probabilistic indirect approach is employed, based on the following six microenvironment equation:

$$\boldsymbol{E} = [(C_h \text{ x } t_h) + (C_w \text{ x } t_w) + (C_{oi} \text{ x } t_{oi}) + (C_o \text{ x } t_o) + (C_{tw} \text{ x } t_{tw}) + (C_{to} \text{ x } t_{to})] / T \quad (2)$$

$\boldsymbol{E}$ is the total exposure expressed in pollution concentration units; C_h is the pollutant concentration at *home indoor*; C_w is the pollutant concentration at *work indoor*; C_{oi} is the pollutant concentration at *other indoor*; C_o is the pollutant concentration *outdoor*; C_{tw} is the pollutant concentration in *transit to work*; C_{to} is the pollutant concentration in *transit other*; t_{h}, t_{w}, t_{oi}, t_{o}, t_{tw} and t_{to} are the time spent in each respective microenvironment, based on the time-activity pattern; and T equals the duration of time activity pattern. For this study, $\boldsymbol{E}$ is referred to as the total exposure, and the value associated with each microenvironment variable as the partial exposure. As per Equation 2, there will be six partial exposure estimates, one for each microenvironment listed on the right hand side of the equation. For this research, $\boldsymbol{E}$ refers to exposure for a group, i.e., *workers*, rather than to individuals.

Model specification and data. A spatial exposure simulation model (SESM) was developed using a geographic information system (ESRI ArcGIS 9.1$^{©}$) and custom C^{++} programming. The SESM requires 1) time-activity patterns for the population(s) of interest; 2) census-based work flow data indicating home and work census areas; 3) spatially allocated concentrations of the pollutant of interest; 4) spatial locations for residential and commercial buildings; 5) the selection of suitable indoor/outdoor ratios for the pollutant and associated indoor MEs; and 6) a detailed road network.

1) Time-activity pattern data consist of the amount of time spent in different types of locations (but not the actual geographic locations), typically for a 24 hour period. Data from the Canadian Human Activity Pattern Survey study (Leech, Wilby et al. 1997), which also includes the date of survey, age, gender and the number of hours worked, were used as a basis for simulation in the SESM. Time reported as spent in a variety of

locations over 24 hours was aggregated for each time-activity pattern into the six MEs used for this research: *home indoor*, *work indoor*, *other indoor* (including time spent shopping or in restaurants, for example), *outdoor*, transit work, and *transit other* (all non-work transit time). It is important to note here that no statistically significant differences were found in the time spent in each ME between female and male commuters, so these time activity patterns were pooled.

Certain assumptions were made based on the need to use daily time activity patterns to simulate annual exposures, most importantly that workers have the same time-activity pattern on all workdays in the year, and have a random non-work pattern on each weekend day of the year. In order to incorporate weekday/weekend and summer/winter variations in the amount of time spent in different MEs over a year, the time-activity pattern records were grouped into three categories: non-workers summer (320 records), non-workers winter (278 records), and workers (178 records). The numbers of unique time-activity pattern records in each group are comparable to those used in other studies, for example, Kruize, Hanninen et al, (2003) used 434, 322, 83, and 100 time-activity pattern records to represent the total population of urban adults in Helsinki, Basel, Prague, and Athens respectively. In the SESM, the same set of time-activity patterns is used for the simulation in each census tract, thus controlling for variation due to demographic differences.

2) Work flow data for all people aged 15 and over reporting employment, based on a 20 percent sample in each census tract on May 15th, 2001, were purchased from Statistics Canada for the study area. For each census tract, the numbers of workers going from the census tract of their residence to another census tract in the study area for work were used to develop frequency-weighted work pair lists for use in the SESM. Workers who had a place of employment within the census tract of their residence were excluded, under the assumption that commuting distance would be negligible, and that the ambient pollution levels at home and work would be similar. The implemented SESM does not employ specific demographics for each census tract, so the results of the simulations need to be interpreted with caution. The resulting distributions of total and partial exposure estimates do not represent the total population in a census tract, but rather provide an

indication of the probable range of exposure for a population group (i.e., *workers*) living in the census tract.

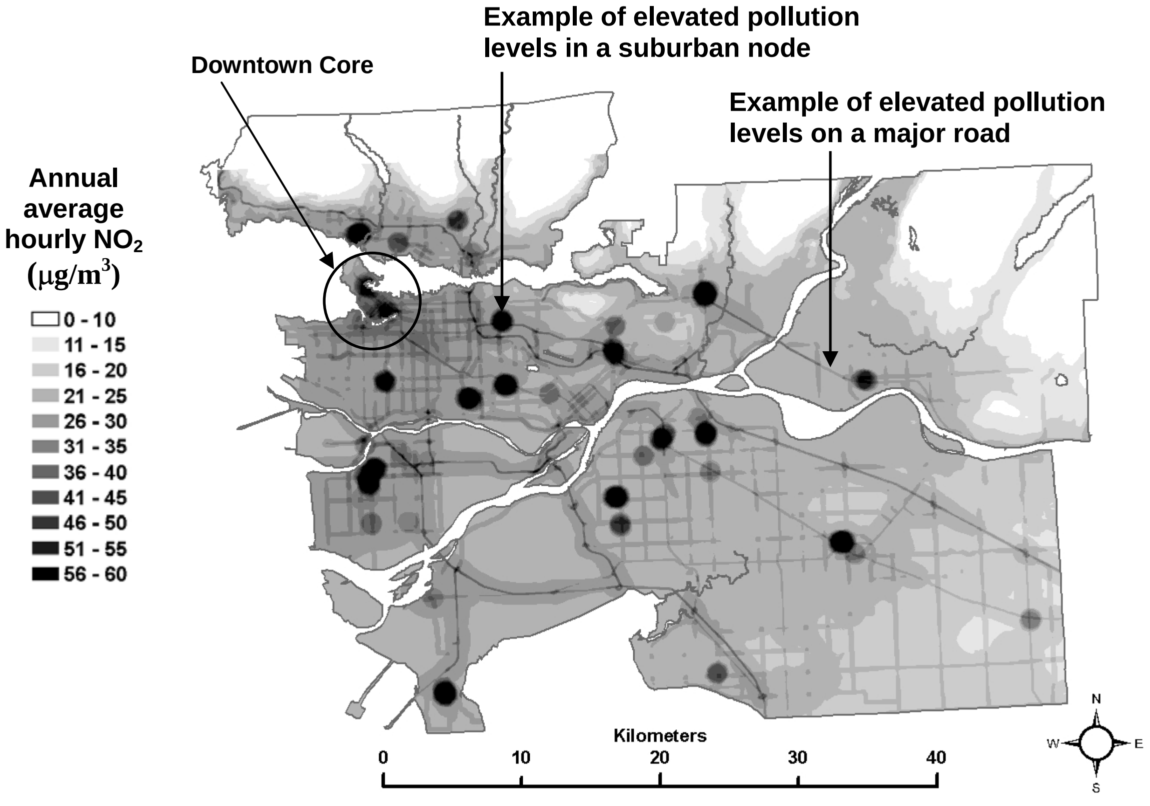
3) For this research, a spatial estimate of annual average NO_2 levels (Figure 1.1), developed by researchers at the University of British Columbia using the land use regression (LUR) method with field monitoring conducted in 2003, was employed and is fully described in (Henderson, Beckerman et al. 2007). Briefly, the method uses linear regression to relate surrounding geographic variables to field measurements of the pollutant of interest, and the resulting model is used to predict pollution levels for every cell in a grid that covers the entire study area. The grid spacing is usually very fine (i.e., 5 metres), and captures pollution gradients associated with roadways and dense urban and commercial development. The most important features of the spatial estimates are that gradients in NO_2 with distance from roadways are captured, as are higher concentrations of NO_2 in commercially developed areas and the regional gradient from the more polluted urban core, to the less polluted rural areas. It is this level of detail in the spatial allocation of NO_2 levels that allows the SESM, as employed in this study, to differentiate among census tracts based on their location in the study area and among transit, work, and home MEs.

4) Additional geographic detail is incorporated in the SESM through the use of spatial property assessment data. Spatial property assessment data were used to identify the geographic location of every property in the study area for which taxes are assessed as well as the primary use of the building on the property. Within each census tract, property locations (either residential or commercial) were used to constrain the SESM to areas where these buildings exist, rather than assuming a homogeneous spatial distribution.

5) Since people spend most of their time indoors and outdoor air pollution does not always fully infiltrate into indoor areas, indoor/outdoor (I/O) ratios are applied to adjust pollution level distributions for the indoor MEs used in the SESM. In the absence of data on long-term I/O ratios for NO_2, fixed I/O ratios are used in the SESM based on the primary building use documented in the spatial property assessment data. Residential buildings were assigned an I/O ratio of 0.70, large office buildings 0.35, manufacturing, industrial, and civic buildings 0.50, and small stores, services, and restaurants 0.70, based

on a review of available indoor/outdoor monitoring studies (for example, (Liao, Bacon-shone et al. 1991; Ekberg 1995; Monn, Brandli et al. 1998; Lee, Chan et al. 1999; Chao and Law 2000; Partti-Pellinen, Marttila et al. 2000; Guo, Lee et al. 2004; Lai, Kendall et al. 2004; Blondeau, Iordache et al. 2005). During the development of the SESM, results were found to be insensitive to the use of different I/O ratios. For example, results were not significantly different under a ‘worst case’ scenario where all commercial buildings were set to 0.35 and all residential buildings to 0.75, when compared to results using the more moderate scenario used in the application of the SESM described here. A comprehensive review of studies including I/O ratios for a variety of locations is available in Chapter 3, Section 3.2.7.

Figure 1.1 Spatial estimate of annual average NO_2 levels



6) A digital road dataset was acquired for the study area from DMTI Spatial Inc. under an academic research agreement. This dataset was converted into a GIS network

using ArcGIS 9.1 ©, thereby allowing for the identification of the shortest route, assuming travel by car, between two points while observing appropriate travel restrictions such as one way streets and speed limits. For every home census tract, the shortest route based on time for every work census tract listed in the work pair file was identified and saved as a unique GIS file using a specific identifier (i.e., originCT10_destinationCT_205) with attributes including total distance and total time associated with the route. In total, 34,782 GIS files were created, representing the shortest routes between each home census tract and all associated work census tracts.

Given the spatial pollution estimate, routes between home and work census tracts, building locations and associated I/O ratios, a geographic information system (GIS) was used to develop distributions of NO_2 for each ME that are unique to each census tract in the study area. For a specific census tract, the distribution of NO_2 levels for the *home indoor* ME is comprised of values extracted from the NO_2 surface for each residential building location (assumed to be the centroid of each property parcel) in the census tract and multiplied by 0.70. For the *work indoor* ME, the pollution distribution is developed the same way, extracting NO_2 levels at commercial building locations within the work census tract and multiplying by I/O ratios of 0.35, 0.50, or 0.70, according to building type. Pollution distributions for the *other indoor* ME are based on sampling the pollution surface at commercial locations within 5 kilometers of the residential census tract and again multiplying by the appropriate I/O ratio. Similarly, for the *outdoor* ME, a regularly spaced grid of sample points is used to extract NO_2 values from the surface within 5 kilometers of the residential census tract. For the *transit other* ME, the road network is used to create sample points for extracting NO_2 values along roadways within 5 kilometers of the residential census tract; these values are then averaged to provide a single *transit other* value for the census tract. A distance of 5 kilometers was chosen to represent the average distance people travel from home on non-work related trips based on a review of studies reporting a typical range between 2 and 8 kilometers (Janelle, Goodchild et al. 1988; Handy 1996; Crane and Crepeau 1998). As well, the SESM results were found to be insensitive to variations in the distance chosen between 2.5 and 7.5 kilometers (Chapter 3). For the *transit to work* ME, distributions are made up of the length-weighted average pollution level along the shortest route between each home-work pair associated with the census tract. No I/O ratios are applied to the *outdoor*, *transit othe*r or *transit to work* MEs. It is important to note here than no indoor sources of NO_2 are included in the simulation. For indoor microenvironments, the distributions of NO_2 levels represent the amount of NO_2 generated by traffic that infiltrates indoors.

Once the pollution concentration distributions for each census tract are developed, random sampling is used to calculate total exposures for a year. Beginning with the first census tract, one worker time-activity pattern is randomly selected to represent all workdays in a year, a work destination is randomly chosen from the frequency-weighted distribution of possible work pairs for that census tract, and pollution concentrations are randomly chosen from the appropriate distributions for the MEs. Total exposure is then calculated as a time-weighted average of these randomly selected pollution levels for each ME, as per Equation (2), as are the partial exposures associated with each ME. For summer weekends (53 days between March 21st and September 21st), a non-worker summer time-activity pattern is randomly selected, the appropriate distributions sampled for pollution levels, and exposure calculated as per Equation (2). This is repeated 53 times, and the average taken to represent the total and partial exposures for summer weekends. A similar procedure is used to calculate the total and partial exposures for winter weekends (53 days between September 22nd and March 20th). Results for workdays and summer and winter weekends are then combined to provide a time-weighted, seasonally adjusted estimate of total exposure to annual average hourly NO_2, as per Equation (3):

$$\boldsymbol{E_y} = [\{(W_a * 0.72) + (W_{ws} * 0.28)\} * 0.50] + [\{(W_a * 0.72) + (W_{ww} * 0.28)\} * 0.50] \quad (3)$$

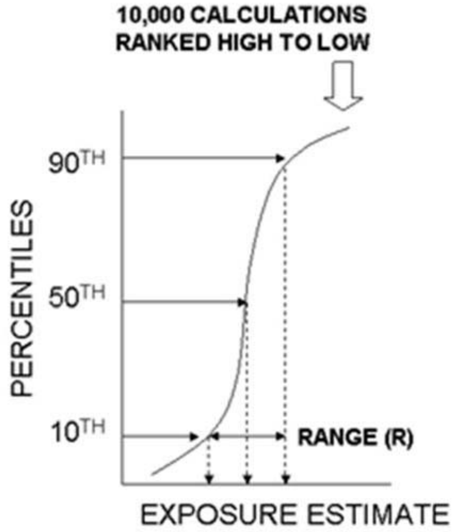
Where $\boldsymbol{E_y}$ is a single calculation of the annual total exposure; W_a is the exposure during weekdays; W_{ws} is the exposure during summer weekends; W_{ww} is the exposure during winter weekends; the weight 0 .72 represents the proportion of working days in summer or winter; the weight 0.28 represents the proportion of weekend days in summer or winter; and the weight 0.50 gives the summer and winter components equal weight in the sum.

This set of calculations is repeated 10,000 times for a census tract, producing distributions of total exposure estimates as well as partial exposure estimates for each ME, with 95% confidence of estimating exposure at any percentile to within +/-1 percentile (Cullen and Frey 1998). This procedure is then repeated for each census tract in the study area, and the resulting distributions can be compared statistically as well as visually through mapping (Figure 1.2). For example, the median (referred to as the 50th percentile values) of the total or partial exposure distributions in each census tract can be mapped to identify spatial patterns. The 10th percentile and 90th percentile values can be similarly mapped and compared to identify the lower and upper ranges of the exposure distributions. The differences between the 10th and 90th percentiles can be calculated and mapped to show where variability within census tracts is highest, i.e., where the range between the 10th and 90th percentile values is largest.

Due to the specification of the SESM as applied here, results must be interpreted with caution, under the following caveats. (1) Results apply to workers commuting by car, not working in the census tract of residence, and who have a fixed place of employment all year. Therefore, the SESM does not reflect exposures of people who work in transit-related occupations (e.g., bus, taxi, truck drivers), who regularly work outdoors, who have a variable work location (e.g., real estate sales, home care workers), or who use other modes of transportation. (2) Results do not reflect real measured personal exposures, but are estimates of the distribution of exposure within census tracts for a class of people (i.e. *workers*). (3) The results reported here are specific to NO_2 and may reflect exposure to other traffic-related air pollutants. The results do not include any indoor sources of NO_2 such as gas stoves or work-related equipment. (4) SESM results are sensitive to the use of different methods for estimating pollution levels, e.g., spatial interpolation based on fixed-site monitoring or LUR (see Chapter 3). Here, the most spatially detailed estimate of NO_2 levels available for the study area was employed. Less detailed estimates, such as might be produced via spatial interpolation from fixed-site air quality monitors, may produce results that differ from those reported here.

Figure 1.2. Distributions and measures used for comparisons

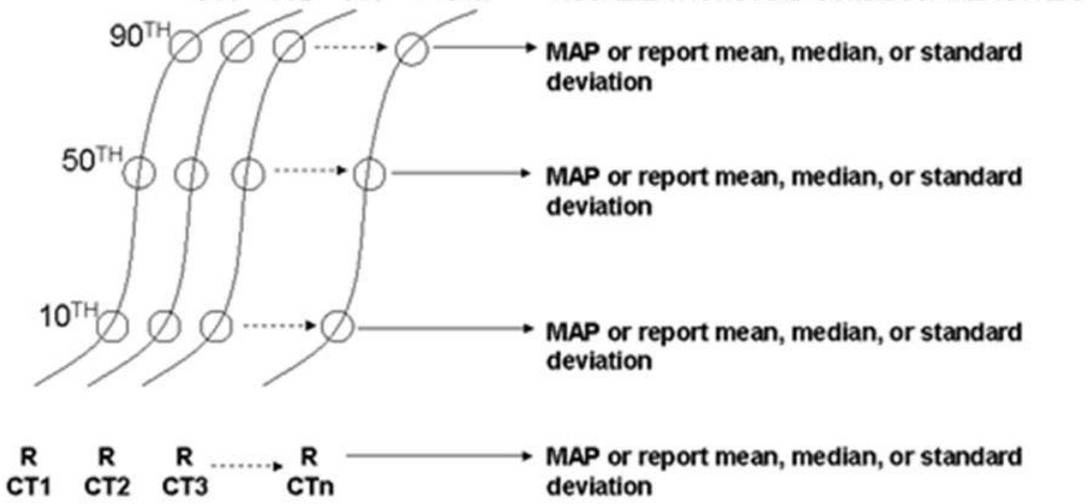
FOR A CENSUS TRACT:



These measures are available for total exposure and partial exposure in each microenvironment

FOR ALL CENSUS TRACTS:

These could be for the total or partial exposure estimates



Results

Looking first at the total exposure estimates, the SESM distributions show that, on average, total exposures range from as high as 35 $\mu g/m^3$ of annual average hourly NO_2 in the downtown core to as low as 8 $\mu g/m^3$ in rural areas. When the 50th percentile values for the distributions in each census tract are mapped (Figure 1.3), this generally decreasing gradient based on distance from the urban core is apparent, as are hot spots of elevated total exposures in suburban areas where nodes of dense commercial development exist.[13] Comparing the map of the 50th percentile of the total exposure estimates (Figure 1.3) to the map of the spatial estimate of NO_2 used in the analysis (Figure 1.1), it appears that median total exposures generally follow the same spatial pattern as the pollution estimate. This pattern remains the same at the 10th and 90th percentile levels of the total exposure distributions (not shown here), although the 10th percentile levels are systematically lower and the 90th percentile levels are systematically higher than the 50th percentile levels shown in Figure 1.3. These results are not unexpected, since it would not be unreasonable to predict higher exposures where pollution is higher, based on the estimated ambient pollution surface. It should also be noted that the magnitude of the total exposure estimates is generally lower than the ambient pollution levels due to the use of indoor/outdoor ratios in the SESM to adjust for the lower levels of ambient pollution infiltrating inside.

Next, looking at the partial exposure estimates associated with each ME, unique spatial patterns are also evident, as shown using quintiles of the median of the exposure distributions in each census tract in Figures 1.4 through 1.9. The spatial pattern of the median partial exposure associated with the *home indoor* ME , shown in Figure 1.4, closely resembles the pollution estimate (Figure 1.1), with high median partial exposures corresponding to high pollution areas. Since the SESM calculates partial exposures for the *home indoor* ME based on the pollution level at residences within a given census tract, this pattern is not unexpected.

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[13] Note: For maps presenting SESM results, areas where there is less than one residential building per 500 meters are not shown. This is done to avoid giving visual importance to unpopulated portions of large rural census tracts.

Figure 1.3. Map of the median (50th percentile) total exposure distributions

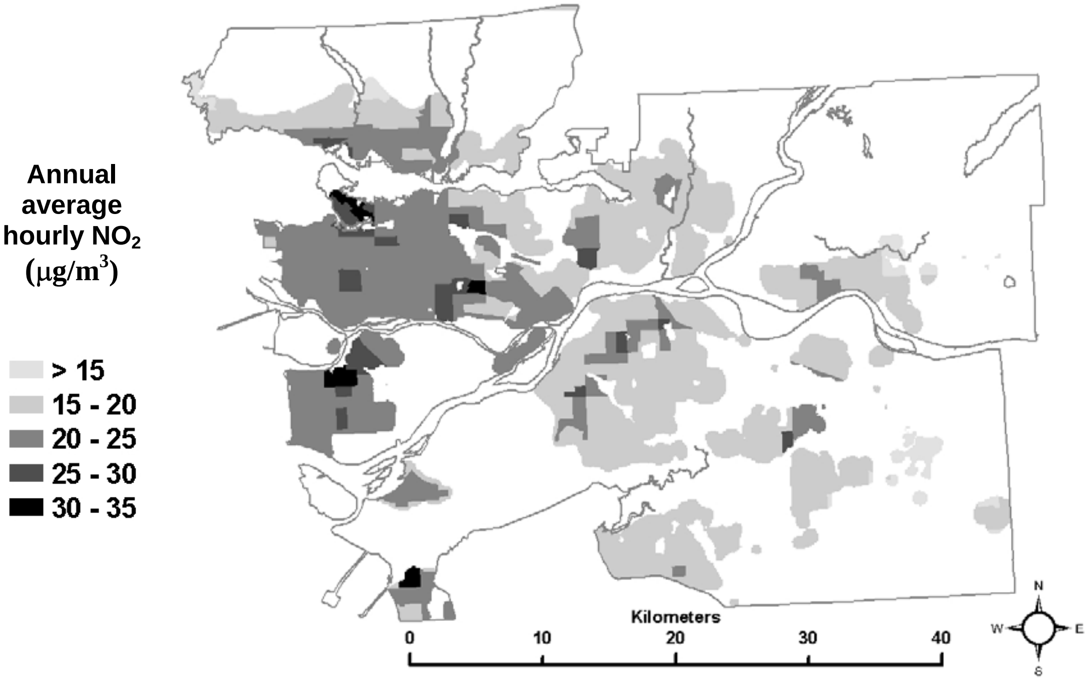


Figure 1.5 shows quintiles of the median partial exposure associated with the *work indoor* ME. In this case, median partial exposure is highest in the urban core and surrounding densely developed areas. In the SESM, partial exposure associated with the *work indoor* ME is based on NO_2 levels in the census tracts where residents report working, according to the Statistics Canada work flow data. Higher median exposure estimates in a census tract therefore suggest that most of the workers living there are working in other census tracts where pollution levels are similar to each other and relatively high. It seems reasonable to suggest that the pattern of higher median partial exposures for workers living in and around the urban core associated with the *work indoor* ME is due to a preponderance of work locations within the same general area, indicating relatively short commute distances to work destinations within the more highly polluted urban core and nearby areas. This interpretation is supported by local planning documents, that report that the municipalities within the area indicated in Figure 1.5 have the lowest percentages of people who go to other municipalities to work (Greater Vancouver Transportation Authority 2004).

Quintiles of the median partial exposure associated with the *other indoor*, *outdoor*, and *transit other* MEs are shown in Figures 1.6, 1.7 and 1.8. In the SESM, these partial exposures are based on pollution levels at commercial locations, outdoors, and along roads within 5 km of each individual census tract, and so reflect the larger scale regional variation in NO_2 levels: higher in the urban core and nearby developed areas and decreasing toward rural areas.

The spatial pattern in the median of the partial exposure distributions associated with the *transit to work* ME is shown in Figure 1.9. Here, census tracts with the highest quintile of median partial exposure are located in suburban and rural areas. For this ME, partial exposures in a particular census tract are based on the length-weighted average NO_2 level along the shortest routes between that census tract and all other census tracts where people report working. In addition, the frequency with which each work census tract is reported as a destination is incorporated in the SESM calculations, so the distribution of partial exposures is most influenced by the NO_2 levels along the routes traveled to the most-often reported work census tracts. The spatial pattern seen here is consistent with longer commutes from suburban and rural areas on highways and major roads where NO_2 levels are elevated.

Figure 1.4. Map of the median (50th percentile) partial exposure distributions associated with the *home indoor* microenvironment

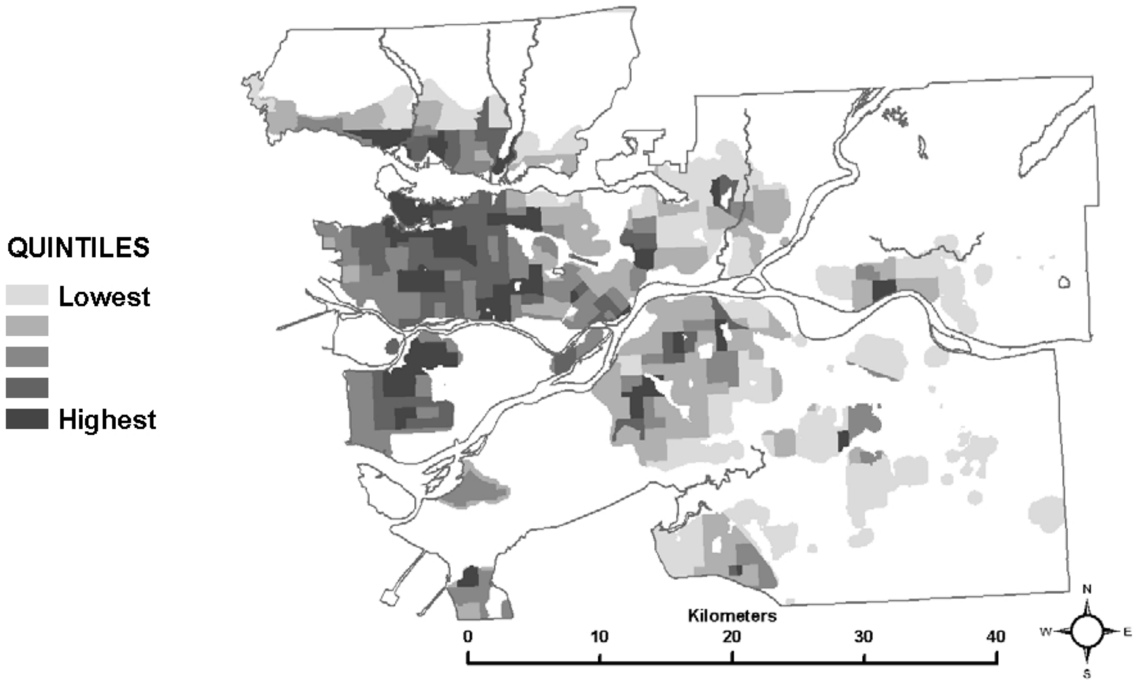
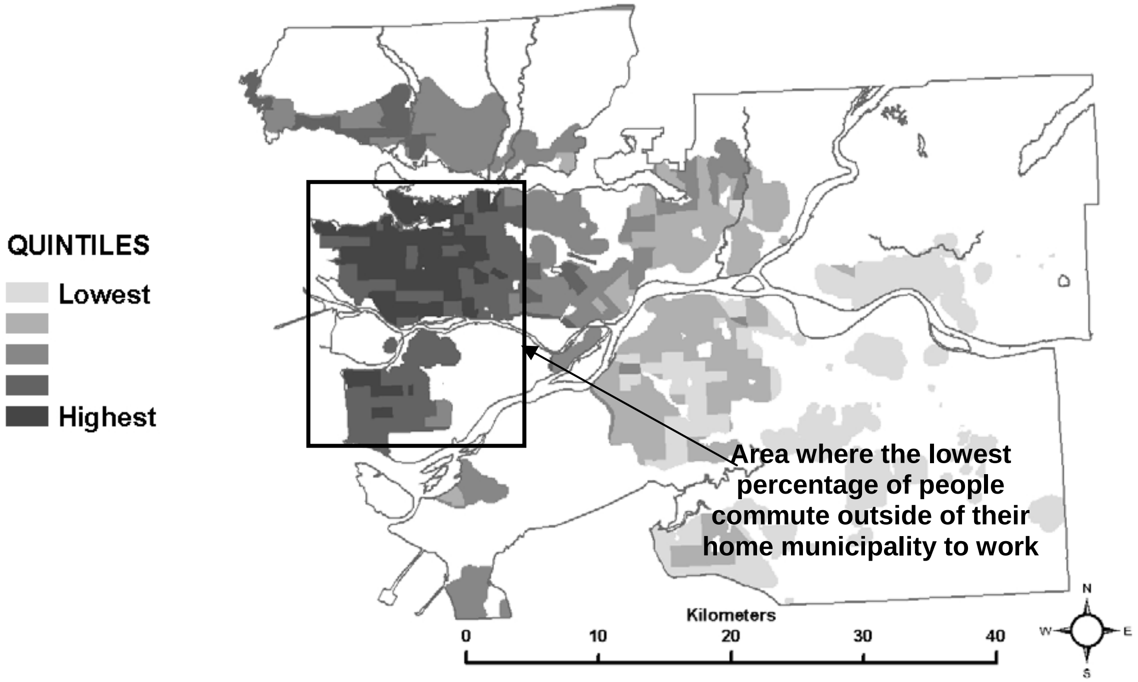


Figure 1.5. Map of the median (50th percentile) partial exposure distributions associated with the *work indoor* microenvironment



Area where the lowest percentage of people commute outside of their home municipality to work

Figure 1.6. Map of the median (50th percentile) partial exposure distributions associated with the *other indoor* microenvironment

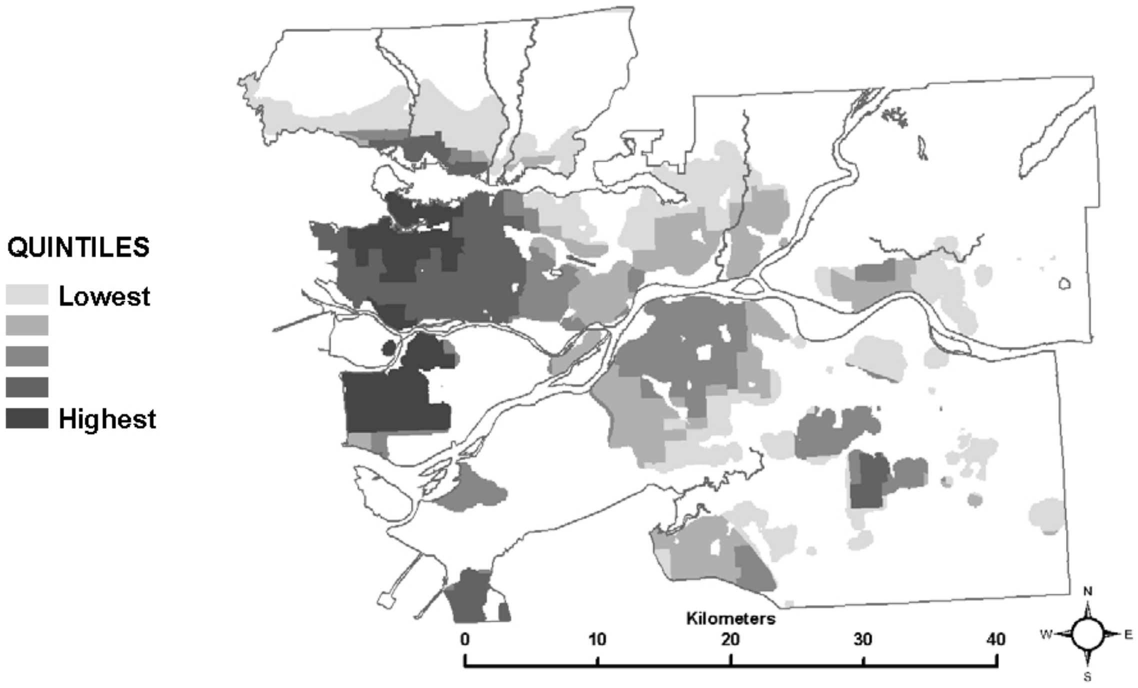


Figure 1.7 Map of the median (50th percentile) partial exposure distributions associated with the *outdoor* microenvironment

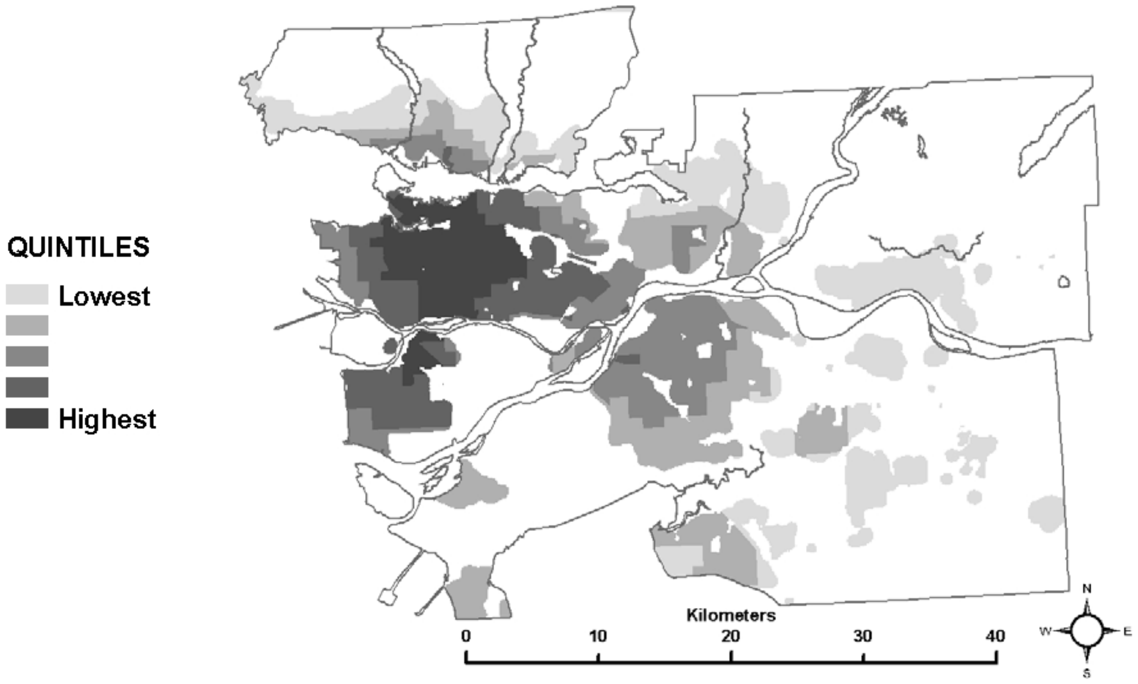


Figure 1.8 Map of the median (50th percentile) partial exposure distributions associated with the *transit other* microenvironment

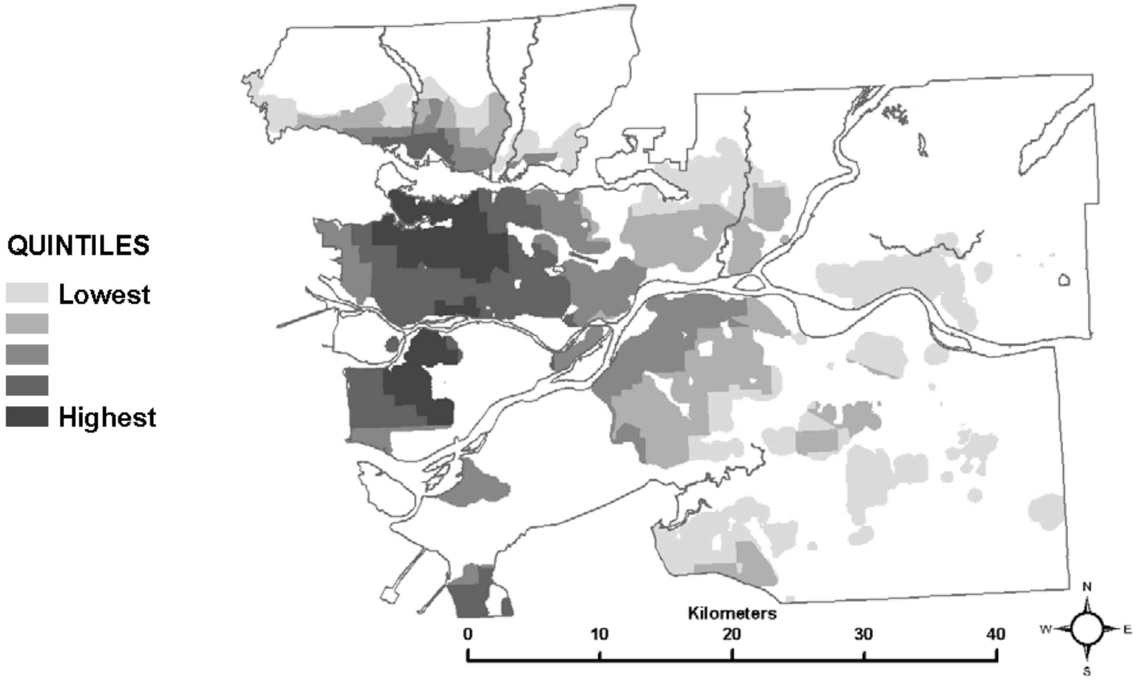
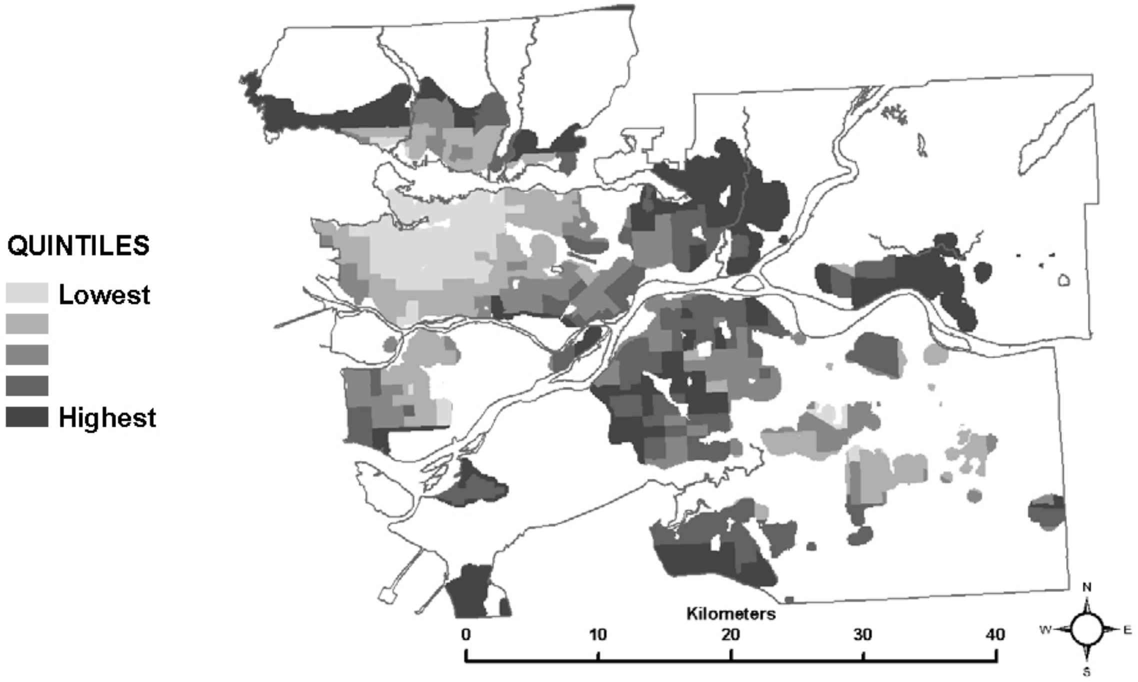
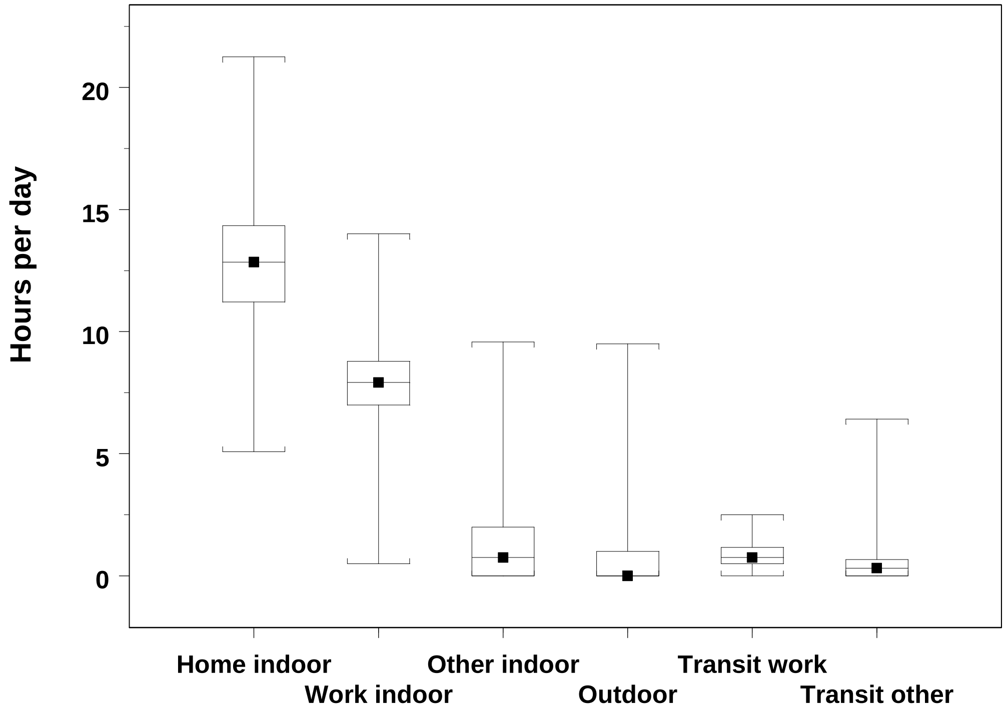


Figure 1.9. Map of the median (50th percentile) partial exposure distributions associated with the *transit to work* microenvironment



While the medians of the partial exposures associated with the six MEs included in the SESM have distinct patterns, each partial exposure has a different level of influence on the pattern of total exposures (Figure 1.3). As noted previously, the spatial pattern of median total exposure appears most similar to the spatial pattern shown for the median partial exposure for the *home indoor* ME (Figure 1.4), which in turn most closely follows the ambient pollution estimate (Figure 1.1). This is due to the typically large amount of time spent in the *home indoor* ME compared to others. Box plots of the amount of time spent in each ME for all of the time-activity patterns used in the SESM are shown in Figure 1.10. Each box plot shows the minimum and maximum (the lowest and highest horizontal line), and the 25th percentile, median and 75th percentile level (bottom, middle, and top of box) of time spent in the associated ME. Within a 24 hour period, the amount of time spent in the *home indoor* ME is the highest, with a median of about 13 hours, followed by the *work indoor* ME, with a median of about 8 hours. Median time spent in each remaining ME is less than one hour each. The SESM produces a time-weighted, seasonally adjusted average of total exposure based on the input set of 24 hour time-activity patterns, so even though pollution levels may be high in some MEs (i.e., *transit to work*), the relatively small amount of time spent in these MEs in any 24 hour period reduces the importance of these exposures in terms of the annual average hourly total exposure.

Figure 1.10. Box plot showing the number of hours per day spent in each microenvironment



The previous results have focused on the 50th percentile levels of the distributions for total and partial exposures in the study area, and regional gradients in exposure are evident; however, additional detail can be found by comparing other points of the distributions produced for each census tract. Table 1.1 provides a summary of the mean, median, and standard deviations at the 10th, 50th, and 90th percentiles for the total and partial exposure distributions produced for each of the 382 census tracts in the study area. Also reported is the range between the mean of the 10th and 90th percentiles for all census tracts. Looking down the columns in Table 1.1 for the 10th, 50th, and 90th percentiles, the relative contribution of each ME to the total exposure is apparent, and is associated with the time spent in each ME, as discussed earlier. Of particular interest to note is the relatively negligible partial exposure associated with the *transit to work* ME. Also of interest are the ranges associated with each ME, shown in the last column of Table 1.1. These are produced by subtracting the mean of the 10th percentile values for all census tracts from the mean of the 90th percentile values for all census tracts, and indicate the variability of exposure within census tracts as opposed to between census tracts. The mean range for total exposure is approximately 5 μg/m^3, while the mean ranges associated with each ME are 1 μg/m^3 or less, with the exception of the *work indoor* ME, shown in bold. The mean range for the *work indoor* ME is almost 7 μg/m^3, which is far higher than that of any other ME. More detailed discussion of the very low partial exposure estimates associated with the *transit to work* ME , and the very high range in partial exposure estimates associated with the *work indoor* ME is provided next.

Table 1.1. Descriptive statistics of the exposure estimate distributions in 382 census tracts

		Annual average hourly NO_2 (μg/m^3)			
Exposure estimates	**Descriptive statistics**	**10th percentile (n = 382)**	**50th percentile (n = 382)**	**90th percentile (n = 382)**	**Range (10th – 90th)**
Total exposure	mean	18.87	20.96	23.89	5.02
	median	18.61	20.62	23.58	
	st. deviation	3.24	3.48	3.49	
Home indoor	mean	14.88	15.39	15.89	1.01
	median	14.48	15.00	15.47	
	st. deviation	3.50	3.63	3.76	
Work indoor	mean	3.79	6.40	10.60	**6.81**
	median	3.72	6.39	10.52	
	st. deviation	0.37	0.64	0.76	
Other indoor	mean	1.76	2.09	2.44	0.68
	median	1.67	1.99	2.35	
	st. deviation	0.43	0.50	0.58	
Outdoor	mean	2.36	2.78	3.24	0.88
	median	2.39	2.82	3.28	
	st. deviation	0.36	0.42	0.49	
Transit to work	mean	0.19	0.54	1.06	0.87
	median	0.16	0.52	0.99	
	st. deviation	0.15	0.24	0.36	
Transit other	mean	1.32	1.53	1.76	0.44
	median	1.33	1.54	1.77	
	st. deviation	0.18	0.21	0.25	

Although the amount of time spent in the *transit to work* ME was known to be low, it was expected that the use of a spatial estimate of NO_2 that captured elevated concentrations along roadways and the use of GIS to identify routes along those roadways would act to give additional importance to the contribution of this ME to total exposure. This clearly was not the case, and may be due to some routes (or portions of routes) following local roads where levels are not particularly elevated in the pollution estimate. The summary of LUR NO_2 levels associated with residential locations and different road classes in the study area, provided in Table 1.2, supports this interpretation. The mean annual average hourly NO_2 level at each of the residential locations in the study area is 28 $\mu g/m^3$, compared to 34 $\mu g/m^3$ on highways, freeways and arterial roads, and 26 $\mu g/m^3$ or less on all other classes of roads. Also notable is the relatively low percentage of highways, freeways and arterial roads (17 %) in the study area compared to other road classes with lower NO_2 levels. Therefore, only long commutes on major roads will have relatively high partial exposures, and are not frequent enough in the study area to have a significant influence on total exposure. Another contributing factor could be the use of shortest paths in the model, solved to optimize total time based on speed limits, thus representing the best case scenario where there is no congestion or stop and go traffic and so may not be completely realistic.

Table 1.2. Estimated pollution levels associated with residential locations and different road classes

Location		**Annual average hourly NO_2 ($\mu g/m^3$) based on the LUR estimate**			
	percent	**min**	**max**	**mean**	**sd**
Residences	100	6	56	28	8
freeway/highway/arterial/ramp	17	15	56	34	9
collector	17	2	56	26	8
local/strata/lane	66	2	56	26	8
rural	0.2	11	39	19	5

A more detailed look at the *work indoor* ME results provides additional information that aids in the explanation of the high range observed in the partial exposure associated with this ME. The SESM results suggest workers in the top 10 percent of the exposure distribution (90th percentile) could be exposed to, on average 6.8 $\mu g/m^3$ more annual average NO_2 than workers in the bottom 10 percent of exposure distribution (10th percentile) within the same census tract. The mean ratio of the 90th percentile to the 10th percentile for all census tracts is 2.8, indicating that on average, workers in the top 10 percent could have exposures 2.8 times greater than workers in the bottom 10 percent of exposures who live in the same census tract. The effect of this variation on the total exposure is diminished by the influence of time spent in other MEs, producing a mean ratio of the 90th percentile to 10th percentile total exposure of 1.3.

In the SESM, distributions of partial exposure associated with the *work indoor* ME are based on the work flow frequency data specific to each census tract in conjunction with the time-activity pattern data. A large range in a census tract for the partial exposure distribution for this ME suggest that workers go to a set of work census tracts with diverse pollution levels, which should be true of suburban and rural census tracts. Conversely, a low range suggests that most workers go to census tracts which are all relatively similar in terms of pollution levels, and this is likely true of census tracts in and near densely developed areas such as the urban core. A map of the 10th – 90th percentile range for the partial exposure distributions associated with the *work indoor* ME is shown in Figure 1.11. Larger ranges in the partial exposures associated with the *work indoor* ME are in fact more frequent in the suburban areas, and less frequent near the urban core. This interpretation is also supported by the proportional work flows shown in Figures 1.12(a) and (b), for example. Figure 1.12(a) shows that in a census tract with a low range in partial exposure, the majority of workers are going most often to census tracts relatively close to the home census tract. Figure 1.12(b) shows that in a census tract with a high range in partial exposure, workers visit a number of census tracts at varying distances from the home census tract in relatively equal proportions, where pollution levels may vary widely.

Figure 1.11. Variability in partial exposures associated with the *work indoor* microenvironment (range from 10th to 90th percentile)

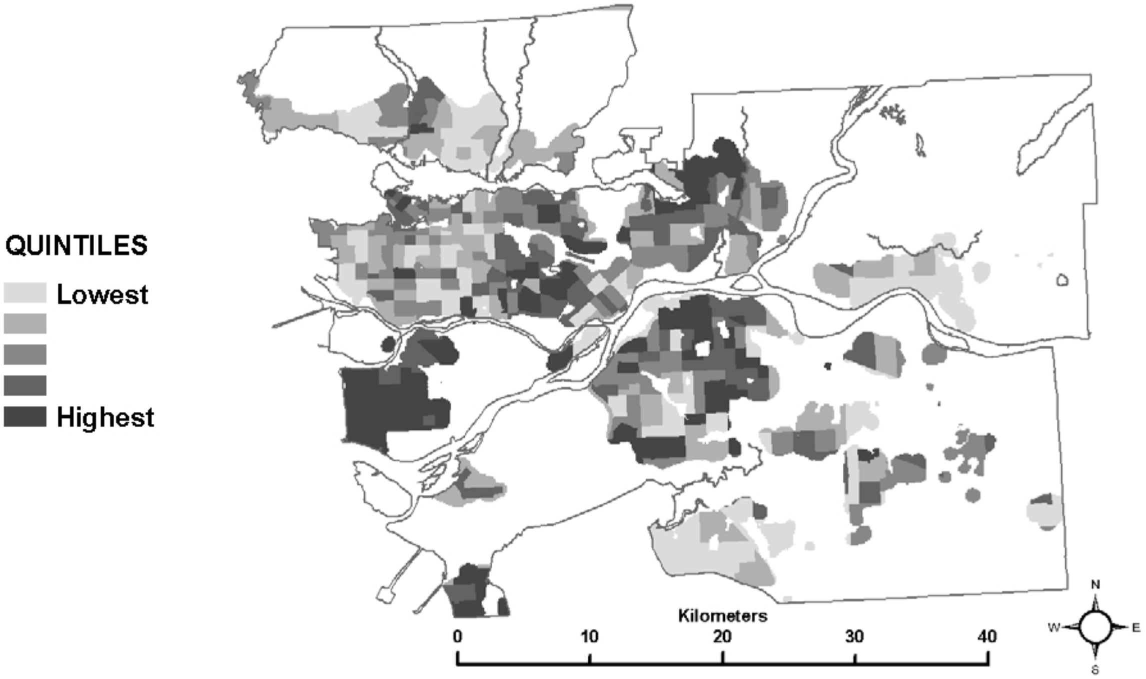
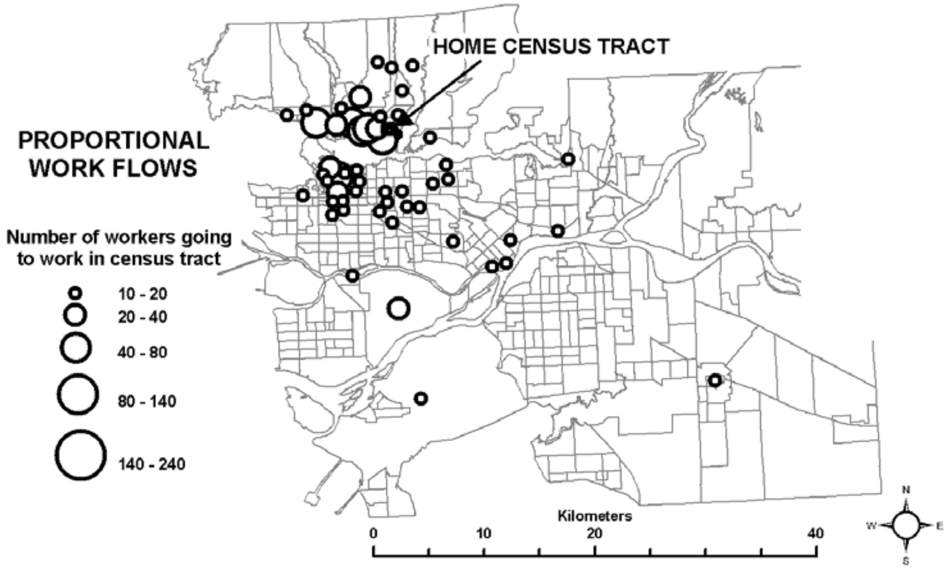
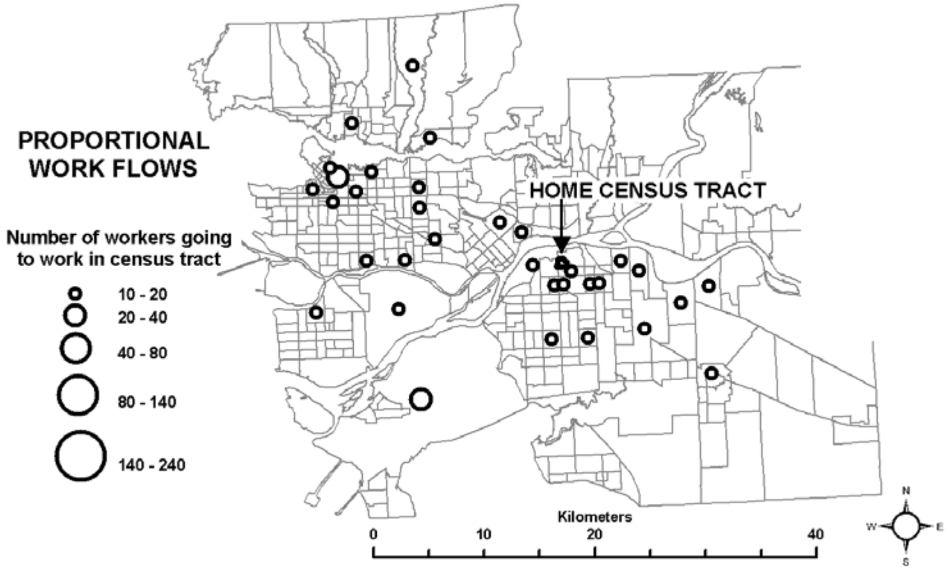


Figure 1.12. An example of work flow patterns for selected census tracts with a low range and a high range in partial exposures associated with the *work indoor* microenvironment



(a) census tract with a low range



(b) census tract with a high range

Discussion

A spatial exposure simulation model was described and used to estimate within-community variability in exposure to annual average hourly NO_2 (μg/m^3). The results produced show that while time spent in the *home indoor* ME contributes most to between census tract variation in exposures, time spent in the *work indoor* ME contributes most to within census tract variation, and time spent in transit makes a negligible contribution at best.

The simulation results suggest that workers in the study area may experience an annual average exposure to ambient NO_2 ranging from as low as 8 μg/m^3 to as high as 35 μg/m^3, with the average of the mean total exposure across all census tracts being 21 μg/m^3 (SD 3.5). The level of exposure is closely associated with the pollution level in the census tract of residence, which ranges from 8 μg/m^3 to 56 μg/m^3 (mean = 30 μg/m^3, SD 7.5 μg/m^3) annual average hourly NO_2, based on an area weighted average of the LUR values within each census tract. These results appear to be reasonable in comparison with existing short-term personal monitoring studies (although none were conducted in the study area), and are most similar to results from a study of adults from eight cities in Switzerland. In that study, the average total personal exposure to NO_2 in a sample of adults in eight cities in Switzerland was 27 μg/m^3 compared to an average ambient level of 31 μg/m^3, with approximately 7 μg/m^3 of personal exposure identified as being due to NO_2 originating indoors from gas cooking and smoking (Monn, Brandli et al. 1998).

Table 1.3 provides a summary of additional personal monitoring studies of NO_2. While the average of the SESM results in this paper is generally within the ranges shown, direct comparisons are difficult to make due to the inclusion of indoor sources at home and at work in the personal monitoring results. An important caveat must also be included here: the SESM produces an estimate of annual average hourly exposure, whereas the personal monitoring studies report the average hourly exposure for a single day. To evaluate the SESM results, personal monitoring for representative samples of commuters for each census tract would be required for a period of time that would adequately represent an entire year.

Table 1.3. Summary of NO_2 levels measured in personal monitoring studies

Author	Location	Number of study subjects	Total personal exposure to NO_2 (*u*g/m^3)	Ambient NO_2 (*u*g/m^3)	Study group
(Quackenboss, Spengler et al. 1986)	Wisconsin	350	16 - 44	12 - 17	general population
(Spengler, Schwab et al. 1994)	Los Angeles basin	682	64	70	general population 50th percentile
(Levy 1998)	International (18 cities)	14 - 117	22 - 103	24 - 105	adults
(Monn, Brandli et al. 1998)	Switzerland	500	27	31	working adults
(Rotko, Kousa et al. 2001)	Helsinki	176	25	24	adults
(Kousa, Monn et al. 2001)	Basel, Prague	85	30 - 43	36 - 61	urban adults
(Lai, Kendall et al. 2004)	Oxford, UK	50	29	27	adults
(Nerriere, Zmirou-Navier et al. 2005)	France	~ 250	15 - 42	17 - 75	adults and children

The simulation results also show that within census tract variability is due to different work flow patterns among census tracts. The partial exposures at the 90th percentile for *work indoor* (i.e., in the top ten percent of workers) on average can be 6.8

μg/m^3 higher than the partial exposure at the 10th percentile (i.e., in the bottom ten percent of workers) in the same census tract, which translates into a partial exposure 2.8 times higher, and a total exposure 1.3 times higher. The largest variability is generally found in suburban areas where workers travel to a large number of different work destinations. This is a new insight, in terms of the magnitude of variability in exposure, and is made possible by the SESM used for this study. The authors are unaware of any existing studies specifically comparing worker's exposure to air pollution depending on the location of their residence within a community, either through personal monitoring or exposure simulation.

Time spent commuting to work contributed a negligible amount to estimated exposure. This was somewhat unexpected; however, some empirical evidence exists that supports the conclusion that exposures encountered while in transit do not contribute significantly to total exposure when measured for a full 24 hour period or longer, or when there are other sources of the pollutant that are not associated specifically with traffic, as is the case for NO_2 (i.e., gas stoves and heaters). In Oxford UK, a study using the EXPOLIS monitoring methodology found personal 24 hour exposures to NO_2 (mean 24.5 μg/m^3 , SD 1.7) were similar to levels measured indoors at residences with gas stoves (mean 22.3 μg/m^3; SD 1.8) and indoors at workplaces (mean 29.6 μg/m^3, 1.5) (Lai, Kendall et al. 2004), which could reasonably be interpreted as an indication of no other significant sources of exposure other than indoor at home and work. In Helsinki, as part of the EXPOLIS study, Rotko, Kousa et al (2001) found no association between time spent in commute (categorized as less than or more than 1 hour) and personal 24 hour NO_2 exposure, even in the absence of gas stoves (only 9 of the 176 residences monitored used gas stoves). Similarly, a commute time greater than 1 hour was not significantly associated with NO_2 exposure for a combined group of EXPOLIS subjects from Helsinki, Basle, and Prague (Kousa, Monn et al. 2001). Conversely, in a personal monitoring study of NO_2 exposure conducted in 18 cities around the world, commute time exceeding one hour was found to be significantly correlated with total personal exposure (Levy 1998). In Levy (1998), the mean personal NO_2 exposure for people with a commute longer than 1 hour was 60 μg/m^3, compared to 56 μg/m^3 for people with commutes of less than 1 hour, a relatively small difference in terms of the total exposure. So, for people employed in non-transit related occupations, for which typical round-trip commutes are under 1 hour, it seems reasonable to conclude that the simulated results for partial exposure associated with the *transit to work* ME presented here would be unlikely to be significantly higher even if improvements to the SESM could be incorporated. A final note of caution is warranted here. The lack of importance of the *transit to work* ME to total exposure may be reasonable for NO_2, but in the case of other pollutants, such as some VOCs, where there may be few indoor sources and extremely elevated levels on roadways, exposure while commuting may be much more important.

Although the simulation results represent exposure estimates rather than actual exposures, the new, explicitly spatial perspective represented here has utility for informing targeted air quality policies meant to reduce exposures and environmental inequity in terms of exposure to traffic-related air pollution. All residents of an area would benefit from an overall decrease in traffic-related air pollution, such as might be achieved by further reducing tail-pipe emissions or switching to alternative fuels. If, however, the goal of policy is to reduce exposures for those most affected, either the spatial pattern of pollution or the spatial patterns of where people live and where they commute must change. No doubt changes in one pattern will be caused or influenced by changes in the others. The SESM has significant future potential as a policy evaluation tool, given input data that reflect changes in pollution levels or work flow patterns due to traffic demand management and land use development policy.

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PAPER 2. GENDER-BASED DIFFERENCES IN ESTIMATES OF COMMUTERS' EXPOSURE TO TRAFFIC-RELATED AIR POLLUTION – A SIMULATION STUDY

PAPER 2

GENDER-BASED DIFFERENCES IN ESTIMATES OF COMMUTERS' EXPOSURE TO TRAFFIC-RELATED AIR POLLUTION – A SIMULATION STUDY

Abstract

A unique spatial exposure simulation model was used to explore variability in exposure to traffic-related air pollution (nitrogen dioxide) in the Greater Vancouver Regional District of British Columbia, Canada. The model produces distributions of estimated exposures to annual average hourly nitrogen dioxide in six microenvironments (*home indoor*, *work indoor*, *other indoor*, *outdoor*, *transit to work* and *transit other*) for female and male commuters, using randomly sampled time-activity patterns from the Canadian Human Activity Pattern Survey and work flow data from Statistics Canada, in each of 382 census tracts. No statistically significant differences in the distributions of total exposure were found between female and male commuters, although there were small but observable differences between female and male commuters at the upper end of the partial exposure distribution associated specifically with the *work indoor* microenvironment. These differences were highest in suburban areas (up to 3 $\mu g/m^3$ of annual hourly average NO_2 higher for female commuters), illustrating the impact of systematically different work locations for female compared to male commuters in these same census tracts. The SESM results suggest that female and male commuters could be treated as the same population in large epidemiological studies of traffic-related air pollution, as far as commuting behaviour and work locations affect total exposure. These results may differ for other pollutants, particularly those exhibiting spatial patterns unlike that observed for NO_2, such as ground-level ozone.

Introduction

An extensive body of literature exists that documents differences in commute patterns between working females and males, particularly in terms of typical commute distance, but also in terms of typical work locations (i.e., in the central business district or in other regional employment centres). Given the spatial component of interurban commuting differences, this paper explores how these differences might affect exposure to traffic-related air pollution for female and male commuters. Just as commuting patterns vary spatially within a region, so too can traffic-related air pollution, and if female and male commuters are systematically exposed to pollution in different ways over space and time, there may be observable gender differences in exposure to traffic-related air pollution.

The specific objective of this study is to investigate the magnitude and spatial pattern of variability in estimates of chronic (annual average hourly) exposure to nitrogen dioxide (NO_2) between female and male commuters in the Greater Vancouver Regional District of British Columbia. A spatial exposure simulation model is employed which incorporates six microenvironments (*home indoor, work indoor, other indoor, outdoor, transit to work* and *transit other*) to estimate the distributions of total exposure as well as partial exposure associated with each microenvironment (ME) for working females and males in each of 382 census tracts in the study area. Summary statistics relating to the distributions of estimated exposures are compared visually through box plots and mapping, and tested for statistically significant differences using the standard t-test. Observed variations are explained through analyses of the model inputs.

Background

Decades of research exist on commuting to and from work and what these patterns suggest about urban form and social structure. Of particular interest is the consistent finding in many urban areas that women tend to work closer to home than do men. In a comparison of commute times among the major metropolitan areas in the US, none were found where women report longer commute times than men, with the average difference nationally being 3.5 minutes, based on average commute times of 25.4 minutes (one way) for men and 21.9 minutes for women. Within two dozen of the metropolitan areas, average differences in one way commute times were larger than 6 minutes (Wyly 1998). While the use of self-reported commute time introduces reporting biases and may be more related to mode of transport than actual distance traveled, in a comprehensive review of the literature, Blumen (1994) finds general concurrence that females commute shorter distances in general, and that differences in commute distance are larger than differences in commute time between men and women (Blumen 1994).

Various theoretical approaches inform research on what influences commuting patterns in general, such as a spatial mismatch between housing and employment opportunities (Kain 1968; McLafferty and Preston 1996); rational economic decisions made by workers to optimize the tradeoffs between wages, housing costs, and transport costs (Rouwendal and Nijkamp 2004; Shearmur 2006); and gender specific roles in terms of household duties and economic sectors that constrain women from working at distant locations (Hanson and Pratt 1995). Regardless of theoretical approach, there is little doubt that commuting patterns differ within metropolitan areas and depend in part on the relationships between residential and work locations in urban and suburban areas and gender.

Understanding gender-based differences in exposure to traffic-related air pollution is important because of potential inequalities in health impacts related to exposure. Traffic-related emissions contain a mix of air pollutants that can be inhaled, including fine particulate matter, sulfur oxides, volatile organic compounds, nitrogen oxides, and carbon monoxide. In addition, in the presence of sunlight, volatile organic compounds and nitrogen oxides interact to form ozone. Long-term exposure to traffic-related air pollution is associated with a range of health impacts, including impaired lung function in people with bronchitis, and increased total and cardiopulmonary mortality (Brunekreef and Holgate 2002; HEI 2004). These effects are especially associated with fine particulates, the sources of which include fossil fuel combustion. Differences, if found, in exposure estimates between female and male commuters could highlight important areas for exposure reduction policies addressing gender equity, and could be of particular importance in addressing gender specific health effects.

Methods

The following provides a brief overview of the study area and model used for this research; and is similarly described in Chapters 4 and 6. A detailed description is available in Chapter 3.

Study area. This research was conducted as part of the Border Air Quality Study (BAQS), funded by Health Canada via the BC Centre for Disease Control, using data for the Greater Vancouver Regional District (GVRD), located in southern British Columbia on the west coast of Canada. As of 2004, the total population of the GVRD was approximately 2.1 million people(Greater Vancouver Regional District 2006). Nearly 3.5 million trips are made daily in the GVRD, with about 75 percent of these made by private vehicle. On average, 57 percent of commuters travel outside of their home municipality to work, although this percent is lower near the downtown core and higher in the near suburbs(Greater Vancouver Transportation Authority 2004).

Approach. Exposure simulation is used to investigate variability in estimates of chronic exposure to NO_2. This approach is based on the indirect method of exposure assessment, in which total exposure is equivalent to a time-weighted average of the concentrations of pollutants in various microenvironments (MEs) encountered throughout a day (Duan 1982; Ott 1985; Klepeis 1999). In theory, given the amount of time a person spends in each ME (i.e., indoor at home, indoor at work, commuting, shopping, and so on) and the associated pollution concentrations, the calculation of total exposure is straightforward, as shown in Ott (1985):

$$E_i = \sum_{j=1}^{J} C_j t_{ij} \tag{1}$$

E_i = the integrated exposure of person i over the time period of interest; C_j = the concentration of pollutant encountered in microenvironment j; t_{ij} = time spent by person i in microenvironment j; J = total number of microenvironments occupied by person i over the time period of interest. Dividing E_i by the total time period provides an estimate of exposure expressed in the units of the pollution estimate (i.e., parts per billion, or micrograms per cubic metre).

In reality, these kinds of data are not readily available for large populations. Instead, simulation is used to estimate a range of exposure estimates based on randomly sampling from representative time-activity patterns and distributions of possible pollution concentrations (Ozkaynak, Zufall et al. 1999; Kruize, Hanninen et al. 2003). This approach has been used extensively by the US Environmental Protection Agency (US EPA) in support of setting air quality management objectives and standards (Johnson 1995; McCurdy 1995; Burke, Zufall et al. 2001; U.S. Environmental Protection Agency 2005a; U.S. Environmental Protection Agency 2005b). For this research, the indirect approach is employed, based on the following six microenvironment equation:

$$\boldsymbol{E} = [(C_h \text{ x } t_h) + (C_w \text{ x } t_w) + (C_{oi} \text{ x } t_{oi}) + (C_o \text{ x } t_o) + (C_{tw} \text{ x } t_{tw}) + (C_{to} \text{ x } t_{to})] /T \quad (2)$$

$\boldsymbol{E}$ is the total exposure of a ‘person’ expressed in pollution concentration units; C_h is the pollutant concentration at *home indoor*; C_w is the pollutant concentration at *work indoor*; C_{oi} is the pollutant concentration at *other indoor*; C_o is the pollutant concentration outdoor; C_{tw} is the pollutant concentration in *transit to work*; C_{to} is the pollutant concentration in *transit other*; t_{h}, t_{w}, t_{oi}, t_{o}, t_{tw} and t_{to} are the time spent in each respective microenvironment, based on the time-activity pattern; and T equals the duration of time activity pattern. For this study, E is referred to as the total exposure, and the value associated with each microenvironment variable as the partial exposure. As per Equation 2, there will be six partial exposure estiamtes, one for each microenvironment listed on the right hand side of the equation.

Model specification and data. A spatial exposure simulation model (SESM) was developed using a geographic information system (ESRI ArcGIS 9.1$^{©}$) and custom C^{++} programming. The SESM requires 1) time-activity patterns for the population(s) of interest; 2) census-based work flow data indicating home and work census areas; 3) spatially allocated concentrations of the pollutant of interest; 4) spatial locations for residential and commercial buildings; 5) the selection of suitable indoor/outdoor ratios for the pollutant and associated indoor MEs; and 6) a detailed road network.

1) Time-activity pattern data consist of the amount of time spent in different types of locations (but not the actual geographic locations), typically for a 24 hour period. Data from the Canadian Human Activity Pattern Survey study (Leech, Wilby et al. 1997), which also includes the date of survey, age, gender and the number of hours worked, were used as a basis for simulation in the SESM. Time reported as spent in a variety of locations in CHAPS was aggregated for each time-activity pattern into the six MEs used for this research: *home indoor*, *work indoor*, *other indoor* (including time spent shopping or in restaurants, for example), outdoor, transit work, and *transit other* (all non-work transit time). It is important to note here that no statistically significant differences were found in the time spent in each ME between female and male commuters, so these time activity patterns were pooled.

Certain assumptions were made based on the need to use daily time activity patterns to simulate annual exposures, most importantly that commuters have the same time-activity pattern on all workdays in the year, and have a random non-work pattern on each weekend day of the year. In order to incorporate weekday/weekend and summer/winter variations in the amount of time spent in different MEs over a year, the time-activity pattern records were grouped into five categories: non-working females summer (161), non-working females winter (161), non-working males summer (159), non-working males winter (117), and workers (178). The numbers of unique time-activity pattern records in each group are comparable to those used in other studies, for example, Kruize, Hanninen et al, (2003) used 434, 322, 83, and 100 time-activity pattern records to represent the total population of urban adults in Helsinki, Basel, Prague, and Athens respectively. In the SESM, the same set of time-activity patterns is used for the simulation in each census tract, thus controlling for variation due to demographic differences.

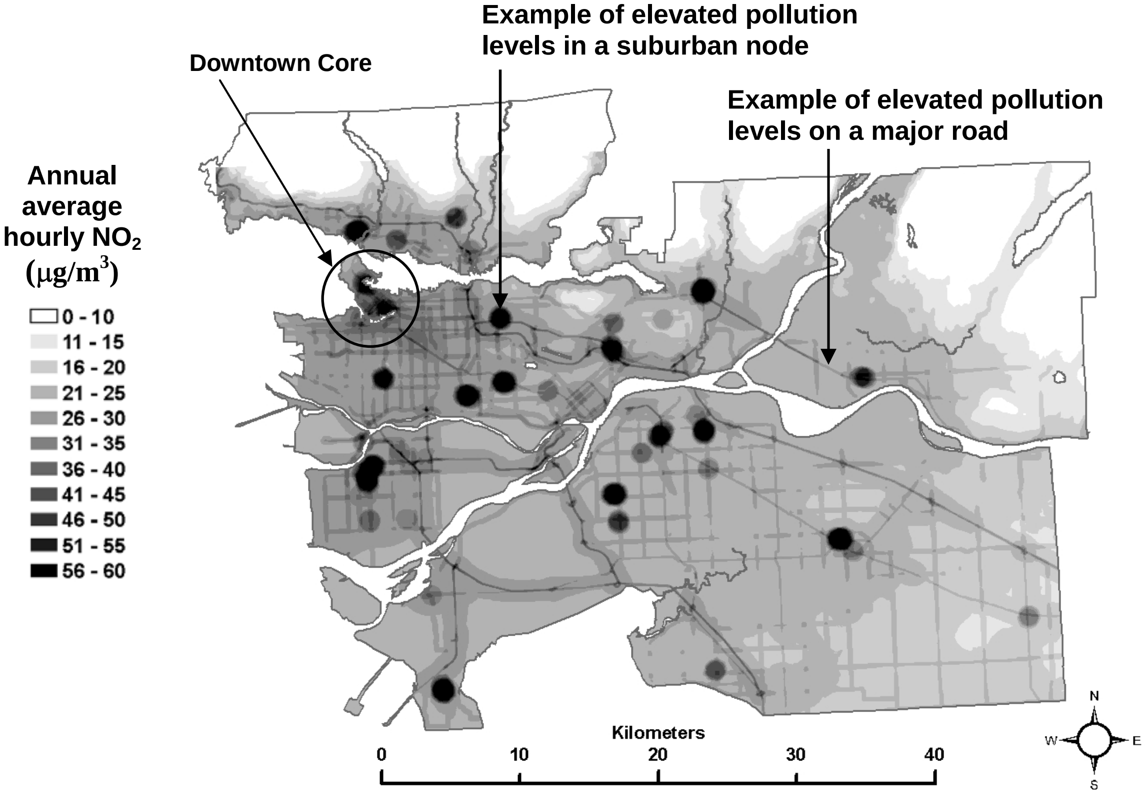
2) Work flow data for all people aged 15 and over reporting employment, based on a 20 percent sample in each census tract on May 15th, 2001, were purchased from Statistics Canada. For each census tract, the numbers of commuters going from the census tract of their residence to another census tract for work were used to develop

separate female and male work pair lists and associated frequencies for use in the SESM. Commuters who had a place of employment within the census tract of their residence were excluded, under the assumption that commuting distance would be negligible, and that the ambient pollution levels at home and work would be similar. Data showing a work census tract outside of the study area also were not included. The implemented SESM does not employ specific demographics for each census tract, so the results of the simulations need to be interpreted with caution. The resulting distributions of total and partial exposure estimates do not represent the total population in a census tract, but rather provide an indication of the possible range of exposure a commuter living in the census tract might experience, given the input data.

3) The SESM requires a spatial estimate of pollution levels for the study area. In terms of traffic-related air pollution, many epidemiological studies of traffic-related air pollution use nitrogen dioxide (NO_2) as an indicator of exposure to the total mix of pollutants as it has been shown to be associated with proximity to roads (Roorda-Knape, Janssen et al. 1998; Janssen, van Vliet et al. 2001; Gilbert, Woodhouse et al. 2003; Maruo, Ogawa et al. 2003), traffic volume (Kramer, Koch et al. 2000; Smargiassi, Baldwin et al. 2005) and some of the other constituents of traffic-related air pollution thought to be most harmful, such as black carbon from heavy duty diesel vehicles (Brunekreef, Janssen et al. 1997; Le Tertre, Medina et al. 2002; Kim, Smorodinsky et al. 2004).

For this research, a spatial estimate of annual average hourly NO_2 levels (Figure 2.1), developed by researchers at the University of British Columbia using the land use regression (LUR) method with field monitoring conducted in 2003, was employed and is fully described in (Henderson, Beckerman et al. 2007). Briefly, the method uses linear regression to relate surrounding geographic variables to field measurements of the pollutant of interest, and the resulting model is used to predict pollution levels for every cell in a grid that covers the entire study area. The grid spacing is usually very fine (5 m), and captures pollution gradients associated with roadways as well as dense urban and commercial development. The most important features of the spatial estimates are that gradients in NO_2 with distance from roadways are captured, as are higher concentrations of NO_2 in commercially developed areas and the regional gradient from the more polluted urban core, to the less polluted rural areas. It is this level of detail in the spatial allocation of NO_2 levels that allows the SESM, as employed in this study, to differentiate among census tracts based on their location in the study area and among the MEs included in the model.

Figure 2.1. Spatial estimate of annual average NO_2 levels



4) Additional geographic detail is incorporated in the SESM through the use of spatial property assessment data. Spatial property assessment data were used to identify the geographic location of every property in the study area for which taxes are assessed as well as the primary use of the building on the property. Within each census tract, property locations (either residential or commercial) were used to constrain the SESM to areas where these buildings exist, rather than assuming a homogeneous distribution.

5) Since people spend most of their time indoors and outdoor air pollution does not always fully infiltrate into indoor areas, indoor/outdoor (I/O) ratios are applied to

adjust pollution level distributions for the indoor MEs used in the SESM. In the absence of data on long-term I/O ratios for NO_2, fixed I/O ratios are used in the SESM based on the primary building use documented in the spatial property assessment data. Residential buildings were assigned an I/O ratio of 0.70, large office buildings 0.35, manufacturing, industrial, and civic buildings 0.50, and small stores, services, and restaurants 0.70, based on a review of available indoor/outdoor monitoring studies (for example, (Liao, Bacon-shone et al. 1991; Ekberg 1995; Monn, Brandli et al. 1998; Lee, Chan et al. 1999; Chao and Law 2000; Partti-Pellinen, Marttila et al. 2000; Guo, Lee et al. 2004; Lai, Kendall et al. 2004; Blondeau, Iordache et al. 2005). During the development of the SESM, results were found to be insensitive to the use of different I/O ratios. For example, results were not significantly different under a 'worst case' scenario where all commercial buildings were set to 0.35 and all residential buildings to 0.75, when compared to results using the more moderate scenario used in the application of the SESM described here. A comprehensive review of studies including I/O ratios for a variety of locations is available in Chapter 3, Section 3.2.7.

6) A digital road dataset was acquired for the study area from DMTI Spatial Inc. under an academic research agreement. This dataset was converted into a GIS network using ArcGIS 9.1, thereby allowing for the identification of the shortest route (assuming travel by car) between two points while observing appropriate travel restrictions such as one way streets and speed limits. For every home census tract, the shortest route based on time for every work census tract listed in the work pair file was identified and saved as a unique GIS file using a specific identifier (i.e., originCT10_destinationCT_205) with attributes including total distance and total time associated with the route. In total, 34,782 GIS files were created, representing the shortest routes between each home census tract and all associated work census tracts.

Given the spatial pollution estimate, routes between home and work census tracts, building locations and associated I/O ratios, a geographic information system (GIS) was used to develop distributions of NO_2 for each ME that are unique to each census tract in the study area. For a specific census tract, the distribution of NO_2 levels for the *home indoor* ME is comprised of values extracted from the NO_2 surface for each residential building location (assumed to be the centroid of each property parcel) in the census tract and multiplied by 0.70. For the *work indoor* ME, the pollution distribution is developed the same way, extracting NO_2 levels at commercial building locations within the census tract and multiplying by I/O ratios of 0.35, 0.50, or 0.70 according to building type. Pollution distributions for the *other indoor* ME are based on sampling the pollution surface at commercial locations within 5 kilometers of the residential census tract and again multiplying by the appropriate I/O ratio. Similarly, for the *outdoor* ME, a regularly spaced grid of sample points is used to extract NO_2 values from the surface within 5 kilometers of the residential census tract. For the *transit other* ME, the road network is used to create sample points for extracting NO_2 values along roadways within 5 kilometers of the residential census tract; these values are then averaged to provide a single *transit other* value for the census tract. A distance of 5 kilometers was chosen to represent the average distance people travel from home on non-work related trips based on a review of studies reporting a typical range between 2 and 8 kilometers (Janelle, Goodchild et al. 1988; Handy 1996; Crane and Crepeau 1998). As well, the SESM results were found to be insensitive to variations in the distance chosen between 2.5 and 7.5 kilometers (Chapter 3). For the *transit to work* ME, distributions are made up of the length-weighted average pollution level along the shortest route between each home-work pair associated with the census tract. No I/O ratios are applied to the *outdoor*, *transit other* or *transit to work* MEs. It is important to note here than no indoor sources of NO_2 are included in the simulation. For indoor microenvironments, the distributions of NO_2 levels represent the amount of NO_2 generated by traffic that infiltrates indoors.

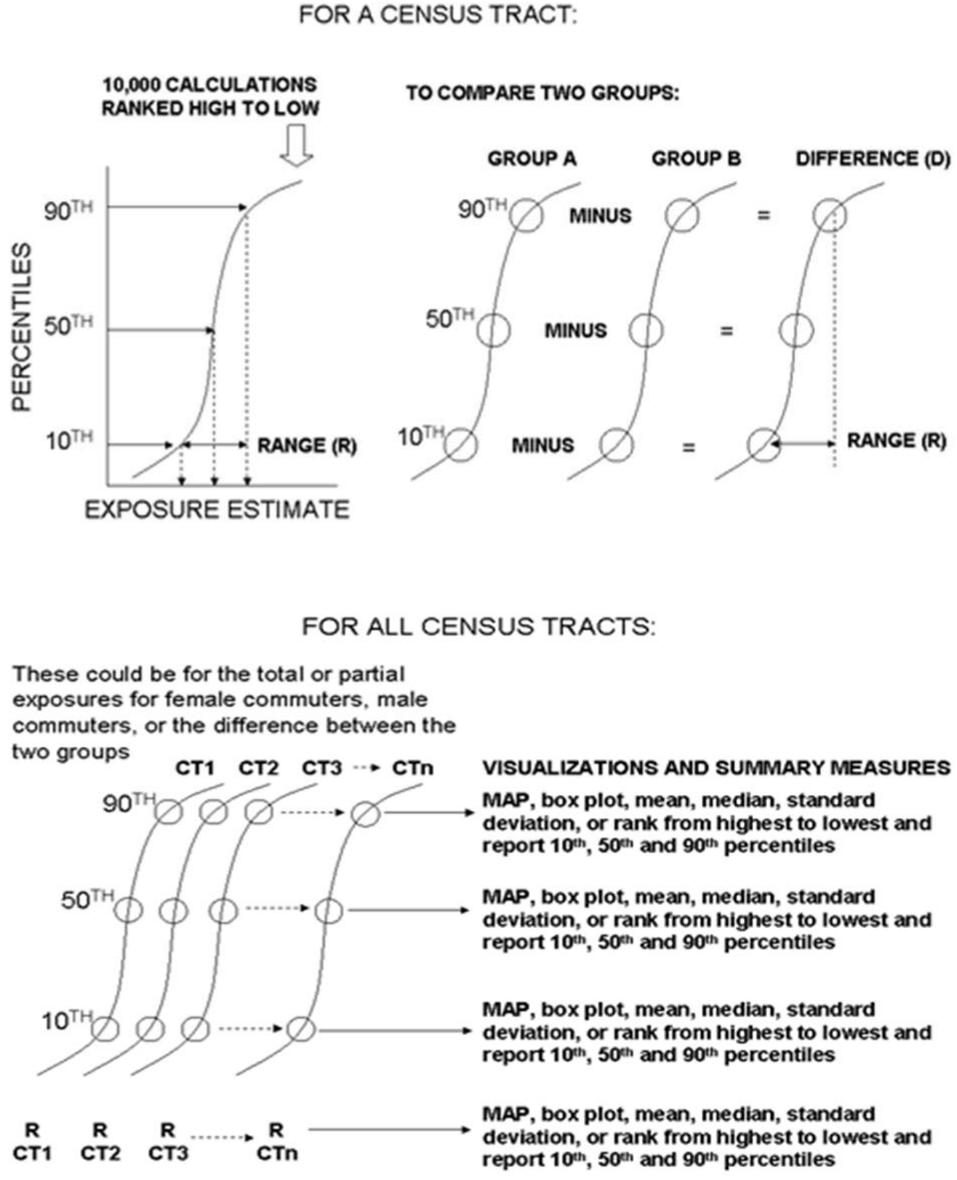
Once the distributions for each census tract are developed, random sampling is used to calculate the total exposure for a year. For example, to simulate exposure for female commuters in the first census tract, a single time-activity pattern is randomly selected to represent all workdays in a year, a work destination is randomly chosen from the frequency-weighted distribution of possible work pairs, and pollution levels are randomly chosen from the appropriate distributions for the MEs. Total exposure for workdays is then calculated as a time-weighted average of these randomly selected pollution levels for each ME, as per Equation (2), as are the partial values associated with each ME. For summer weekends (53 days in a year), a female non-worker summer time-activity pattern is randomly selected, the appropriate distributions sampled for pollution levels, and exposure calculated as per Equation (2). This is repeated 53 times, and the average taken to represent the total and partial exposures for summer weekends. A similar procedure is used to calculate the total and partial exposures for winter weekends. Results for workdays and summer and winter weekends are then combined to provide a time-weighted, seasonally adjusted estimate of total exposure to annual average hourly NO_2, as per Equation (3):

$$\boldsymbol{E_y} = [\{(W_a * 0.72) + (W_{ws} * 0.28)\} * 0.50] + [\{(W_a * 0.72) + (W_{ww} * 0.28)\} * 0.50] \quad (3)$$

Where $\boldsymbol{E_y}$ is the annual total exposure estimate; W_a is the exposure during weekdays; W_{ws} is the exposure during summer weekends; W_{ww} is the exposure during winter weekends; the weight 0 .72 represents the proportion of working days in summer or winter; the weight 0.28 represents the proportion of weekend days in summer or winter; and the weight 0.50 gives the summer and winter components equal weight in the sum.

This set of calculations is repeated 10,000 times for each gender in each census tract, producing distributions of total exposures and partial exposures for each ME with 95% confidence of estimating exposure at any percentile to within +/-1 percentile (Cullen and Frey 1998). The resulting distributions can be compared statistically as well as visually through graphs and maps (Figure 2.2). For example, the median (referred to as the 50th percentile values) of the total or partial exposure estimate distributions in each census tract can be mapped to identify spatial patterns. The 10th percentile and 90th percentile levels can be similarly mapped and compared to identify the lower and upper ranges of the exposure estimates. The differences between the 10th and 90th percentiles can be calculated and mapped to show where variability within census tracts is highest, i.e., where the range between the 10th and 90th percentile values is largest.

Figure 2.2. Distributions produced and measures used for comparison



Due to the specification of the SESM as applied here, results must be interpreted with caution, under the following caveats. (1) Results apply to workers commuting by car, not working in the census tract of residence, and who have a fixed indoor place of employment all year. Therefore, the SESM does not reflect exposures for people who work in transit-related occupations (e.g., bus, taxi, truck drivers), who regularly work outdoor or at different locations within a region (e.g., real estate sales, home care workers, construction workers), or who use other modes of transportation. (2) Results do not reflect real measured personal exposures, but instead reflect possible exposures based on the input data. (3) The results reported here are specific to ambient traffic-related air pollution as indicated by NO_2, and do not include any indoor sources of NO_2 such as gas stoves or work-related equipment. (4) SESM results are sensitive to the use of different methods for estimating the spatial allocation of pollution levels, e.g. spatial interpolation based on fixed-site monitoring (see Chapter 3). Here, the most spatially detailed estimate of NO_2 levels available for the study area was employed. Less detailed estimates, such as might be produced via spatial interpolation from fixed-site air quality monitors, may produce results that differ from those reported here.

Results

With respect to total exposure, the 10th, 50th, and 90th percentiles of the distributions in each census tracts appear very similar for both female and male commuters, as shown in the box plots in Figure 2.3. Each box plot shows the minimum and maximum (the lowest and highest horizontal line), and the 25th percentile, median and 75th percentile level (bottom, middle, and top of box) of the simulated exposure estimates at each percentile, as observed across the 382 census tracts in the study area. The similarity of the distributions for female and male commuters is confirmed through the use of the standard t-test. No statistically significant differences were found between means of the distributions of total exposure at the 10th, 50th, or 90th percentiles across census tracts (Table 2.1). Overall, total exposure, expressed as annual average hourly NO_2 ($\mu g/m^3$), ranges approximately from 19 to 24 $\mu g/m^3$ across the percentiles for both females and males, with differences between means of less than 0.2 $\mu g/m^3$, +/- approximately 0.5 $\mu g/m^3$.

Figure 2.3. Box plots of the 10th, 50th and 90th percentiles of total exposure distributions for female and male commuters in 382 census tracts

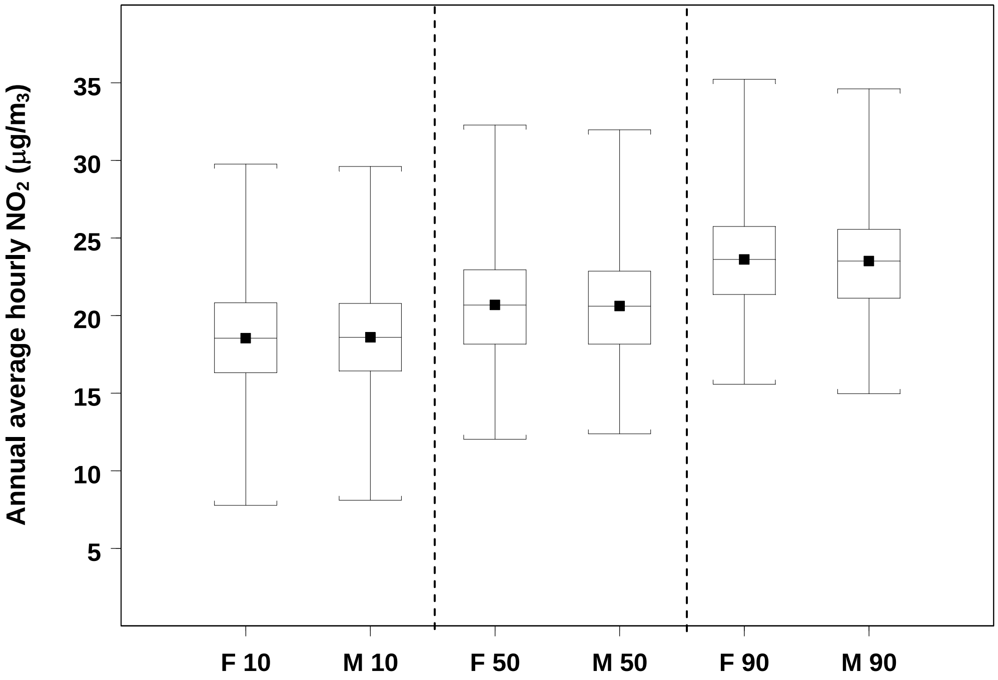


Table 2.1. Statistical tests for differences in the distributions of the 10th, 50th and 90th percentiles of total exposure estimates

		Annual Average Hourly NO_2 (µg/m^3)			
Total exposure Percentile	t-test [significance 95% two-tailed]	Mean (F) *n* = 382	Mean (M) *n* = 382	Difference in means (F minus M)	CI (95%) difference in means
10th	-0.22 [.8308]	18.82	18.87	-0.05	-0.51 to 0.41
50th	0.22 [.8279]	20.96	20.90	0.04	-0.44 to 0.56
90th	0.72 [.4718]	23.95	23.77	0.18	-0.32 to 0.68

Although no statistically significant differences were observed in the distributions of total exposure for female and male commuters, differences are observed in the partial exposure estimates associated with the different MEs, as shown in Table 2.2. In every ME, the t-test results (2nd column of Table 2.2) for the means of the 10th, 50th, and 90th percentile values for female versus male commuters in all census tracts indicate the means are significantly different. The 5th column in Table 2.2 shows the numerical difference in the mean of the distributions for the 10th, 50th, and 90th percentiles of the partial exposure distributions for female and male commuters. Mean partial exposure associated with the *home indoo*r ME is approximately 1.4 μg/m^3 (9 percent) higher for female commuters than male commuters at the 10th, 50th, and 90th percentiles, and slightly more than 1 μg/m^3 (40 to 45 percent) lower for female commuters than male commuters in the *outdoor* ME at each percentile level. In all other MEs, the mean partial exposure is lower for female commuters than for male commuters, but by less than 0.5 μg/m^3 of annual average hourly NO_2. In every case other than the *home indoor* ME, differences in partial exposure increase from the 10th to the 90th percentiles, suggesting that exposure for female and male commuters is more similar at low exposure levels than at high exposure levels in these MEs.

These observed statistically significant differences in the mean partial exposures associated with each ME can be attributed to the time-activity patterns used in the simulation. Figures 2.4 and 2.5 show box plots of the time spent in different MEs for female and male commuters and female and male non-workers respectively. Recall that in order to simulate exposures for a year, the SESM uses time-activity patterns for working people on weekdays, and for non-working people on weekend days. For weekdays, the box plots in Figure 2.3 show that time spent in each ME is very similar for females and males. For weekends, the box plots in Figure 2.4 show noticeable differences in the time spent in the *home indoor* ME (higher for females) and time spent in the *outdoor* ME (lower for females). These are the MEs for which the largest differences in means are seen in Table 2.2 (5th column), suggesting that the inclusion of these weekend non-worker patterns is enough to influence the total exposure distributions and produces differences between female and male commuters on an annual basis that are not related directly to time spent at work or commuting.

Table 2.2. Statistical tests for differences in female and male exposure estimate distributions for each microenvironment (female minus male)

		Annual Average Hourly NO_2 ($\mu g/m^3$)			
Microenvironment Percentile	t-test [significance 95% two-tailed]	Mean (F) *n* = 382	Mean (M) *n* = 382	Difference in means (F minus M)	CI (95%) difference in means
Home indoor					
10th	5.33 [**.0000**]	16.31	14.89	1.41	0.90 to 1.94
50th	5.14 [**.0000**]	16.81	15.40	1.41	0.87 to 1.95
90th	4.94 [**.0000**]	17.31	15.90	1.41	0.85 to 1.97
Work indoor					
10th	3.57 [**.0004**]	3.87	3.77	0.10	0.05 to 0.16
50th	5.31 [**.0000**]	6.56	6.30	0.26	0.16 to 0.35
90th	8.57 [**.0000**]	10.90	10.36	0.54	0.42 to 0.67
Other indoor					
10th	-10.87 [**.0000**]	1.45	1.76	-0.31	-0.37 to -0.25
50th	-10.40 [**.0000**]	1.74	2.09	-0.35	-0.41 to -0.28
90th	-10.03 [**.0000**]	2.06	2.44	-0.38	-0.46 to -0.31
Outdoor					
10th	-50.27 [**.0000**]	1.29	2.36	-1.07	-1.11 to -1.03
50th	-46.65 [**.0000**]	1.61	2.78	-1.17	-1.22 to -1.12
90th	-43.50 [**.0000**]	1.97	3.24	-1.27	-1.33 to -1.22
Transit other					
10th	-16.36 [**.0000**]	1.12	1.33	-0.21	-0.23 to -0.18
50th	-15.12 [**.0000**]	1.31	1.53	-0.22	-0.25 to -0.19
90th	-13.84 [**.0000**]	1.53	1.76	-0.23	-0.26 to -0.20
Transit work					
10th	-2.50 [**.0125**]	0.17	0.20	-0.03	-0.05 to -0.01
50th	-5.06 [**.0000**]	0.48	0.56	-0.08	-0.12 to -0.05
90th	-3.47 [**.0005**]	0.99	1.08	-0.09]	-0.14 to -0.04

bold indicates statistically significant difference

In summary, no statistically significant differences in the means of female and male commuters was observed in the distributions of total exposure. The differences in partial exposure distributions between female and male commuters may be statistically significant in all MEs, but the differences are small and could be considered for exposure assessment purposes to be biologically insignificant.

Figure 2.4. Box plots of time spent on weekdays in each microenvironment by female and male commuters

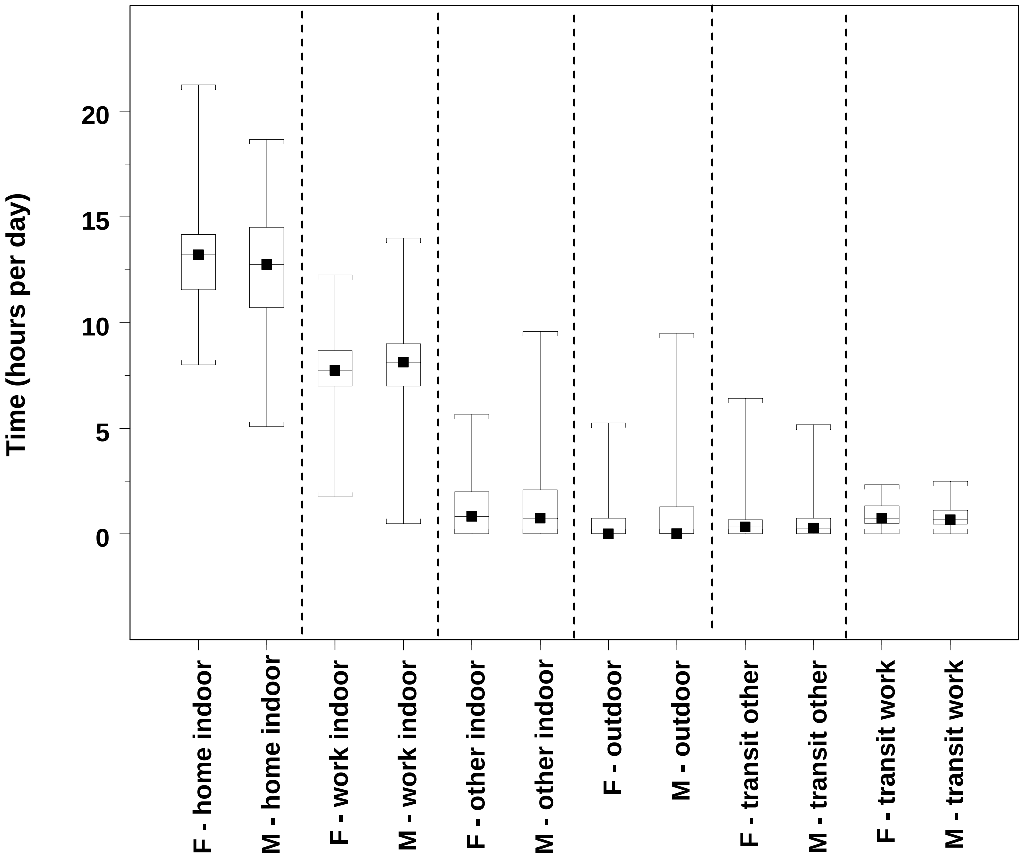
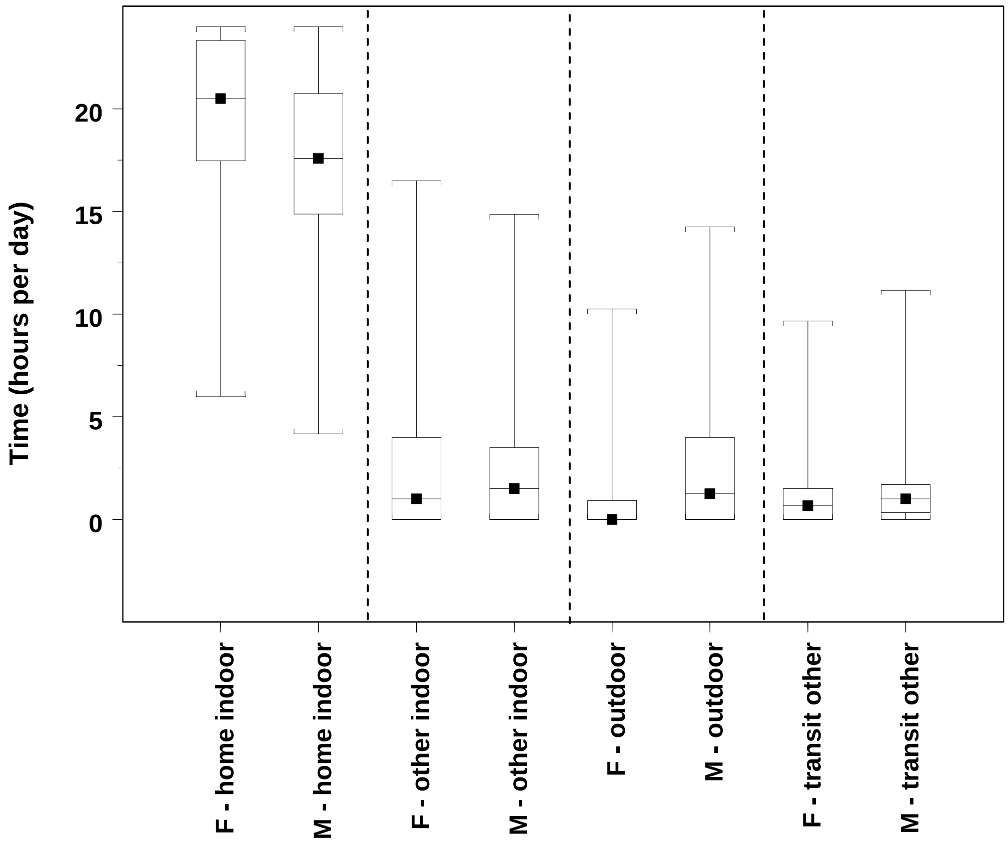


Figure 2.5. Box plots of time spent on weekends in each microenvironment by female and male non-workers



The preceding analyses have focused on the differences in mean total and partial exposures between female and male commuters across census tracts; however, an analysis of variability in the differences provides additional insight. Table 2.3 shows the differences in mean levels, the same as those reported in the 5th column of Table 2.2 above, but also provides an indication of the range of differences across census tracts by including the lower (10th percentile of differences) and upper (90th percentile of differences) levels observed in the SESM results. These values are produced by first subtracting the male 10th percentile levels from the female 10th percentile levels in each census tract, then ranking the differences for all census tracts and reporting the low end (10th percentile), mean, and high end (90th percentile). Values for the 50th percentile and 90th percentile differences are calculated in the same fashion (see Figure 2.2)

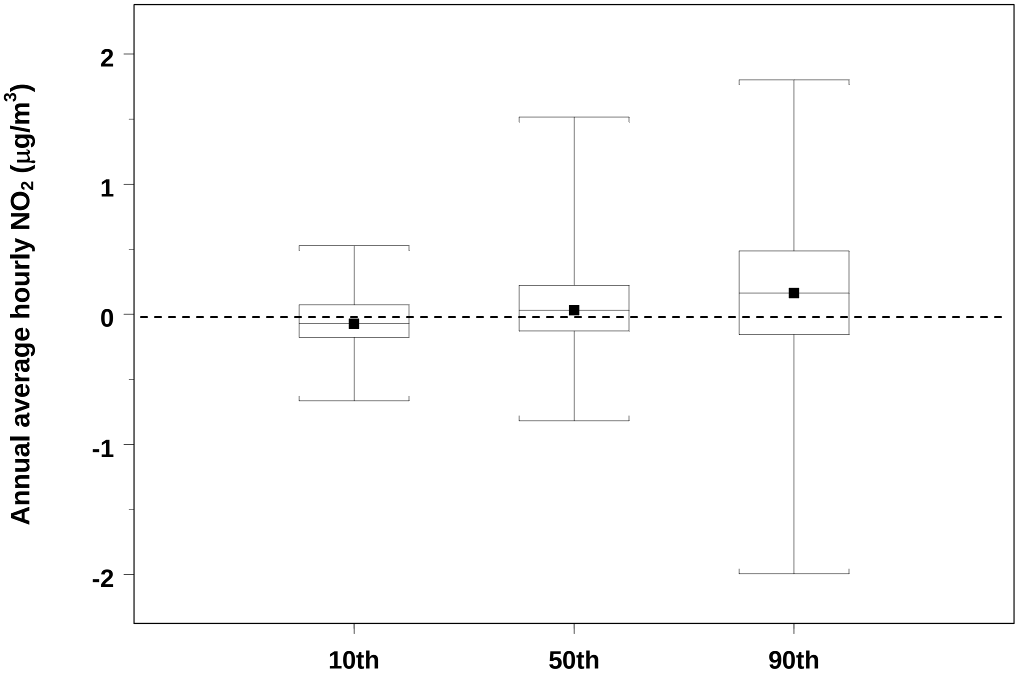
Table 2.3. Summary of the differences in the 10th, 50th, and 90th percentiles of the distributions for female and male exposure estimates (female – male)

Microenvironment	Percentile		**Annual Average Hourly NO_2 (μg/m^3)**		
		10th percentile of differences *n* = 382	Mean of differences *n* = 382	90th percentile of differences *n* = 382	Range of differences (90th minus 10th)
Total exposure					
	10th	-0.28	-0.05	0.21	0.49
	50th	-0.27	0.05	0.39	0.66
	90th	-0.46	0.16	0.83	1.29
Home indoor					
	10th	1.10	1.41	1.84	0.74
	50th	1.09	1.41	1.84	0.75
	90th	1.08	1.41	1.82	0.74
Work indoor					
	10th	-0.18	0.10	0.37	0.55
	50th	-0.18	0.26	0.66	0.84
	90th	-0.44	0.53	1.66	**2.10**
Other indoor					
	10th	-0.40	-0.31	-0.23	0.17
	50th	-0.44	-0.35	-0.26	0.18
	90th	-0.49	-0.39	-0.29	0.20
Outdoor					
	10th	-1.26	-1.07	-0.86	0.40
	50th	-1.39	-1.17	-0.94	0.45
	90th	-1.51	-1.27	-1.03	0.48
Transit other					
	10th	-0.24	-0.20	-0.17	0.07
	50th	-0.25	-0.22	-0.18	0.07
	90th	-0.27	-0.23	-0.19	0.08
Transit work					
	10th	-0.09	-0.03	0.01	0.10
	50th	-0.25	-0.08	0.00	0.25
	90th	-0.28	-0.09	0.05	0.33

The same general trends observed in Table 2.2 are evident in Table 2.3. The overall magnitude of the differences in the distributions of total exposures is small. For partial exposure distributions, the largest differences are seen for the *home indoor* ME and the *outdoor* ME for the 10th, mean, and 90th percentiles. The last column of Table 2.3 shows the range between the 10th and 90th percentiles of the differences. Most notable here is the comparatively large range (2.1 μg/m^3 of annual average hourly NO_2, shown in bold in Table 2.3) for the *work indoor* ME, when looking at the differences between female and male commuters at the 90th percentile of the partial exposure distribution.

The observed differences in partial exposure distributions between female and male commuters at the 90th percentile level for the *work indoor* ME are not explained by differences in time activity patterns. During the SESM development, no statistically significant differences were found between female and male commuters with respect to time spent in any ME, so time-activity patterns for both female and male commuters were pooled. However, box plots of the differences between female and male commuters at the 10th, 50th, and 90th percentiles of partial exposures associated with the *work indoor* ME in each census tract clearly show an increasing disparity (Figure 2.6). Only the work flow data remain as a source of explanation for the differentially greater partial exposure levels associated with the *work indoor* ME for female commuters at the 90th percentile.

Figure 2.6. Box plot of differences between female and male commuters' partial exposure distributions for the *work indoor* microenvironment (female minus male)



Mapping the differences in the distributions of partial exposures for the *work indoor* ME provides useful insight into why these differences are observed. Figure 2.7 shows the spatial distribution of the differences between the partial exposure distributions for the *work indoor* ME for female and male commuters at the 10th percentile.[14] At the 10th percentile, differences are all within +/- 1 μg/m^3, and there is no distinct spatial pattern. At the 90th percentile, shown in Figure 2.8, differences are greater than 2.0 μg/m^3 in 20 of the 382 census tracts, and these are predominantly in suburban areas.

There are two possible explanations for the spatial pattern seen in Figure 2.8. One is that suburban male commuters may be travelling to work in census tracts with a much larger proportion of office buildings with lower I/O ratios than suburban females, thereby reducing their exposure due to a protective effect of being indoors in buildings where less traffic-related NO_2 infiltrates. In the study area, these buildings are more common in the downtown core, and so if suburban males are more often working in the downtown core than suburban females, this might contribute to the observed difference. A second explanation is that suburban female commuters are travelling to work in census tracts in the study area where pollution levels are higher more often than suburban male commuters, and therefore have higher exposures. Comparing the home-work pairs and frequencies for females and males in those suburban census tracts exhibiting high differences suggests that the latter explanation appears to hold true. Figures 2.9 and 2.10 show proportional work flows for a selected suburban census tract where the difference between female and male commuters at the 90th percentile of partial exposure for the *work indoor* ME is 3 μg/m^3 of annual average hourly NO_2. In Figure 2.9, the proportional circles identify where female commuters from the selected home census tract work, and in what proportions. Overall, the largest proportions of female commuters work in census tracts in the developed commercial areas in the downtown core and suburban nodes where NO_2 levels are among the highest in the study area. The work flow patterns are markedly different for the male commuters from the same suburban census tract, as shown in Figure 2.10. In this case, the largest proportions of male commuters work in census tracts that are not in the downtown core or suburban commercial centres. This pattern tends to hold true for each of the census tracts where differences are at least 2 μg/m^3, although not always as clearly as in the example in Figures 2.9 and 2.10.

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[14] Note: For maps presenting SESM results, areas where there is less than one residential building per 500 meters are not shown. This is done to avoid giving visual importance to unpopulated portions of large rural census tracts.

Figure 2.7. Differences (female minus male) in partial exposure distributions for the *work indoor* microenvironment at the 10th percentile

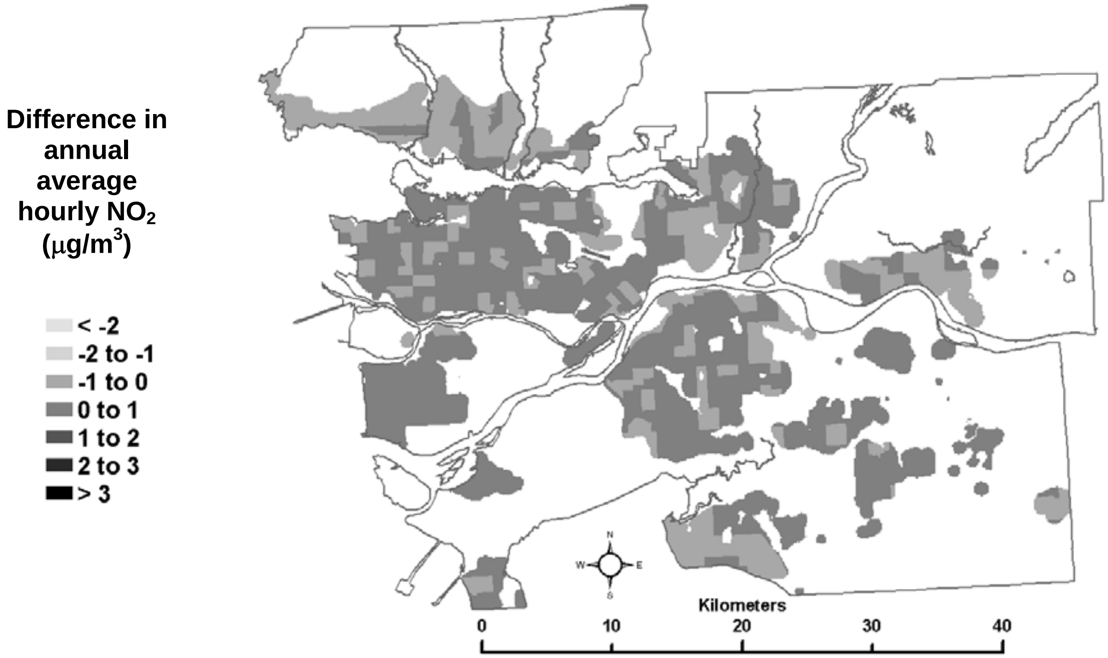


Figure 2.8. Differences (female minus male) in partial exposure distributions for the *work indoor* microenvironment at the 90th percentile

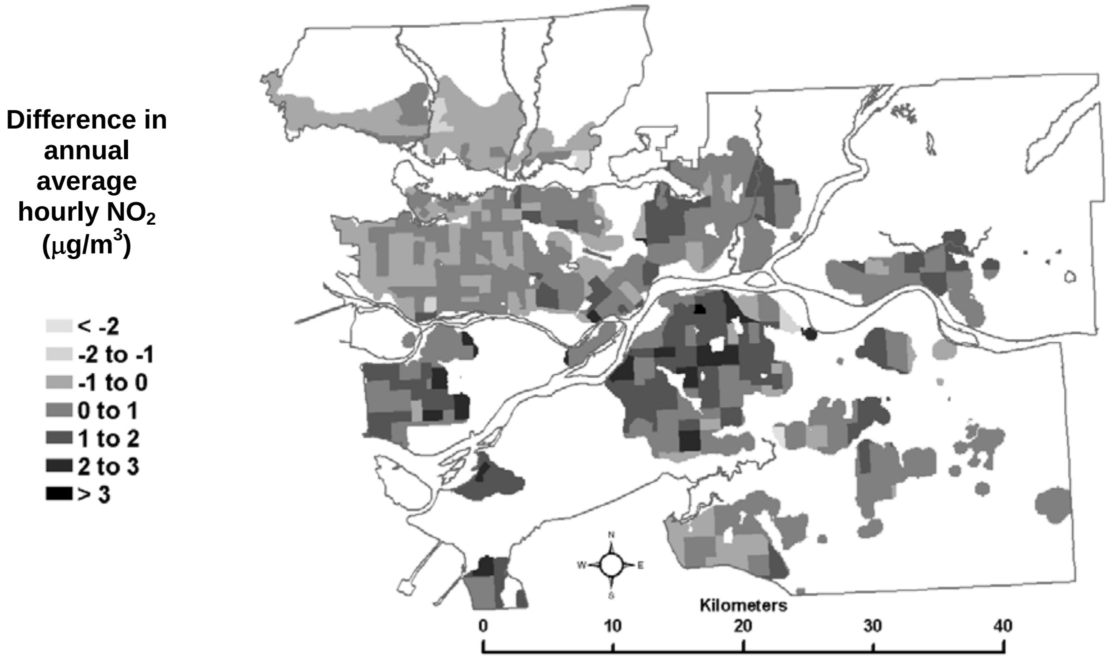


Figure 2.9. Work destinations and frequencies for female commuters in a suburban census tract

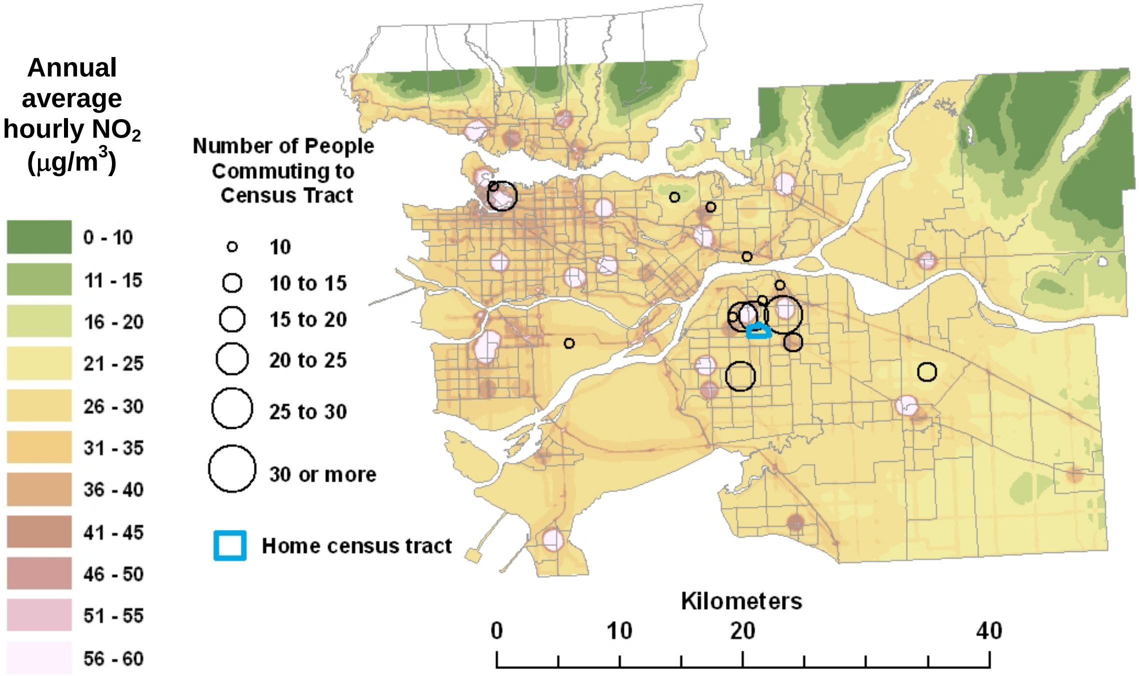
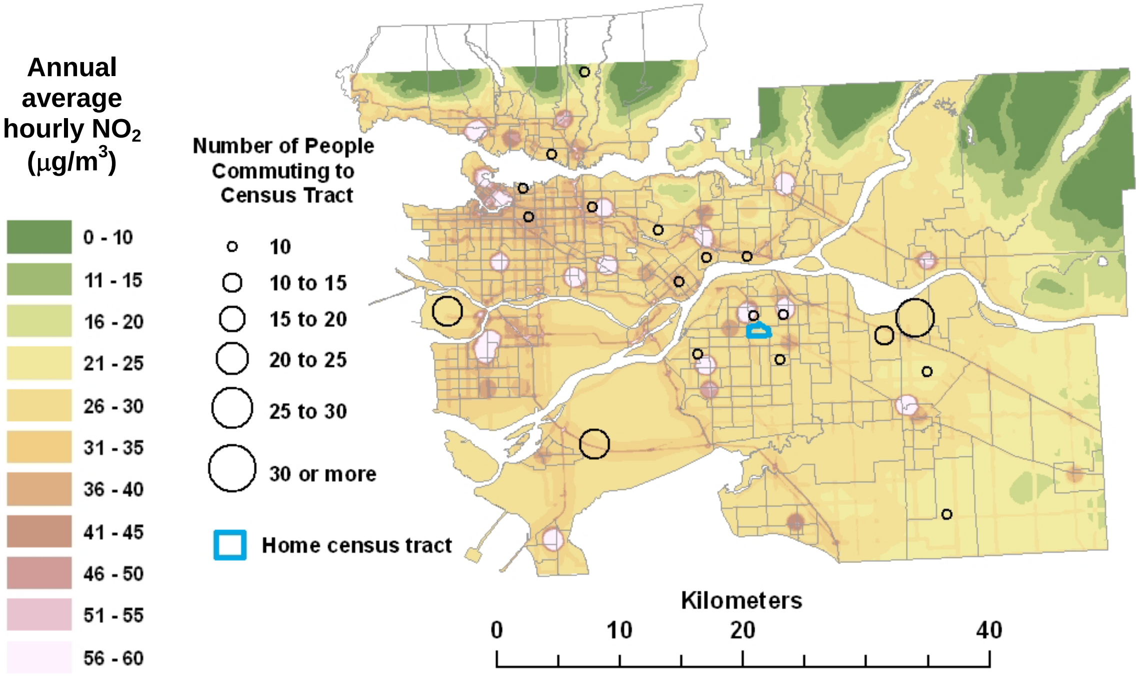


Figure 2.10. Work destinations and frequencies for male commuters in a suburban census tract



Discussion

No statistically significant difference in the distributions of total exposure estimates to NO_2 was observed in female and male commuters. Small but statistically significant differences were observed between females and males in the partial exposure distributions associated with each ME included in the SESM, but these balance out when aggregated in the total exposure distributions. This result suggests that for population-level epidemiological studies and exposure reduction policies, female and male commuters in the study area can be treated as a single group with respect to commuting and time spent at work locations. This may not be the case in other metropolitan areas, or for other pollutants.

With respect to the lack of a statistically significant difference in the distributions of exposure estimates between female and male commuters, there are existing studies which provide similar evidence. In a multi-city study on NO_2 exposure based on personal monitoring of 568 adults, gender was found not to be significantly correlated with total NO_2 exposure (Levy 1998). Personal monitoring of working aged adults conducted for the EXPOLIS study in Europe also found no significant difference between genders, with the mean hourly NO_2 exposures measured being 25.5 and 24.6 $\mu g/m^3$ for males and females respectively (Rotko, Kousa et al. 2001). Conversely, gender was found to be a significant predictor of total NO_2 exposure in the summer, along with being a full-time worker, working with or near gas furnaces, boilers, ovens or flames, and commute distance (Quackenboss, Spengler et al. 1986). In the winter, gender is not a factor; only working with or near welding or cutting torches, and individual age were found to be significant predictors of total NO_2 exposure. These results are difficult to interpret in the context of the SESM results because the magnitude of difference in NO_2 exposure between males and females in the summer is not reported.

In the simulation results presented here, differences between female and male commuters were seen at the 90th percentile of partial exposure distributions associated with the *work indoor* ME. The largest differences (top 10 percent) were in the suburban portions of the study area. This result appears to be due to systematic differences in where female and male commuters go to work within the study area in relation to the urban core and suburban nodes. This observation reconciles well with a number of studies on gender-based differences in commuting distance. Blumen (1994) presents a comparison of studies from the US, Canada, France, Australia, and Israel, showing that differences in commute distance between female and male commuters are more pronounced in suburban areas. More recently, Shearmur (2006) analyzed the characteristics of the female and male commuter populations associated with six employment nodes in Montreal, including the central business district. While he finds that on average women work closer to home than do men by about 1.05 km, he also finds no particular gender association in the differences seen between each employment node. Instead, he does find that females are more often employed in the central business district and other employment nodes, while males more often work at various locations throughout the region rather than preferentially in the central business district or employment nodes – findings that correspond to the patterns seen in Figures 2.9 and 2.10.

The spatial pattern of differences appears consistent with studies showing female and male work destinations are different; however, the differences were seen only in the top ten percent of the differences between female and male commuters at the 90th percentile of the distribution of partial exposures associated with each census tract. In the simulation, this means there is only a 1 percent chance of being exposed at these levels, and for those in this upper range, the maximum difference between female and male commuters is 3.1 $\mu g/m^3$ of annual average hourly NO_2. In comparison, the mean 99th percentile total exposure estimate for both female and male commuters is approximately 26 $\mu g/m^3$ of annual average hourly NO_2, and the highest 99th percentile total exposure is 37 $\mu g/m^3$ of annual average hourly NO_2 for both female and male commuters.

In conclusion, the SESM results suggest that female and male commuters in the study area could be treated as the same population with respect to commuting behaviour and its effect on exposure to traffic-related NO_2, in population level epidemiological studies of air pollution. Of course, other gender-based differences such as body weight and respiratory characteristics are still important factors to consider, as are commuters who use different modes of transportation, work outdoors, or in regularly varying locations. These results also suggest that there may be little to gain from gender-based exposure reduction policies for traffic-related air pollution in the study area. A small percentage of female commuters living in suburban regions of the study area could be systematically exposed to higher levels of annual average hourly NO_2, and these differences could be confirmed with a focused personal monitoring study of female and male commuters from the census tracts exhibiting the largest differences. Finally, these results are specific to NO_2, and may be different for other pollutants, particularly those with spatial patterns that differ from that observed for NO_2 in the study area.

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PAPER 3. WORKERS AND NON-WORKERS: A SPATIAL COMPARISON OF DIFFERENCES IN ESTIMATES OF CHRONIC EXPOSURE TO TRAFFIC-RELATED AIR POLLUTION

PAPER 3

WORKERS AND NON-WORKERS: A SPATIAL COMPARISON OF DIFFERENCES IN ESTIMATES OF CHRONIC EXPOSURE TO TRAFFIC-RELATED AIR POLLUTION

Abstract

A unique spatial exposure simulation model, incorporating six microenvironments, is employed to investigate the effects of time spent away from home on estimates of chronic exposure to traffic-related nitrogen dioxide (NO_2). Simulated exposure estimates for *workers*, *non-workers*, and a base scenario where all time is spent at the *residence only* are produced for each of 382 census tracts to illustrate spatial differences. Statistically significant differences were found in the exposure distributions for *workers* versus *non-workers, workers* versus *residence only*, and *non-workers* versus *residence only*, although the differences were generally on the order of 1 or 2 $\mu g/m^3$ of annual average hourly NO_2. On average, given median exposure estimates ranging from 8 to 40 $\mu g/m^3$, the use of a residence only–based approach to assign exposure for population-level epidemiological studies of ambient air pollution may be adequate for NO_2. Larger, systematic differences between workers and non-workers occurred, however, at the 10th and 90th percentiles of the exposure estimate distributions, and were on the order of -5.4 to +6.5 $\mu g/m^3$ of annual average hourly nitrogen dioxide (NO_2) respectively for *workers* compared to *non-workers*. It is recommended that future epidemiological studies incorporate geographic locations of work and time spent there into exposure assessments in order to reduce the potential effects of exposure measurement error.

Introduction

Numerous epidemiological studies of traffic-related air pollution show associations between increased exposure and increased risk of negative health impacts. In many cases, either residential proximity to roadways or the estimated level of ambient (outdoor) pollution at the residential address is used to indicate long-term exposure. If study subjects spend time away from home at work, school, or shopping, these approaches to exposure assessment may cause exposure misclassification or measurement error. This paper has two objectives: 1) to identify if there are significant differences in estimates of chronic exposure to traffic-related pollution between workers and non-workers based on the typical locations visited regularly, and 2) to compare the estimated exposure of these two groups to estimates that do not incorporate time spent away from home.

For this study, distributions of exposure estimates are produced through probabilistic simulation for three groups in each census tract: 1) people who leave the census tract to work (*worker*s); 2) people who do not work but leave the census tract for non-work related activities, e.g., shopping, or outdoor recreation (*non-workers*); and 3) people who remain in their residence at all times (*residence only*). This last scenario is analogous to assessing exposure using the ambient pollution level at or near subjects' residential addresses, an approach that has been used in numerous epidemiological studies. Summary statistics relating to the distributions of the exposure estimates are compared visually through graphing and maps, and observed variations are explained through analyses of the model inputs.

Background

The effects of chronic exposure to traffic-related air pollution have been the subject of epidemiological research for several decades, and recent studies suggest that even in the face of increasingly clean emissions from motor vehicles, adverse health effects can still be observed in association with exposure. In a cohort of 5,000 people aged 55 to 69 years in the Netherlands, the relative risk of mortality from cardiopulmonary causes was 1.95 (CI 1.09 – 3.52) among those living near a major road, whereas the relative risk of dying from non-cardiopulmonary, non-lung cancer related illnesses was 1.03 (CI 0.54 – 1.96) in the same group (Hoek, Brunekreef et al. 2002). A study of pulmonary function in female adults in Japan found that those women living in high pollution areas (defined as being within 50 m of a major road with daytime average traffic density of > 20,000 vehicles, including 4,000 large vehicles), had higher prevalence rates of respiratory symptoms and decreases in lung function (Sekine, Shima et al. 2004). In Hamilton, Ontario, people living within 50 m of a major urban road had an increased risk of mortality of 1.18 (CI 1.02 – 1.38), and the mortality rate was advanced by 2.5 years (Finkelstein, Jerrett et al. 2004).

Many recent population level epidemiological studies use measures of chronic exposure based on the subjects' residential address, likely since this information is relatively accessible in health records and can be mapped using a geographic information system (GIS). Given a spatial estimate of pollution levels, or a digital map of roads of varying types or traffic volumes, a GIS can be used to identify the pollution level at each residence or measure the distance between each residence and the nearest roadway, thereby providing a surrogate measure of chronic exposure for each subject in the study. Studies using residential location in relation to roadways, or with a spatial estimate of pollution are not comprehensively reviewed here but include, in addition to the three described earlier, (Wjst, Reitmeir et al. 1993; Livingstone, Shaddick et al. 1996; Oosterlee, Drijver et al. 1996; Brunekreef, Janssen et al. 1997; Ciccone, Forastiere et al. 1998; Feychting, Svensson et al. 1998; English, Neutra et al. 1999; Best, Ickstadt et al. 2000; Nyberg, Gustavsson et al. 2000; Raaschou-Nielsen, Hertel et al. 2001; Venn, Lewis et al. 2001; Buckeridge, Glazier et al. 2002; Lin, Munsie et al. 2002; Yang, Chang et al. 2003; Scoggins, Kjellstrom et al. 2004).

In reality, many people do not spend all of their time at home, but go to work, school, or run errands in the local neighbourhood where pollution levels differ from those at home. Thus, assigning exposure based on pollution levels only at residential locations has the potential to cause exposure measurement error, which may in certain cases lead to biases in the estimates of associations between exposure and the health outcomes of interest (Shy, Kleinbaum et al. 1978; Armstrong 1998). In cases where the association is underestimated (i.e., the relative risk of a health outcome occurring as a function of exposure) could have substantial consequences, particularly when relative risk is used as a basis for the setting of air quality standard meant to be protective of human health (Jerrett, Burnett et al. 2005).

Certainly, when exposure to air pollution is assigned to an individual according to their residential address, spatial inaccuracies in the pollution estimate itself contribute to exposure measurement error. Attempts to reduce this source of potential error with respect to traffic related air pollution employ increasingly sophisticated methods to estimate pollution levels, e.g., (Feychting, Svensson et al. 1998; Hoek, Brunekreef et al. 2002; Hoek, Meliefste et al. 2002). Little progress, however, has occurred in terms of improving individual exposure estimates in large populations with additional information on subject's locations when away from home. This is not particularly surprising, given that many population-level epidemiological studies use health system data that may provide residential addresses but not individual level information such as the geographic location of work. Moreover, personal monitoring of large study populations is not generally feasible. The necessary assumption is that since people spend most of the time at home, exposure at home is a reasonable proxy for chronic exposure over the long term.

In the absence of geographically detailed data for large populations, it becomes important to understand what implications are associated with the use of pollution levels at residence only as a surrogate measure for total exposure. The study presented in this paper explores the differences between estimates of exposure representing the *residence only* scenario and estimated exposures that are influenced by time spent away from home on a regular basis for two groups – *workers* and *non-workers*. To our knowledge, this study is the first to provide estimates of the magnitude of differences in exposure at the neighbourhood level when individual mobility is incorporated in the exposure estimate.

Methods

The following provides a brief overview of the study area and model used for this research; and is similarly described in Chapters 4 and 5. The most detailed description is provided in Chapter 3.

Study area. This research was conducted as part of the Border Air Quality Study (BAQS), funded by Health Canada via the BC Centre for Disease Control, using data for the Greater Vancouver Regional District (GVRD), located in southern British Columbia on the west coast of Canada. As of 2004, the total population of the GVRD was approximately 2.1 million people (Greater Vancouver Regional District 2006). Nearly 3.5 million trips are made daily in the GVRD, with about 75 percent of these made by private vehicle (Greater Vancouver Transportation Authority 2004). The same study also found that, on average, 57 percent of commuters travel outside of their home municipality to work, although this percent is lower near the downtown core and higher in the near suburbs.

Approach. Exposure simulation is used to investigate variability in estimates of chronic exposure to NO_2. This approach is based on the indirect method of exposure assessment, in which total exposure is equivalent to a time-weighted average of the concentrations of pollutants in various microenvironments (MEs) encountered throughout a day (Duan 1982; Ott 1985; Klepeis 1999). In theory, given the amount of time a person spends in each ME (i.e., indoor at home, indoor at work, commuting, shopping, and so on) and the associated pollution concentrations, the calculation of total exposure is straightforward, as shown in Ott (1985):

$$E_i = \sum_{j=1}^{J} C_j t_{ij} \tag{1}$$

E_i = the integrated exposure of person i over the time period of interest; C_j = the concentration of pollutant encountered in microenvironment j; t_{ij} = time spent by person i in microenvironment j; J = total number of microenvironments occupied by person i over the time period of interest. Dividing E_i by the total time period provides an estimate of exposure expressed in the units of the pollution estimate (i.e., parts per billion, or micrograms per cubic metre).

These kinds of data are not often readily available for large populations. Instead, probabilistic simulation is used to estimate a range of exposure estimates based on randomly sampling from representative time-activity patterns and distributions of possible pollution concentrations (Ozkaynak, Zufall et al. 1999; Kruize, Hanninen et al.

2003). This approach has been used extensively by the US Environmental Protection Agency (US EPA) in support of setting air quality management objectives and standards (Johnson 1995; McCurdy 1995; Burke, Zufall et al. 2001; U.S. Environmental Protection Agency 2005a; U.S. Environmental Protection Agency 2005b). For this research, the indirect approach is employed, based on the following six microenvironment equation:

$$\boldsymbol{E} = [(C_h \text{ x } t_h) + (C_w \text{ x } t_w) + (C_{oi} \text{ x } t_{oi}) + (C_o \text{ x } t_o) + (C_{tw} \text{ x } t_{tw}) + (C_{to} \text{ x } t_{to})] / T \quad (2)$$

$\boldsymbol{E}$ is a single estimate of exposure associated with the group *workers*, expressed in pollution concentration units; C_h is the pollutant concentration at *home indoor*; C_w is the pollutant concentration at *work indoor*; C_{oi} is the pollutant concentration at *other indoor*; C_o is the pollutant concentration outdoor; C_{tw} is the pollutant concentration in *transit to work*; C_{to} is the pollutant concentration in *transit other*; t_{h}, t_{w}, t_{oi}, t_{o}, t_{tw} and t_{to} are the time spent in each respective microenvironment, based on the time-activity pattern; and T equals the duration of time activity pattern. For the non-working group, the *work indoor* and *transit to work* MEs are omitted. For the *residence only* scenario, only the *home indoor* ME is employed. ***E*** is the total exposure estimate, and the valus associated with each microenvironment variable are the partial exposure estimates. As per Equation 2, there will be either four partial exposure estimates for *non-workers*, or six partial exposure estimates for *workers*, one for each microenvironment listed on the right hand side of the equation. For the *residence only* scenario, the total exposure estimates are equivalent to the partial exposure estimates produced for the *home indoor* ME.

Model specification and data. A spatial exposure simulation model (SESM) was developed using a geographic information system (ESRI ArcGIS 9.1©) and custom C++ programming. The SESM requires 1) time-activity patterns for the population(s) of interest; 2) census-based work flow data indicating home and work census areas; 3) spatially allocated concentrations of the pollutant of interest; 4) spatial locations for residential and commercial buildings; 5) the selection of suitable indoor/outdoor ratios for the pollutant studied and associated indoor MEs; and 6) a detailed road network.

1) Time-activity pattern data consist of the amount of time spent in different types of locations (but not the actual geographic locations), typically for a 24 hour period. Data from the Canadian Human Activity Pattern Survey study (Leech, Wilby et al. 1997), which also includes the date of survey, age, gender and the number of hours worked, were used as a basis for simulation in the SESM. Time reported as spent in a variety of locations in CHAPS was aggregated for each time-activity pattern into the six MEs used for this research: *home indoor*, *work indoor*, *other indoor* (including time spent shopping or in restaurants, for example), outdoor, transit work, and *transit other* (all non-work transit time). It is important to note here that no statistically significant differences were found in the time spent in each ME between female and male workers, so these time-activity patterns were pooled.

Certain assumptions were made based on the need to use daily time activity patterns to simulate the annual exposures, most importantly that *workers* have the same time-activity pattern on all workdays in the year, and have a random non-work pattern on each weekend day of the year. In order to incorporate weekday/weekend and summer/winter variations in the amount of time spent in different MEs over a year, the time-activity pattern records were grouped into three categories: *non-workers* summer (320 records), *non-workers* winter (278), and *workers* (178 records, including male and female, summer and winter). The numbers of unique time-activity pattern records in each group are comparable to those used in other studies, for example, Kruize, Hanninen et al, (2003) used 434, 322, 83, and 100 time-activity pattern records to represent the total population of urban adults in Helsinki, Basel, Prague, and Athens respectively. An additional file with one time-activity pattern showing 24 hours in the *home indoor* ME was used to simulate exposure estimates for the *residence only* scenario. In the SESM, the same set of time-activity patterns is used for the simulation in each census tract, thus controlling for variation due to demographic differences, and allowing for the identification of variability due to the spatial relationships between pollution levels and typical mobility patterns.

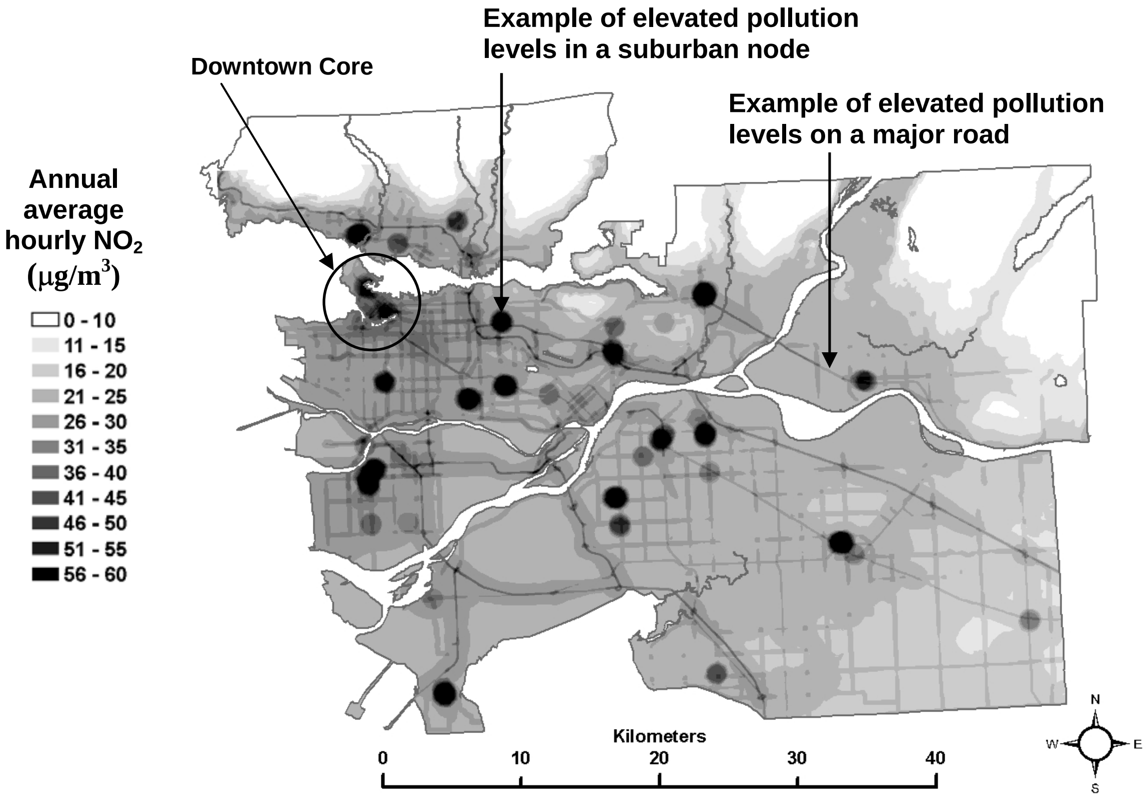
2) Work flow data for all people aged 15 and over reporting employment, based on a 20 percent sample in each census tract on May 15th, 2001, were purchased from Statistics Canada. For each census tract, the numbers of workers going from the census

tract of their residence to another census tract for work were used to develop separate female and male work pair lists and associated frequencies for use in the SESM. Workers who had a place of employment within the census tract of their residence were excluded, under the assumption that commuting distance would be negligible, and that the ambient pollution levels at home and work would be similar. Data showing a work census tract outside of the study area also were not included. The implemented SESM does not employ specific demographics for each census tract, so the results of the simulations need to be interpreted with caution. The resulting distributions of exposure estimates do not represent the total population in a census tract, but rather provide an indication of the possible range of exposures members of the groups *worker* or *non-worker* in the census tract could experience.

3) The SESM requires a spatial estimate of pollution levels for the study area. In terms of traffic-related air pollution, many epidemiological studies of traffic-related air pollution use nitrogen dioxide (NO_2) as an indicator of exposure to the total mix of pollutants as it has been show to be associated with proximity to roads (Roorda-Knape, Janssen et al. 1998; Janssen, van Vliet et al. 2001; Gilbert, Woodhouse et al. 2003; Maruo, Ogawa et al. 2003), traffic volume (Kramer, Koch et al. 2000; Smargiassi, Baldwin et al. 2005) and some of the other constituents of traffic-related air pollution thought to be most harmful, such as black carbon from heavy duty diesel vehicles (Brunekreef, Janssen et al. 1997; Le Tertre, Medina et al. 2002; Kim, Smorodinsky et al. 2004). For this research, it is assumed that outdoor NO_2 in the study area is predominantly produced by traffic rather than other sources such as industrial processes or space heating.

A spatial estimate of annual average hourly NO_2 levels (Figure 3.1), developed by researchers at the University of British Columbia using the land use regression (LUR) method with field monitoring conducted in 2003, was employed and is fully described in (Henderson, Beckerman et al. 2007). Briefly, the method uses linear regression to relate surrounding geographic variables to field measurements of the pollutant of interest, and the resulting model is used to predict pollution levels for every cell in a grid that covers the entire study area. The grid spacing is usually very fine (5 m). The most important features of the spatial estimates are that gradients in NO_2 with distance from roadways are captured, as are higher concentrations of NO_2 in commercially developed areas and regional gradients from the more polluted urban areas to less polluted rural areas. It is this level of detail in the spatial allocation of NO_2 levels that allows the SESM, as employed in this study, to differentiate among census tracts based on their location in the study area and among the MEs included in the model.

Figure 3.1. Spatial estimate of annual average NO_2 levels



4) Additional geographic detail is incorporated in the SESM through the use of spatial property assessment data. Spatial property assessment data were used to identify the geographic location of every property in the study area for which taxes are assessed as well as the primary use of the building on the property. Within each census tract, property locations (either residential or commercial) were used to constrain the SESM to areas where these buildings exist, rather than assuming a homogeneous distribution.

5) Since people spend most of their time indoors and outdoor air pollution does not always fully infiltrate into indoor areas, indoor/outdoor (I/O) ratios are applied to adjust pollution level distributions for the indoor MEs used in the SESM. In the absence of data on long-term I/O ratios for NO_2, fixed I/O ratios are used in the SESM based on the primary building use documented in the spatial property assessment data. Residential buildings were assigned an I/O ratio of 0.70, large office buildings 0.35, manufacturing, industrial, and civic buildings 0.50, and small stores, services, and restaurants 0.70, based on a review of available indoor/outdoor monitoring studies (for example, (Liao, Bacon-shone et al. 1991; Ekberg 1995; Monn, Brandli et al. 1998; Lee, Chan et al. 1999; Chao and Law 2000; Partti-Pellinen, Marttila et al. 2000; Guo, Lee et al. 2004; Lai, Kendall et al. 2004; Blondeau, Iordache et al. 2005). During the development of the SESM, results were found to be insensitive to the use of different I/O ratios. For example, results were not significantly different under a ‘worst case’ scenario where all commercial buildings were set to 0.35 and all residential buildings to 0.75, when compared to results using the more moderate scenario used in the application of the SESM described here. A comprehensive review of studies including I/O ratios for a variety of locations is available in Chapter 3, Section 3.2.7.

6) A digital road dataset was acquired for the study area from DMTI Spatial Inc. under an academic research agreement. This dataset was converted into a GIS network using ArcGIS 9.1, thereby allowing for the identification of the shortest route (assuming travel by car) between two points while observing appropriate travel restrictions such as one way streets and speed limits. For every home census tract, the shortest route based on time for every work census tract listed in the work pair file was identified and saved as a unique GIS file using a specific identifier (i.e., originCT10_destinationCT_205) with attributes including total distance and total time associated with the route. In total, 34,782 GIS files were created, representing the shortest routes between each home census tract and all associated work census tracts.

Given the spatial pollution estimate, routes between home and work census tracts, building locations and associated I/O ratios, a geographic information system (GIS) was used to develop distributions of NO_2 for each ME that are unique to each census tract in the study area. For a specific census tract, the distribution of NO_2 levels for the *home* *indoor* ME is comprised of values extracted from the NO_2 surface for each residential building location (assumed to be the centroid of each property parcel) in the census tract and multiplied by 0.70. For the *work indoor* ME, the pollution distribution is developed the same way, extracting NO_2 levels at commercial building locations within the work census tract and multiplying by I/O ratios of 0.35, 0.50, or 0.70 according to building type. Pollution distributions for the *other indoor* ME are based on sampling the pollution surface at commercial locations within 5 kilometers of the residential census tract and again multiplying by the appropriate I/O ratio. Similarly, for the *outdoor* ME, a regularly spaced grid of sample points is used to extract NO_2 values from the surface within 5 kilometers of the residential census tract. For the *transit other* ME, the road network is used to create sample points for extracting NO_2 values along roadways within 5 kilometers of the residential census tract; these values are then averaged to provide a single *transit other* value for the census tract. A distance of 5 kilometers was chosen to represent the average distance people travel from home on non-work related trips based on a review of studies reporting a typical range between 2 and 8 kilometers (Janelle, Goodchild et al. 1988; Handy 1996; Crane and Crepeau 1998). As well, the SESM results were found to be insensitive to variations in the distance chosen between 2.5 and 7.5 kilometers (Chapter 3). For the *transit to work* ME, distributions are made up of the length-weighted average pollution level along the shortest route between each home-work pair associated with the census tract. No I/O ratios are applied to the *outdoor*, *transit other* or *transit to work* MEs. It is important to note here than no indoor sources of NO_2 are included in the simulation. For indoor microenvironments, the distributions of NO_2 levels represent the amount of NO_2 generated by traffic that infiltrates indoors.

Once the pollution concentration distributions for each census tract are developed, random sampling is used to calculate the exposure estimates for a year. For example, to simulate exposure estimates for *workers* in the first census tract, a single time-activity pattern is randomly selected to represent all workdays in a year, a work destination is randomly chosen from the frequency-weighted distribution of possible work pairs, and pollution levels are randomly chosen from the appropriate distributions for the MEs. Exposure estimates for workdays is then calculated as a time-weighted average of these randomly selected pollution levels for each ME, as per Equation (2). For summer weekends (53 days between March 21st and September 21st), a non-worker summer time-activity pattern is randomly selected, the appropriate distributions sampled for pollution levels, and an exposure estimate calculated as per Equation (2). This is repeated 53 times, and the average taken to represent the total and partial exposures for summer weekends. A similar procedure is used to calculate the exposure estimates for winter weekends (53 days between September 22nd and March 20th). Results for workdays and summer and winter weekends are then combined to provide a time-weighted, seasonally adjusted estimate of exposure to annual average hourly NO_2, as per Equation (3):

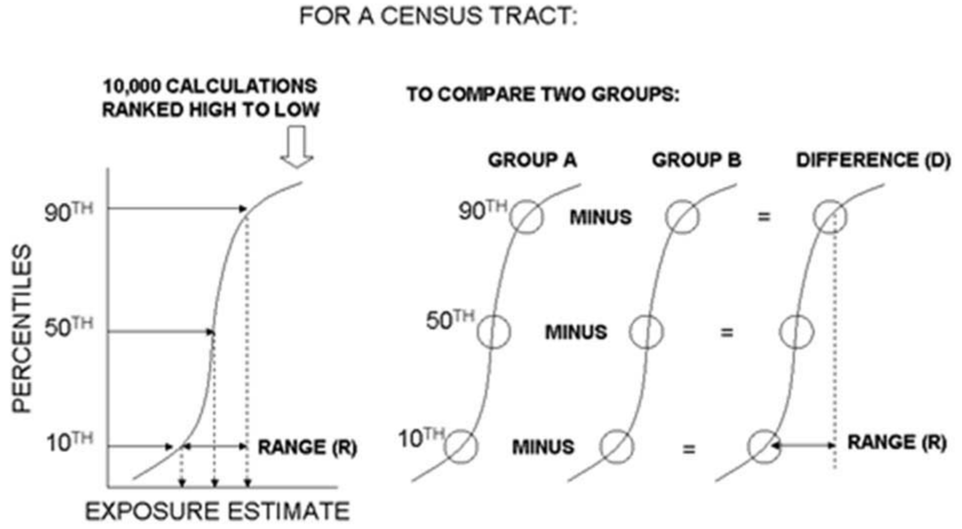
$$\boldsymbol{E_y} = [\{(W_a * 0.72) + (W_{ws} * 0.28)\} * 0.50] + [\{(W_a * 0.72) + (W_{ww} * 0.28)\} * 0.50] \quad (3)$$

Where $\boldsymbol{E_y}$ is the annual total exposure estimate; W_a is the exposure during weekdays; W_{ws} is the exposure during summer weekends; W_{ww} is the exposure during winter weekends; the weight 0 .72 represents the proportions of working days in summer or winter; the weight 0.28 represents the proportion of weekend days in summer or winter; and the weight 0.50 gives the summer and winter components equal weight in the sum.

This set of calculations is repeated 10,000 times in each census tract, producing distributions of exposure estimates with 95% confidence of estimating exposure at any percentile to within +/-1 percentile (Cullen and Frey 1998). Exposure estimates for *non-workers* are produced the same way, although for only four microenvironments: *home indoor*, *other indoor*, *outdoor* and *transit other*. Exposure estimates for the *residence only* scenario is produced using only the *home indoor* ME.

The resulting distributions can be compared statistically as well as visually through graphs or maps (Figure 3.2). For example, the median (referred to as the 50th percentile) of the exposure distributions in each census tract can be mapped to identify spatial patterns. The 10th percentile and 90th percentile values can be similarly mapped and compared to identify the spatial patterns in the lower and upper ranges of the exposure estimates. The differences between the 10th and 90th percentiles in a distribution can be calculated and mapped to show the range of the distribution, which indicates variability within census tracts (i.e., a low range indicates low variability and a large range indicates higher variability). In this study, particular attention is given to the differences between distributions for the same census tract, produced by subtracting, for example, the 50th percentile of the *residence only* distribution from the 50th percentile of the *worker* distribution.

Figure 3.2. Distributions produced and measures used for comparison



Due to the specification of the SESM as applied here, results must be interpreted with caution, under the following caveats. (1) Results apply to workers commuting by car, not working in the census tract of residence, and who have a fixed place of employment all year. Therefore, the SESM does not reflect exposure estimates for people who work in transit-related occupations (e.g., bus, taxi, truck drivers), people who regularly work at different locations within a region or outdoors (e.g., real estate sales, home care workers, construction workers), or people who use other modes of transportation. (2) Results do not reflect real measured personal exposures, but instead reflect possible exposure based on the input data. (3) The results reported here are specific to ambient traffic-related air pollution as indicated by NO_2, and do not include any indoor sources of NO_2 such as gas stoves or work-related equipment. (4) SESM results are sensitive to the use of different methods for estimating the spatial allocation of pollution levels, e.g. spatial interpolation based on fixed-site monitoring (see Chapter 3). Here, the most spatially detailed estimate of NO_2 levels available for the study area was employed. Less detailed estimates, such as might be produced via spatial interpolation from fixed-site air quality monitors, may produce results that differ from those reported here.

Results

The objectives of this paper are to identify if there are significant differences among the distributions of exposure estimates for the two simulated groups: *workers* and *non-workers,* and to compare the estimated exposures for these groups with exposures estimated for a *residence only* scenario. First, a map showing the 50th percentile exposure estimate of the distributions produced for each census tract in the study area for the *residence only* scenario provide an indication of the spatial pattern and relative magnitude of the median exposure estimates.[15] Figure 3.3 shows that median exposures range from less than 10 $\mu g/m^3$ to approximately 40 $\mu g/m^3$ of annual average hourly NO_2. Highest medians are associated with areas where the ambient pollution levels are highest (i.e. the urban core and suburban nodes), and a regional gradient is also evident, with higher median exposures nearer the urban core and lower median exposures in the farther suburban and rural areas. The spatial patterns and magnitudes of the median exposures for workers and non-workers is almost identical, and so are not shown here.

Next, differences in the estimated exposures are analyzed quantitatively. The 10th percentile level of the exposure distributions for each group in each census tract are treated as summary distributions (each with 382 values, the number of census tracts in the study area). In other words, all of the 10th percentile levels for the *non-worker* exposure distributions in the study area are treated as a single summary distribution, the 10th percentile levels for all the *worker* exposure distributions in the study area are treated as a single summary distribution, and the 10th percentile levels for all the *residence only* exposure distributions in the study area are treated as a single summary distribution. The two sample t-test is then used to ascertain if statistically significant differences exist between the means of the summary distributions for (A) *non-workers* and *residence only*; (B) *workers* and *residence only,* and (C) *workers* and *non-workers*. This is repeated for

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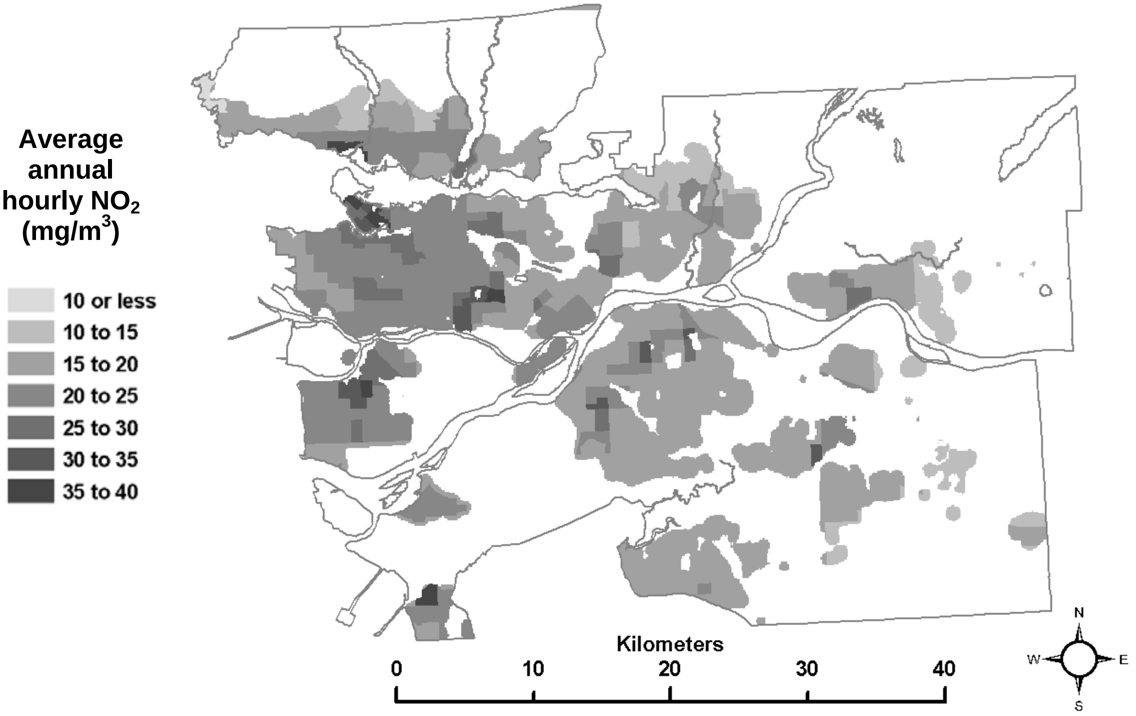
[15] Note: For maps presenting SESM results, areas where there is less than one residential building per 500 meters are not shown. This is done to avoid giving visual importance to unpopulated portions of large rural census tracts.

all of the 50th percentile levels from the exposure distributions, and all of the 90th percentile levels as well. The results are presented in Table 3.1, which shows for each comparison (A, B, and C) at each percentile level, the t-test value and significance, the mean for each summary distribution, the difference in the means, and the confidence interval associated with the difference in the means.

Figure 3.3 Median (50th percentile) exposure estimates for the *residence only* scenario



Tests of the means of the summary distributions at the 10th, 50th, and 90th percentiles across all census tracts (column 3 in Table 3.1) show that all are significantly different, with the exception of the 50th percentile levels for *workers* and *residence only*. The differences are, however, relatively small (column 6 in Table 3.1). Notably, differences in the means of the 10th, 50th, and 90th percentiles for (A) *non-worker*s and *residence only* are close to 1.00 μg/m^3 of annual average hourly NO_2, and means are always higher for *non-workers* than for *residence* only. For (B) *workers* and *residence only*, the difference in the means at the 10th percentile level is -1.93 μg/m^3 of annual average hourly NO_2, indicating that at the 10th percentile, *workers* estimated exposure is lower than *residence only* estimated exposure. This is reversed at the 90th percentile, where the difference in the means is 2.72 μg/m^3, indicating that *workers* estimated exposure is higher than *residence only* estimated exposure. This is also true of the differences in means for (C) *workers* compared to *non-worker*s (-2.89 and 1.71 at the 10th and 90th percentiles respectively).

Table 3.1. Statistical tests for differences in estimated exposure distributions across census tracts

Comparison	Percentile	t-test [significance 95% two-tailed]	**Annual Average Hourly NO$_2$ (μg/m^3)** Mean *n* = 382 (a)	Mean *n* = 382 (b)	Diff. in means (a) – (b)	CI (95%) for the difference in means
			Non-worker	**Residence only**		
	10th	2.79 [.0054]	21.72	20.76	0.96	0.29 to 1.65
A	50th	2.83 [.0048]	21.92	20.93	0.99	0.30 to 1.67
	90th	2.86 [.0043]	22.13	21.12	1.01	0.32 to 1.70
			Worker	**Residence only**		
	10th	-6.12 [.0000]	18.83	20.76	-1.93	-2.54 to -1.32
B	50th	**-0.05 [.9574]**	20.92	20.93	-0.01	-0.65 to 0.61
	90th	-8.42 [.0000]	23.84	21.12	2.72	2.09 to 3.36
			Worker	**Non-worker**		
	10th	-10.00 [.0000]	18.83	21.72	-2.89	-3.46 to -2.32
C	50th	-3.37 [.0008]	20.92	21.92	-1.00	-1.59 to -0.42
	90th	5.70 [.0000]	23.84	22.13	1.71	1.12 to 2.30

Bold indicates no significant difference

The t-test results show that there are statistically significant differences when comparing the exposure distributions across the study area. The pattern in the differences suggests lower exposures at the 10th percentile and higher exposures at the 90th percentile for *workers* compared to *non-workers* or *residence only*. The following analysis takes a closer look at the differences between *workers* and *non-workers* within each census tract. The focus is on the difference between the 10th percentile value for the *worker* exposure distribution and the 10th percentile value for the *non-worker* exposure distribution in the same census tract (i.e., *worker* minus *non-worker* at the 10th percentile). The difference between these two exposure distributions is then mapped to provide insight into why the differences may be occurring. The same is done for the *workers* and *non-workers* at the 90th percentile.

Maps illustrating the differences between the *worker* and *non-worker* exposure distributions at the 10th and 90th percentiles are provided in Figure 3.4 and Figure 3.5. At the 10th percentile (Figure 3.4), exposure estimates for *workers* are less than for *non-workers* by as much as 5.4 $\mu g/m^3$ where pollution levels are higher, i.e., in the urban core and around suburban nodes. This pattern suggests that some workers living in the most highly polluted areas (i.e. where the median exposure estimates are generally between 20 and 40 $\mu g/m^3$ of annual average hourly NO_2), could be inadvertently benefiting relative to non-workers in the same census tracts by going away to other less polluted census tract for work. Conversely, exposure estimates at the 90th percentile (Figure 3.5) for *workers* are higher than for *non-workers* by as much as 6.5 $\mu g/m^3$ in the suburban and rural areas where the median exposure estimates are generally between 10 and 20 $\mu g/m^3$ of annual average hourly NO_2. This pattern suggests that workers residing in the suburban and rural areas where pollution levels are low, could have disproportionately higher exposures than non-workers living in the same census tract, due to time spent at work locations where pollution levels are higher.

This interpretation is supported by a simple analysis of the annual average hourly NO_2 levels in residential census tracts compared to the NO_2 levels in the associated work census tracts where the differences are large. Table 3.2 provides the ratios of NO_2 in home census tracts to the NO_2 at work census tracts where differences are largest at the 10th and 90th percentiles. In general, where estimated exposures for *workers* are much lower than for *non-workers* (see Figure 3.4), pollution levels are between 1.34 and 1.65 times higher in home census tracts than in work census tracts. Where estimated exposures for *workers* is much higher than for *non-workers* (see Figure 3.5), pollution levels in home census tracts are approximately one third of the levels in work census tracts. Results comparing the exposure distributions for *workers* and *residence only* are similar, and so are not included here.

Figure 3.4. Areas where estimated exposure at the 10th percentile for *workers* is lower than for *non-workers*

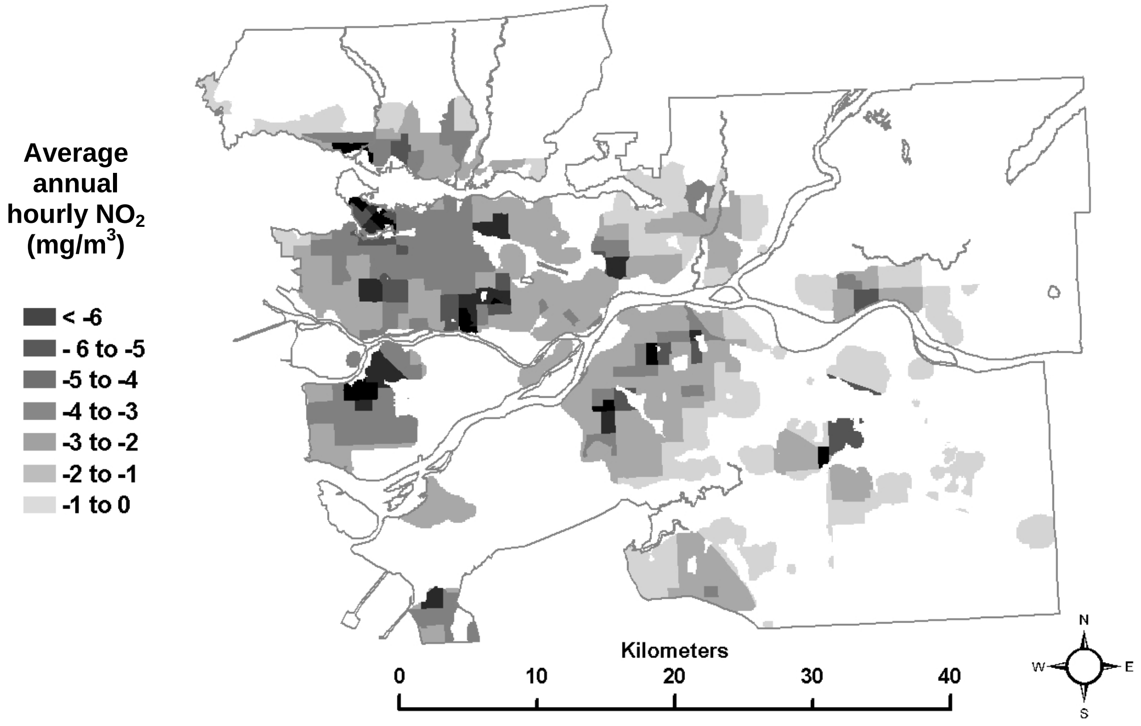


Figure 3.5. Areas where estimated exposure at the 90th percentile for workers is higher than for non-workers

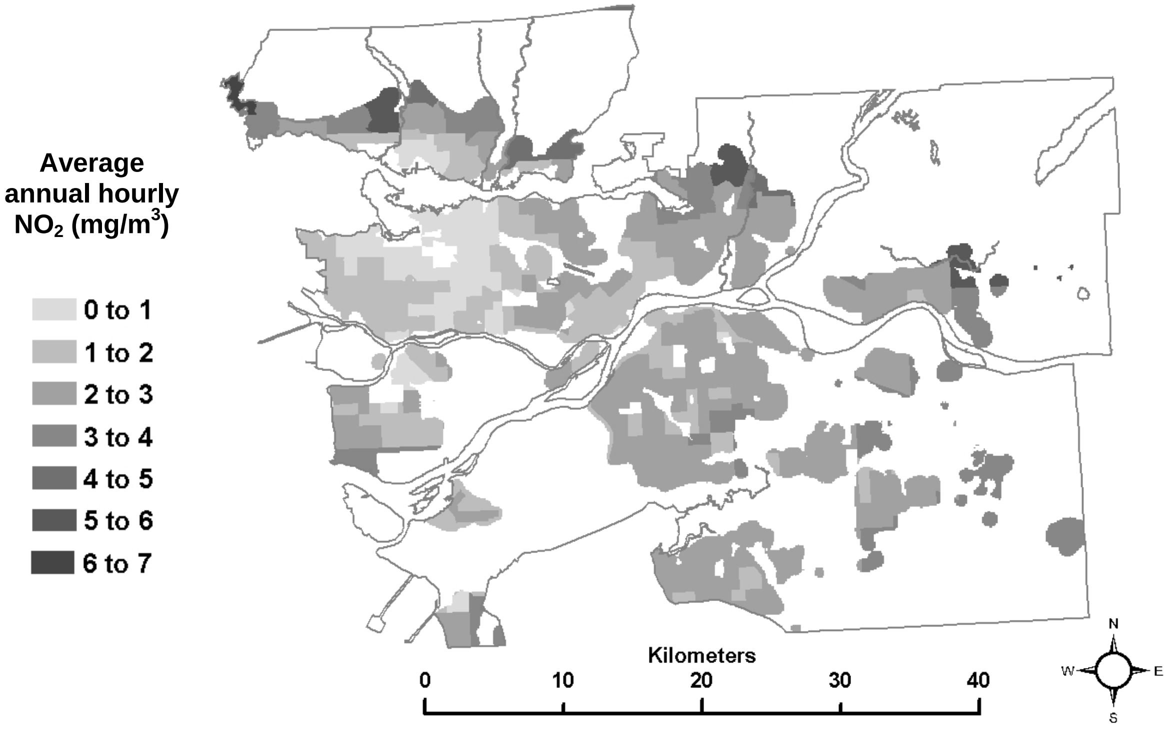


Table 3.2. Comparison of annual average hourly NO_2 at home and work census tracts

Home census tract	Average annual hourly NO_2 ($\mu g/m_3$) Difference in exposure (*worker* minus *non-worker*)	Average at home census tracts (a)	Average at Work census tracts (b)	Ratio of NO_2 at home and work (a) / (b)
***Workers* are much less exposed at the 10th percentile**				
A	-6.5	52	33	1.58
B	-6.5	55	34	1.62
C	-6.3	43	32	1.34
D	-6.3	51	31	1.65
E	-6.1	50	31	1.61
***Workers* are much more exposed at the 90th percentile**				
F	5.4	8	30	0.27
G	5.4	12	33	0.36
H	5.1	11	31	0.35
I	4.9	11	32	0.34
J	4.3	11	31	0.35

Discussion

The SESM presents a unique approach to investigating variability in exposure estimates between *workers* and *non-workers*, and for making comparisons with the often used *residence only* based approach. Very few published studies are available that provide results comparable to the SESM, so it is difficult to place this study within the context of existing research. Personal monitoring of NO_2, conducted in Helsinki as part of the EXPOLIS study, suggests that having a work location downtown results in a mean personal exposure of 30.1 $\mu g/m^3$ of NO_2 , while having a work location in a suburban area produces an average of 23.7 $\mu g/m^3$, a difference of 5.4 $\mu g/m^3$ (Rotko, Kousa et al. 2001). It may be that the people monitored in Helsinki who had a work location downtown also lived downtown where NO_2 levels may be higher than in suburban areas, a factor which could account for the differences noted. Without knowing where the subject lived in relation to downtown, it is not possible to compare these results to the SESM results. No other studies of NO_2 exposure were found which reported specific levels for workers and non-workers with enough spatial detail to allow for comparison.

The authors are aware of one study of traffic-related air pollution, conducted for the South Coast air basin in California, which provides some useful information in terms of interpreting the SESM results. Inhalation intake (a measure of exposure) was estimated using detailed spatial estimates of five pollutants for every hour over a period of one year, and an origin-destination survey giving geographic locations over a 24 hour period for approximately 29,000 person days (Marshall, Granvold et al. 2006). Inhalation intake was seen to increase when mobility was included in the calculation, compared to a base case without including mobility. The effect differed among the pollutants, with the lowest increase (+ 2 percent) seen for ozone, followed by benzene (+ 5 percent), diesel particulates (+ 8 percent), hexavalent chromium (+ 27 percent) and butadiene (+ 30 percent). These results, although not directly comparable to the SESM as implemented here, do show that including geographic information on mobility can have an appreciable effect on exposure. The approach used by Marshall, Granvold et al (2006) is more sophisticated than the SESM, as it includes variable breathing rates and 29,000 geographic location patterns in a 24 hour period for real people that can be generally matched by time to pollution concentrations. The authors have yet to publish any spatially explicit analysis of the data, such as could done by mapping each subject by residential location. Although less sophisticated, the SESM has the advantage of being able to produce comparable exposure estimate distributions within each census tract in a study area, whereas the method used by Marshall, Granvold et al (2006) summarizes distributions over the entire population in their study area. The SESM also employs shortest routes along the actual road network in the study area, rather than straight lines between origins and destinations, as was done by Marshall, Granvold et al (2006).

On average, the exposure estimates based on *residence only* provided a reasonable surrogate of chronic exposure to ambient levels of NO_2, as indicated by the relatively small differences in the means of the *worker*, *non-worker*, and *residence only* distributions. Still, statistically significant differences were observed, and showed distinct spatial patterns where workers were systematically less or more exposed than non-workers in the same census tracts. With respect to the potential effects of using exposure estimates based on *residence only* instead of measures that incorporate mobility in population-level epidemiological studies, again, no other studies similar to the one presented here were found. Otherwise, there are two recent studies which provide some evidence of the effect of exposure measurement error in the study of air pollution effects on health. In a study of $PM_{2.5}$ and mortality in Los Angeles, the relative risk of all-cause mortality for a 10 $\mu g/m^3$ increase in exposure was 1.17 (95% CI 1.05 – 1.30) compared to a previous study which found relative risk to be 1.06 (Jerrett, Burnett et al. 2005). The authors attribute this increase to the use of more spatially refined within-community estimates of pollution levels, compared to the more general between-community differences in pollution levels. They suggest that measurement error was decreased by using the more refined pollution estimate, thereby producing a relative risk estimate almost three times higher. Another study of long term exposure to $PM_{2.5}$ and the effect on the cardiovascular health of women in 36 US cities found that "estimates of effects within cities were often larger than those effects between cities" (Miller, Siscovick et al. 2007). While neither of these studies is directly comparable to the results presented here, they do provide evidence that estimates of relative risk may be higher with more accurate exposure measurement. The SESM results indicate that even when using pollution estimates that capture within-community variation in concentrations, exposure measurement error could still exist, that it may be related to mobility, and that relative risk may be underestimated for some groups, particularly working people.

We recommend that future population level epidemiological studies of ambient air pollution attempt to incorporate location and hours of work into exposure assessments as a means of reducing potential effects of exposure measurement error on estimates of relative risk. This could be particularly important when studying pollutants that exhibit high spatial variability within a study area. Opportunities for accomplishing this could include linking health records with tax records, although privacy and confidentiality concerns may prove to be significant barriers.

The simulation results also identify disparities in terms of estimates of chronic exposure between *workers* and *non-workers*. In areas with relatively high NO_2, *workers* may benefit from leaving residential areas where pollution is high and going to work locations where pollution levels are lower. *Workers* may experience higher exposures than *non-workers* in the same census tract when NO_2 levels are higher at work locations.

Exposure reduction policies should take these disparities into account by developing a range of policies specific to areas and population groups that could benefit most.

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4.0 CONCLUSIONS

The link between exposure to air pollution and a diversity of health outcomes has been the topic of research for many decades, and research results have been used to support the setting of air quality standards in many countries. Population level epidemiological studies have contributed greatly to this field of inquiry, notably the time-series studies conducted in the US, for example by Dockery, Pope et al (1993), and Samet, Dominici et al (2000). Studies like these, in conjunction with others based on clinical research on pollutant toxicity and the biological effects of exposure, and field research on pollutant sources and variability, have provided a substantial body of evidence for associations between exposure to air pollution and many human health impacts, and have helped to highlight the research needs around specific populations, pollution sources and on improving analytical methods. The research presented here addresses aspects of each of these areas. Three populations have been studied: female workers, male workers, and non-workers. The pollution source of interest was NO_2 as a surrogate for exposure to traffic-related pollutants. A new analytical method, taking worker and non-worker mobility and geographic locations for commercial and residential buildings into account, was developed to support improving the exposure assessments inherent in population level epidemiological studies of air pollution.

This final section presents conclusions drawn from this research, organized in the following order. First, a discussion of the results and their implications is presented according to the research question posed at the outset. Second, lessons learned about simulation modelling during the development of the SESM are presented. Finally, refinements to the SESM are recommended and future research areas are identified.

4.1 RESEARCH RESULTS AND IMPLICATIONS

Literature reviews conducted for this dissertation identified two trends in the research on traffic-related air pollution and its effect on population health. First, researchers are using increasingly more detailed pollution estimates to develop exposure assessments in order to reflect within-community variation. Second, the exposure models employed for large populations have remained relatively simplistic, most often using pollution levels only at residential locations to indicate chronic exposure. Given that there can be substantial variation in traffic-related air pollution within a region, and that people move freely about in that region, the objective of the research presented here was to explore how these variations in pollution and people's locations in space and time interact to affect chronic exposure. This research was guided by the following three questions:

- Is there a spatial pattern in exposure due to the activities of working and commuting?

- Are there spatial differences in exposure to traffic-related air pollution based on gender?

- With respect to traffic-related air pollution, how might exposures for working people differ from non-working people, and how might these in turn differ from exposure measures that do not incorporate the mobility patterns of people in a region? If there are differences, what are the implications for population level epidemiological analyses of air pollution?

The remainder of this section provides a summary of the results addressing each of these questions.

4.1.1. Is there a spatial pattern in exposure due to the activities of working and commuting?

In the case of annual average hourly exposure to NO_2, there are several notable spatial patterns in the estimated exposure distributions associated with working and commuting in the GVRD. The highest estimated total exposure to NO_2 is seen in census tracts closest to the urban core where pollution levels are highest, and exposures decrease with distance from the core as pollution levels decrease, reflecting time spent at home. There is, however, substantial variability in exposure within census tracts. The largest within-census tract ranges in exposure are associated with the *work indoor* ME, and are found in suburban census tracts, where some *workers* may experience higher (between 26 and 38 percent, or 5.5 to 8 $\mu g/m^3$) annual average hourly exposure than other *workers* who live in the same suburban census tract. This within-census tract disparity in exposure is caused by the tendency of *workers* in suburban areas to commute to a wide range of other census tracts in the study area, some where pollution is low, and some where pollution is high. In comparison, many *workers* in census tracts closer to the urban core appear to work closer to home and more often in the urban core, so pollution levels in work census tracts are relatively similar and the within-census tract ranges in exposure associated with working are lower. Interestingly, although there is a clear pattern of higher exposures associated with the *transit to work* ME in the census tracts farthest away from the urban core, the level of exposure encountered in transit is negligible in comparison to the exposures encountered in other microenvironments, due to the small amount of time spent in transit relative to time spent, for example, at home.

These results suggest that there can be considerable variability in chronic exposure to NO_2 both regionally and within census tracts. In the first case, variability in exposure is most affected by NO_2 levels in the census tract of residence. Air quality management policies aimed at risk reduction should therefore focus on reducing NO_2 levels in residential areas. In the second case, variability in exposure within census tracts is most affected by where residents commute to work, which is in turn affected by where the census tract of residence is located relative to employment centres. To reduce disparities in exposure within census tracts, air quality management policies should focus on reducing ambient NO_2 in high employment centres, and urban planning and transportation policies should focus on reducing commutes by car from suburban areas. The SESM results identify specific census tracts with higher exposures that could be part of an initial focus for policy.

4.1.2 Are there spatial differences in exposure to traffic-related air pollution based on gender?

Although there is substantial evidence that females tend to commute shorter distances than males, no significant differences in the distributions of total exposure to annual average hourly NO_2 were found in the SESM results. The differences in means between female and male *workers* at the 10th, 50th, and 90th percentiles of the simulation results were less than 0.20 $\mu g/m^3$ of annual average hourly NO_2. Still, there was an observable effect on the partial exposure associated specifically with the *work indoor* ME due to differences in female and male work destinations. This was seen in the highest 10 percent of the differences between female and male *workers* at the 90th percentile of the estimated exposure for the *work indoor* ME. An investigation into the work patterns for female and male *workers* in these few census tracts showed that female *workers* tended to work in the urban core and suburban commercial nodes where pollution was relatively high, and that male *workers* in these census tracts tended to work at census tracts dispersed throughout the study area with no preference for developed commercial centres.

These results suggest that for population level epidemiological studies of air pollution in the study area, female and male *workers* can be treated as the same population, in terms of time spent in various locations (home, work, outdoor, in transit, etc.) and in terms of commuting patterns and their impacts on exposure assessment. The results also suggest that there is no need to develop policy in the GVRD specifically aimed at reducing disparities in chronic exposure to NO_2 based on gender.

4.1.3 Comparing workers, non-workers and residence only estimates of exposure.

The following discussion addresses the last group of research questions. With respect to traffic-related air pollution, how might exposures for working people differ from non-working people, and how might these in turn differ from exposure measures that do not incorporate the mobility patterns of people in a region? If there are differences, what are the implications for population level epidemiological analyses of air pollution?

The distributions of total exposure to NO_2 were, on average, very similar between simulated *workers* and *non-workers* who live in the same census tract, and median exposure levels follow the spatial pattern of pollution in the study area; however, there are interesting spatial patterns in the differences between *workers* and *non-workers* when total exposures are low (10th percentile) or high (90th percentile). At the 10th percentile of the distribution of total exposure, *workers* are less exposed than *non-workers*, particularly where pollution levels are high, by an average of 3 $\mu g/m^3$, and by as much as 6.5 $\mu g/m^3$, of annual average hourly NO_2. This suggests that some *workers* are inadvertently benefiting from leaving high pollution areas in order to go to work. At the 90th percentile of the distribution of total exposure, most *workers* are more exposed than *non-workers* in the same census tracts, on average by 2 $\mu g/m^3$, and by as much as 5 $\mu g/m^3$, of annual average hourly NO_2. The highest differences are seen in the suburban and rural areas, indicating that where pollution levels are low, *workers*' total exposure is increased by going to work where pollution levels are higher.

These results indicate that there can be substantial differences in total exposure to NO_2 among *workers* and *non-workers* living in the same census tracts, and that the differences show a spatial pattern that depends on where the census tract is located in relation to employment centres in commercially developed nodes and the urban core. In order to reduce disparities in exposure to NO_2, air quality management policies should focus on reducing ambient NO_2 levels in the commercially developed nodes and urban core. This would reduce exposures to NO_2 for nonworking residents in these areas. In suburban areas, exposures could be reduced for workers by decreasing commuting to more polluted areas.

There is recent evidence that associations between health effects and exposure to air pollution are found to be higher when pollution levels at residential address are used rather than a single community average (Jerrett, Burnett et al. 2005; Miller, Siscovick et al. 2007), due to the reduction of exposure measurement error. The SESM results suggest there could be additional measurement error due to the lack of accounting for mobility, at least for some working people in the study area.

4.2 SIMULATION MODELLING – LESSONS LEARNED

Evidence from personal monitoring studies and field monitoring of traffic-related air pollution suggest that there is enough variability in pollution levels within a region to create variability in chronic exposure due to individual mobility on a daily basis. To date, no research has specifically investigated what the magnitude of this variability might be both within, and between, neighbourhoods in a community. The SESM results provide a first spatially explicit look at how mobility due to working creates neighbourhood level (i.e., census tract) variability in exposure to annual average hourly NO_2. The model also highlights where disparities in exposure within neighbourhood are highest, and provides an indication of the magnitude of the disparity. The methodology adopted for this research provided interesting and useful results; however, during the development and testing of the SESM, some limitations of the approach and the required data were identified.

One of the early lessons learned here is that there is a general lack of longitudinal data in terms of the time-activity patterns. The time-activity patterns from CHAPS used for the SESM are for single 24 hour periods only. This is true of many other time-activity data sets, due to the difficulty of recruiting and retaining subjects willing to maintain accurate personal activity diaries for durations longer than several days. For example, ten different time-activity pattern data sets are incorporated into the Consolidated Human Activity Database (CHAD) maintained by the US EPA. Of the ten data sets included, the majority provide single-day patterns; however, one provides time-activity patterns for 8 hours, two provide 2-day patterns, one provides 3-day patterns, and one provides 5-day patterns. In the last case, records for only 26 people were collected (McCurdy, Glen et al. 2000). In addition to the lack of longitudinal time-activity patterns, no instances were found where time-activity surveys were conducted in the same city but at a later time. Without these kinds of follow-up surveys, it is not possible to identify any temporal trends in the amount of time spent in different locations and/or activities.

A similar gap exists with respect to data on indoor/outdoor ratios commonly used in air pollution exposure simulation modelling to adjust ambient-generated pollution concentration in indoor microenvironments. Most studies reviewed for this research monitored indoor and outdoor air for no more than two weeks, and some for a little as one hour. Longer periods of monitoring could be helpful to develop better estimates of average indoor/outdoor ratios for an entire year, particularly in the face of potentially large differences between seasons. More importantly, relatively small numbers of buildings (other than residential) and vehicles have been studied, which may affect how well the measures represent the true range of conditions.

One of the unique features of the SESM is the inclusion of shortest routes between residential census tracts and work census tracts. While this represents a potential improvement on other approaches used in air pollution exposure simulation models for capturing exposure while in transit, there are still significant limitations. For instance, there are many possible routes for travelling between two destinations. In this research, the shortest route in terms of time was assumed to best represent the usual route taken, where travel time is calculated as a product of the length of the route and the associated speed limit. Even more problematic is the difficulty of representing changing traffic conditions over time. For example, the effect of lower speeds due to traffic congestion at certain times of the day is not captured, nor is additional time spent at stop lights. The use of relatively simplistic routes therefore presents a ‘best case’ scenario in terms of estimating exposure while in transit-related microenvironments. This approach would be of significant concern if the SESM was used to simulate very short term exposures (i.e., several hours), or to simulate exposures to pollutants known to be very high when in heavy or slow-moving traffic.

One of the most important observations, in terms of the implications for population level epidemiological studies of air pollution, is the relative sensitivity of the SESM outputs to the use of different methods for creating a spatial pollution estimate. In this research, the correlation between outputs using two different methods (IDW and LUR) showed correlations (Pearson’s r) on the order of 0.60 to 0.71. In the literature review conducted for this research, it was observed that numerous methods for assessing exposure to air pollution are employed, including spatial interpolation, regression-based modelling, and dispersion modelling. The choice of methods is rarely explicitly justified, nor are the produced estimates evaluated with field monitoring. The sensitivity of the

SESM results to choice of methods indicates that much more attention should be paid to this potential source of bias. It is recommended here that any air pollution exposure assessment consider the effects of using different methods for estimating pollution levels, and conduct sensitivity analyses. At the least, the choice of method should be justified pragmatically.

Finally, because the SESM is designed to facilitate comparisons within and between neighbourhoods in a region, it is difficult to adequately evaluate the results. Other air pollution exposure simulation models have been evaluated using personal monitoring studies. In these cases, the simulation models produce a single distribution of probable exposures for a demographically representative population in a region, and the personal monitoring studies provide total personal exposure for a sample of demographically representative people in the same region. These kinds of personal monitoring data are not available for the study area included in this research, and because of the SESM design, would not be particularly useful for evaluation purposes. Evaluation of the SESM results would require monitoring of a representative sample of each simulated group (i.e., *workers, non-workers*) in each neighbourhood, resulting in a potentially very large and impractical sample size. Still, the SESM results do highlight specific census tracts where exposure estimates are relatively high. Personal monitoring could be conducted in these particular census tracts to evaluate SESM results specific to each.

4.3 FUTURE APPLICATIONS

Limitations notwithstanding, the SESM is a useful tool for comparing chronic exposure among different groups within and between census tracts (or other neighbourhood boundaries) in a region. Variations seen in the results are a product of the spatial patterns in the pollution estimate, residential and commercial development, work flow behaviour, and the road network, rather than demographic variation. The SESM could be used to evaluate the effect of changes in these characteristics, such as might occur through policy or planning. For example, the SESM could be used to simulate exposure given two different pollution surfaces that represent a change in the spatial pattern of pollution due to policies targeted at reducing levels in commercial or residential areas. Similarly, the effect of changing work flow patterns, such as through the implementation of targeted programs for telecommuting, could be assessed.

For this research, the SESM was used to simulate exposure to NO_2, chosen as an indicator of traffic-related air pollution. The SESM can also be used with any spatial estimate of pollution, and so could be used to simulate exposures for other air pollutants of concern, such as O_3 or $PM_{2.5}$. A relatively simple adjustment of the indoor/outdoor ratios employed would be required; otherwise the SESM needs no other additional programming.

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Appendix A. Scripts and Programs

ArcGIS© 9.1 Python scripts written by the author

```
# Select by Census Tract Loop for home indoor microenvironment
#
#September 2005
#
#Purpose: For a given set of census areas and a pollution surface, selects and calculates
#pollution concentrations for home indoors, then exports to a table for each census area
#
#Add utilities
import os, sys, string, win32com.client
#Add toolboxes
gp = win32com.client.Dispatch ("esriGeoprocessing.GpDispatch.1")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Data Management Tools.tbx")
gp.CheckOutExtension ("spatial")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Conversion Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGis\ArcToolbox\Toolboxes\Analysis Tools.tbx")
gp.OverWriteOutput = 1
#Set arguments
workfolder = sys.argv[1]
outfolder = sys.argv[2]
surface = sys.argv[3]
censuspolygons = sys.argv[4]
residentialpoints = sys.argv[5]
#
try:
# set workspace and counter
  gp.Workspace = workfolder
  gp.MakeFeatureLayer (surface, "Surfpol")
  num = 1
#
# loop through census tracts
  while num <= 383:
    #
    #select the first census area
    #
    gp.MakeFeatureLayer (censuspolygons, "CTtemp")
    gp.SelectLayerByAttribute ("CTtemp", "NEW_SELECTION", "\"selnum" + "\" = " + str(num))
    gp.CopyFeatures ("CTtemp", workfolder + "/CTsingle.shp")
    gp.MakeFeatureLayer (workfolder + "/CTsingle.shp", "CTsel")
    #
    # calculate residential indoor
    #
    gp.MakeFeatureLayer (residentialpoints, "REStemp")
    gp.SelectLayerByLocation ("REStemp", "COMPLETELY_WITHIN", "CTsel")
    gp.CopyFeatures ("REStemp", workfolder + "/RESsel.shp")
    gp.Identity (workfolder + "/RESsel.shp", "Surfpol", workfolder + "/RESval.shp")
    gp.CalculateField(workfolder + "/RESval.shp", "HINDOOR",  "[IN_OUT] * [GRIDCODE]")
    gp.ExportXYv (workfolder + "/RESval.shp", "HINDOOR", "COMMA", outfolder + "/HindoorCT" +
str(num))
```

```
    #
    # clean up
    #
    gp.Delete ("CTtemp", "layer")
    gp.Delete ("REStemp", "layer")
    gp.Delete ("CTsel", "layer")
    gp.Delete ("CTsingle.shp")
    gp.Delete ("RESsel.shp")
    gp.Delete ("RESval.shp")
    #
    # add a loop to delete interim shape files
    #
    fcs = gp.ListFeatureClasses("shape*", "ALL")
    fcs.Reset ()
    fc = fcs.Next ()
    while fc:
      gp.Delete (fc)
      fc = fcs.Next ()
    gp.AddMessage ("Finished Area" + str(num))
    num = num + 1
except:
 gp.AddError(gp.GetMessages())
 print gp.GetMessages()
```

```
# Select by Census Tract Loop for work indoor microenvironment
#
#September 2005
#
#Purpose: For a given set of census areas and a pollution surface, selects and calculates
#pollution concentrations for work indoors, then exports to a table for each census area
#
#Add utilities
import os, sys, string, win32com.client
#Add toolboxes
gp = win32com.client.Dispatch ("esriGeoprocessing.GpDispatch.1")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Data Management Tools.tbx")
gp.CheckOutExtension ("spatial")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Conversion Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGis\ArcToolbox\Toolboxes\Analysis Tools.tbx")
gp.OverWriteOutput = 1
#Set arguments
workfolder = sys.argv[1]
outfolder = sys.argv[2]
surface = sys.argv[3]
censuspolygons = sys.argv[4]
commercialpoints = sys.argv[5]
#
try:
# set workspace and counter
  gp.Workspace = workfolder
  gp.MakeFeatureLayer (surface, "Surfpol")
  num = 210
#
# loop through census tracts
  while num <= 383:
    #
    #select the first census area
    #
    gp.MakeFeatureLayer (censuspolygons, "CTtemp")
    gp.SelectLayerByAttribute ("CTtemp", "NEW_SELECTION", "\"selnum" + "\" = " + str(num))
    gp.CopyFeatures ("CTtemp", workfolder + "/CTsingle.shp")
    gp.MakeFeatureLayer (workfolder + "/CTsingle.shp", "CTsel")
    #
    # calculate work indoor
    #
    gp.MakeFeatureLayer (commercialpoints, "COMtemp")
    gp.SelectLayerByLocation ("COMtemp", "COMPLETELY_WITHIN", "CTsel")
    gp.CopyFeatures ("COMtemp", workfolder + "/COMsel.shp")
    gp.Identity (workfolder + "/COMsel.shp", "Surfpol", workfolder + "/COMval.shp")
    gp.CalculateField(workfolder + "/COMval.shp", "WINDOOR",  "[IN_OUT] * [GRIDCODE]")
    gp.ExportXYv (workfolder + "/COMval.shp", "WINDOOR", "COMMA", outfolder + "/WindoorCT"
            + str(num))
    #
    # clean up
    #
    gp.Delete ("CTtemp", "layer")
    gp.Delete ("COMtemp", "layer")
    gp.Delete ("CTsel", "layer")
    gp.Delete ("CTsingle.shp")
```

```
    gp.Delete ("COMsel.shp")
    gp.Delete ("COMval.shp")
    #
    # add a loop to delete interim shape files
    #
    fcs = gp.ListFeatureClasses("shape*", "ALL")
    fcs.Reset ()
    fc = fcs.Next ()
    while fc:
      gp.Delete (fc)
      fc = fcs.Next ()
    gp.AddMessage ("Finished Area" + str(num))
    num = num + 1
except:
 gp.AddError(gp.GetMessages())
 print gp.GetMessages()
```

```
# Select by Census Tract Loop for other indoor microenvironment
#
#September 2005
#
#Purpose: For a given set of census areas and a pollution surface, selects and calculates
#pollution concentrations for other indoors, then exports to a table for each census area
#
#Add utilities
import os, sys, string, win32com.client
#Add toolboxes
gp = win32com.client.Dispatch ("esriGeoprocessing.GpDispatch.1")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Data Management Tools.tbx")
gp.CheckOutExtension ("spatial")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Conversion Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGis\ArcToolbox\Toolboxes\Analysis Tools.tbx")
gp.OverWriteOutput = 1
#Set arguments
workfolder = sys.argv[1]
outfolder = sys.argv[2]
surface = sys.argv[3]
censusbuffer = sys.argv[4]
commercialpoints = sys.argv[5]
#
try:
# set workspace and counter
  gp.Workspace = workfolder
  gp.MakeFeatureLayer (surface, "Surfpol")
  num = 1
#
# loop through census tracts
  while num <= 383:
    #
    #select the first census area
    #
    gp.MakeFeatureLayer (censusbuffer, "CTtemp")
    gp.SelectLayerByAttribute ("CTtemp", "NEW_SELECTION", "\"selnum" + "\" = " + str(num))
    gp.CopyFeatures ("CTtemp", workfolder + "/CTsingle.shp")
    gp.MakeFeatureLayer (workfolder + "/CTsingle.shp", "CTsel")
    #
    # calculate shopping indoor
    #
    gp.MakeFeatureLayer (commercialpoints, "COMtemp")
    gp.SelectLayerByLocation ("COMtemp", "COMPLETELY_WITHIN", "CTsel")
    gp.CopyFeatures ("COMtemp", workfolder + "/COMsel.shp")
    gp.Identity (workfolder + "/COMsel.shp", "Surfpol", workfolder + "/COMval.shp")
    gp.CalculateField(workfolder + "/COMval.shp", "SINDOOR",  "[IN_OUT] * [GRIDCODE]")
    gp.ExportXYv (workfolder + "/COMval.shp", "SINDOOR", "COMMA", outfolder + "/SindoorCT"
            + str(num))
    #
    # clean up
    #
    gp.Delete ("CTtemp", "layer")
    gp.Delete ("COMtemp", "layer")
    gp.Delete ("CTsel", "layer")
    gp.Delete ("CTsingle.shp")
```

```
    gp.Delete ("COMsel.shp")
    gp.Delete ("COMval.shp")
    #
    # add a loop to delete interim shape files
    #
    fcs = gp.ListFeatureClasses("shape*", "ALL")
    fcs.Reset ()
    fc = fcs.Next ()
    while fc:
      gp.Delete (fc)
      fc = fcs.Next ()
    gp.AddMessage ("Finished Area" + str(num))
    num = num + 1
except:
 gp.AddError(gp.GetMessages())
 print gp.GetMessages()
```

```
# Select by Census Tract centroid, buffer and loop for outdoor microenvironment
#
#September 2005
#
#Purpose: For a given set of census centorids and a pollution surface, selects and calculates
#pollution concentrations for outdoor within a 5km buffer, then exports to a table
# for each census area
#
#Add utilities
import os, sys, string, win32com.client
#Add toolboxes
gp = win32com.client.Dispatch ("esriGeoprocessing.GpDispatch.1")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Data Management Tools.tbx")
gp.CheckOutExtension ("spatial")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Conversion Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGis\ArcToolbox\Toolboxes\Analysis Tools.tbx")
gp.OverWriteOutput = 1
#Set arguments
# infolder = working space with data
# outfolder = working space to save csv files
workfolder = sys.argv[1]
outfolder = sys.argv[2]
surface = sys.argv[3]
censusbuffer = sys.argv[4]
#
try:
# set workspace and counter
  gp.Workspace = workfolder
  gp.MakeFeatureLayer (surface, "Surfpol")
  num = 1
#
# loop through census tract centroids
#
  while num <= 383:
    gp.MakeFeatureLayer (censusbuffer, "CENtemp")
    gp.SelectLayerByAttribute ("CENtemp", "NEW_SELECTION", "\"selnum" + "\" = " + str(num))
    gp.CopyFeatures ("CENtemp", workfolder + "/CENsingle.shp")
    gp.Identity_analysis (workfolder + "/CENsingle.shp", "Surfpol", workfolder + "/CENval.shp")
    gp.FeatureToRaster (workfolder + "/CENval.shp", "GRIDCODE", workfolder + "/CENrast",
            "200")
    gp.RasterToPoint (workfolder + "/CENrast", workfolder + "/CENexp.shp")
    gp.MakeFeatureLayer (workfolder + "/CENexp.shp", "DELzero")
    gp.SelectLayerByAttribute ("DELzero", "NEW_SELECTION", "\"GRID_CODE" + "\" > 0")
    gp.CopyFeatures ("DELzero", workfolder + "/CENfin.shp")
    gp.ExportXYv (workfolder + "/CENfin.shp", "GRID_CODE", "COMMA", outfolder +
            "/OutsideCT" + str(num))
    gp.Delete ("CENtemp", "layer")
    gp.Delete ("CENsingle.shp")
    gp.Delete ("CENval.shp")
    gp.Delete ("CENrast")
    gp.Delete ("CENexp.shp")
    gp.AddMessage ("Finished Area " + str(num))
    num = num + 1
    # go back to the while statement
except:
```

```
gp.AddError(gp.GetMessages())
print gp.GetMessages()
```

 # Select by Census Tract centroid, buffer and loop for transit other microenvironment

```
#
#September 2005
#
#Purpose: For a given set of census centorids and a pollution surface, selects and calculates
#pollution concentrations for transit other within a 5km buffer, then exports to a table
# for each census area
#
#Add utilities
import os, sys, string, win32com.client
#Add toolboxes
gp = win32com.client.Dispatch ("esriGeoprocessing.GpDispatch.1")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Data Management Tools.tbx")
gp.CheckOutExtension ("spatial")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Conversion Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGis\ArcToolbox\Toolboxes\Analysis Tools.tbx")
gp.OverWriteOutput = 1
#Set arguments
# infolder = working space with data
# outfolder = working space to save csv files
workfolder = sys.argv[1]
outfolder = sys.argv[2]
surface = sys.argv[3]
censuspoints = sys.argv[4]
streetpoints = sys.argv[5]
#
##
try:
# set workspace and counter
  gp.Workspace = workfolder
  gp.MakeFeatureLayer (surface, "Surfpol")
  num = 1
#
# loop through census tract centroids
#
  while num <= 383:
    #
    #select the first census area centroid
    #
    gp.MakeFeatureLayer (censuspoints, "CENtemp")
    gp.SelectLayerByAttribute ("CENtemp", "NEW_SELECTION", "\"selnum" + "\" = " + str(num))
    gp.CopyFeatures ("CENtemp", workfolder + "/CENsingle.shp")
    gp.MakeFeatureLayer (workfolder + "/CENsingle.shp", "CENsel")
    gp.Buffer ("CENsel", "CENbuff.shp", "5000")
    gp.MakeFeatureLayer (workfolder + "/CENbuff.shp", "CEN5000")
    #
    # calculate local roads
    #
    gp.MakeFeatureLayer (streetpoints, "STRtemp")
    gp.SelectLayerByLocation ("STRtemp", "COMPLETELY_WITHIN", "CEN5000")
    gp.CopyFeatures ("STRtemp", workfolder + "/STRsel.shp")
    gp.Identity (workfolder + "/STRsel.shp", "Surfpol", workfolder + "/STRval.shp")
    gp.CalculateField (workfolder + "/STRval.shp", "TRANSO", "[IN_OUT] * [GRIDCODE]")
    TBLname3 = "/TransoCT" + str(num)
    TBLname4 = ".dbf"
```

```
    gp.Statistics (workfolder + "/STRval.shp", outfolder + TBLname3 + TBLname4, "Transo
             MEAN")
    #clean up files
    #
    gp.Delete ("CENtemp", "layer")
    gp.Delete ("CENsel", "layer")
    gp.Delete ("CEN5000", "layer")
    gp.Delete ("STRtemp", "layer")
    gp.Delete ("CENsingle.shp")
    gp.Delete ("CENbuff.shp")
    gp.Delete ("STRsel.shp")
    #
    # add a loop to delete interim shape files
    #
    fcs = gp.ListFeatureClasses("shape*", "ALL")
    fcs.Reset ()
    fc = fcs.Next ()
    while fc:
      gp.Delete (fc)
      fc = fcs.Next ()
    gp.AddMessage ("Finished Area " + str(num))
    num = num + 1
    # go back to the while statement
except:
 gp.AddError(gp.GetMessages())
 print gp.GetMessages()
```

```
# Route finding loop for data processing, use results to find transit to work values
#
#September 2005
#
#Purpose: For a given set of census tract centroids, find the shortest route between an
# origin CT centroid and all other listed CT centroids
#
#Add utilities
import os, sys, string, win32com.client
#Add toolboxes
gp = win32com.client.Dispatch ("esriGeoprocessing.GpDispatch.1")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Data Management Tools.tbx")
gp.CheckOutExtension ("Network")
gp.AddToolbox ("C:\Program Files\ArcGis\ArcToolbox\Toolboxes\Network Analyst Tools.tbx")
gp.OverWriteOutput = 1
#Set arguments
# infolder = working space with data
# outfolder = working space to save route files
workfolder = sys.argv[1]
outfolder = sys.argv[2]
censuspoints = sys.argv[3]
streetnetwork = sys.argv[4]
workpair = sys.argv[5]
#
try:
# set workspace and counter
  gp.Workspace = workfolder
  gp.MakeFeatureLayer (censuspoints, "CENtemp")
  gp.MakeTableView (workpair, "Pairlist")
  org = 323
  fields = gp.ListFields ("Pairlist")
  field = fields.Next ()
  while field:
    org = org + 1
    rows = gp.SearchCursor ("Pairlist")
    row = rows.Next ()
    while row:
      des = row.GetValue (field.name)
      if org <> des and des > 0:
        gp.SelectLayerByAttribute ("CENtemp", "NEW_SELECTION", "\"selnum" + "\" = " + str(org))
        gp.CopyFeatures ("CENtemp", workfolder + "/CENorg.shp")
        gp.MakeFeatureLayer (workfolder + "/CENorg.shp", "CTorg")
        gp.SelectLayerByAttribute ("CENtemp", "NEW_SELECTION", "\"selnum" + "\" = " + str(des))
        gp.CopyFeatures ("CENtemp", workfolder + "/CENdes.shp")
        gp.MakeFeatureLayer (workfolder + "/CENdes.shp", "CTdes")
        gp.MakeRouteLayer (streetnetwork, "RT" + str(org),"Minutes", "USE_INPUT_ORDER", "",
             "NO_TIMEWINDOWS", "Minutes", "ALLOW_UTURNS", "Oneway", "NO_HIERARCHY",
             "", "TRUE_LINES_WITH_MEASURES")
        gp.AddLocations ("RT" + str(org), "Stops", "CTorg", "Minutes # 0; CurbApproach # 0", "6000
             Meters", "", "", "MATCH_TO_CLOSEST","CLEAR")
        gp.AddLocations ("RT" + str(org), "Stops", "CTdes", "Minutes # 0; CurbApproach # 0", "6000
             Meters", "", "", "MATCH_TO_CLOSEST", "APPEND")
        try:
          gp.Solve ("RT" + str(org))
          if gp.exists ("RT" + str(org)):
```

```
            gp.CopyFeatures ("RT" + str(org) + "/Routes", outfolder + "/ORG" + str(org) + "DES" +
             str(des) + ".shp")
            gp.AddMessage ("Finished Origin " + str(org) + " Destination " + str(des))
            gp.delete ("RT" + str(org))
        except:
          gp.AddError (gp.GetMessages())
          print gp.GetMessages ()
          gp.delete ("RT" + str(org))
      row = rows.Next ()
    field = fields.Next()
except:
 gp.AddError(gp.GetMessages())
 print gp.GetMessages()#SESM Data Preparation
```

```
#September 2005
#
#Purpose: For a set of route shapefiles, extract surface values, average and export to .dbf file
#
#Add utilities
import os, sys, string, win32com.client
#Add toolboxes
gp = win32com.client.Dispatch ("esriGeoprocessing.GpDispatch.1")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Data Management Tools.tbx")
gp.CheckOutExtension ("spatial")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGIS\ArcToolbox\Toolboxes\Conversion Tools.tbx")
gp.AddToolbox ("C:\Program Files\ArcGis\ArcToolbox\Toolboxes\Analysis Tools.tbx")
gp.OverWriteOutput = 1
#Set arguments
# infolder = working space with route shapefiles
# outfolder = working space to save csv files
workfolder = sys.argv[1]
outfolder = sys.argv[2]
processedfolder = sys.argv[3]
surface = sys.argv[4]
#
#
try:
# set workspace and counter
  gp.Workspace = workfolder
  gp.MakeFeatureLayer (surface, "Surfpol")
#
# Loop through all route shapefiles
#
  fcs = gp.ListFeatureClasses ()
  fcs.Reset ()
  fc = fcs.Next ()
  while fc:
    gp.FeatureToRaster (fc, "Name", workfolder + "/rastemp", "25")
    gp.RasterToPoint (workfolder + "/rastemp", workfolder + "/raspts.shp")
    gp.Identity (workfolder + "/raspts.shp", "Surfpol", workfolder + "/rasval.shp")
    gp.Statistics (workfolder + "/rasval.shp", outfolder + "/Transw" + fc, "GRIDCODE MEAN")
    gp.Copy(fc, processedfolder + "/"+ fc)
    gp.Delete (fc)
    gp.AddMessage ("Finished " + fc)
    fc = fcs.Next ()
except:
 gp.AddError(gp.GetMessages())
 print gp.GetMessages()
```

C++ Program for calculating exposure estimates based on random sampling, written by Dr. Jochen Stier, University of Victoria Computer Sciences Department, under the direction of the author

```
#include <direct.h>
#include <math.h>

#include "LOG.tlh"

#include "FrmMain.h"


#define RANDOM(range) (range) ? rand()%(range) : 0
float sPercent1;
float sPercent2;
float sPercent3;

FrmMain* FrmMain::sInstance = 0;
WorkPair* FrmMain::sWorkPairs[400];

FrmMain::FrmMain()
: mTree()
, mContent(*this)
{
   sInstance = this;
}


LRESULT FrmMain::OnCreate(UINT uMsg, WPARAM wParam, LPARAM lParam, BOOL& bHandled)
{
   RECT lRect;
   LRESULT lRes = DefWindowProc(uMsg, wParam, lParam);

   mImageList.Create(16, 15, ILC_COLOR8, 20, 1);
   CBitmap lBitmap;
   lBitmap.LoadBitmap(IDB_TREEIMAGES);
   mImageList.Add(lBitmap);


   // create splitters
   GetClientRect(&lRect);
   m_hWndClient = mVerticalSplitter.Create(m_hWnd, lRect, NULL, WS_CHILD | WS_VISIBLE | WS_CLIPSIBLINGS |
WS_CLIPCHILDREN);

   // Views
            mTree.Create (mVerticalSplitter, rcDefault, NULL, WS_CHILD | TVS_HASBUTTONS |
TVS_SHOWSELALWAYS | TVS_HASLINES | TVS_LINESATROOT | TVS_EDITLABELS, WS_EX_CLIENTEDGE);
   mContent.Create (mVerticalSplitter, WS_CHILD | WS_CLIPSIBLINGS | WS_CLIPCHILDREN);

            mVerticalSplitter.SetSplitterPanes(mTree, mContent);
   mVerticalSplitter.m_bFullDrag = false;
   mVerticalSplitter.SetSplitterPos(300);

   mContent.ShowWindow(SW_SHOW);

   mTree.ShowWindow(SW_SHOW);
   mTree.SetImageList(mImageList, TVSIL_NORMAL);
   mTree.SetFont(AtlGetStockFont(DEFAULT_GUI_FONT));

   memset(sWorkPairs,0,sizeof sWorkPairs);

            /*
   HANDLE hFile = CreateFile("WORKPAIRS\\Workpairs.csv",
                     GENERIC_READ,
                     FILE_SHARE_READ,
                     NULL,
                     OPEN_EXISTING,
                     FILE_ATTRIBUTE_NORMAL,
```

```
               NULL);

  if (hFile == INVALID_HANDLE_VALUE)
  {
    LPVOID lpMsgBuf;
    FormatMessage(FORMAT_MESSAGE_ALLOCATE_BUFFER |
            FORMAT_MESSAGE_FROM_SYSTEM,
            NULL,
            GetLastError(),
            MAKELANGID(LANG_NEUTRAL, SUBLANG_DEFAULT),
            (LPTSTR) &lpMsgBuf,
            0, NULL );
    LOG<12> () << (char*)lpMsgBuf;
  }
        else
        {
                DWORD lSize= GetFileSize(hFile,0);
                char* lBuffer = new char[lSize];
                DWORD lRead;
                SetFilePointer(hFile, 0, 0, FILE_BEGIN);
                ReadFile(hFile, lBuffer, lSize, &lRead, NULL);
                CloseHandle(hFile);

                char* lPtr = strchr(lBuffer,'\n')+1;
                int lPrev = -1;
                do
                {
                        int lTo;
                        int lNumber;
                        int lFrom;
                        sscanf(lPtr, "%d,%d,%d", &lFrom, &lTo, &lNumber);

                        if (lFrom != lPrev)
                        {
                                char lBuffer[400];
                                sprintf(lBuffer, "Workpairs\\CT%d.csv", lFrom);

                                CloseHandle(hFile);
                                HANDLE hFile = CreateFile(lBuffer,
                                                                                GENERIC_WRITE,

        FILE_SHARE_READ,
                                                                                NULL,
                                                                                OPEN_ALWAYS,

        FILE_ATTRIBUTE_NORMAL,
                                                                                NULL);

                                if (hFile == INVALID_HANDLE_VALUE)
                                {
                                        LPVOID lpMsgBuf;
                                        FormatMessage(FORMAT_MESSAGE_ALLOCATE_BUFFER |

        FORMAT_MESSAGE_FROM_SYSTEM,
                                                                NULL,
                                                                GetLastError(),
                                                                MAKELANGID(LANG_NEUTRAL,
SUBLANG_DEFAULT),
                                                                (LPTSTR) &lpMsgBuf,
                                                                0, NULL );
                                        LOG<12> () << (char*)lpMsgBuf;
                                        break;
                                }
                                lPrev = lFrom;

                                char lTemp[400];
                                sprintf(lTemp, "Dest\n");
                                DWORD lLenght = strlen(lTemp);
                                DWORD lWritten = strlen(lTemp);
                                if (!WriteFile(hFile, lTemp, lLenght, &lWritten, 0))
```

```
                                {
                                        LPVOID lpMsgBuf;
                                        FormatMessage(FORMAT_MESSAGE_ALLOCATE_BUFFER |

        FORMAT_MESSAGE_FROM_SYSTEM,
                                                                NULL,
                                                                GetLastError(),
                                                                MAKELANGID(LANG_NEUTRAL,
SUBLANG_DEFAULT),
                                                                (LPTSTR) &lpMsgBuf,
                                                                0, NULL );
                                        LOG<12> () << (char*)lpMsgBuf;
                                        break;
                                }
                        }

                        if (lFrom != lTo)
                        {
                                char lTemp[400];
                                sprintf(lTemp, "%d\n", lTo);
                                DWORD lLenght = strlen(lTemp);
                                DWORD lWritten = strlen(lTemp);
                                for (int i=0; i<lNumber; i++)
                                {
                                        if (!WriteFile(hFile, lTemp, lLenght, &lWritten, 0))
                                        {
                                                LPVOID lpMsgBuf;

        FormatMessage(FORMAT_MESSAGE_ALLOCATE_BUFFER |

        FORMAT_MESSAGE_FROM_SYSTEM,
                                                                        NULL,
                                                                        GetLastError(),

        MAKELANGID(LANG_NEUTRAL, SUBLANG_DEFAULT),
                                                                        (LPTSTR) &lpMsgBuf,
                                                                        0, NULL );
                                                LOG<12> () << (char*)lpMsgBuf;
                                                break;
                                        }
                                }
                        }

                        lPtr = strchr(lPtr,'\n') + 1;
                } while (lPtr - lBuffer < lSize);
                CloseHandle(hFile);
        }
        */

  {
    HTREEITEM lItem = addItem(0, "ACTIVITY", 1, 0);
    PUSHDIR("ACTIVITY")
    loadActivity(lItem);
    POPDIR;
  }

  {
    HTREEITEM lItem = addItem(0, "WORKPAIRS", 1, 0);
    PUSHDIR("WORKPAIRS")
    loadWorkPairs(lItem);
    POPDIR;
  }

  HTREEITEM lItem = addItem(0, "DIST", 1, 0);
  mContent.mScenario.AddString("Scenario1");
  mContent.mScenario.SetItemData(0, (unsigned long)addItem(lItem, "SCEN1", 1, 0));
  mContent.mScenario.AddString("Scenario2");
  mContent.mScenario.SetItemData(1, (unsigned long)addItem(lItem, "SCEN2", 1, 0));
  mContent.mScenario.AddString("Scenario3");
  mContent.mScenario.SetItemData(2, (unsigned long)addItem(lItem, "SCEN3", 1, 0));
```

```
  mContent.mScenario.AddString("Scenario4");
  mContent.mScenario.SetItemData(3, (unsigned long)addItem(lItem, "SCEN4", 1, 0));
  mContent.mScenario.AddString("Scenario5");
  mContent.mScenario.SetItemData(4, (unsigned long)addItem(lItem, "SCEN5", 1, 0));
  mContent.mScenario.AddString("Scenario6");
  mContent.mScenario.SetItemData(5, (unsigned long)addItem(lItem, "SCEN6", 1, 0));

        _getcwd(mRoot, 400);

        bHandled = TRUE;
        return 0;
}


Distribution* FrmMain::getDistribution(int iScenario, char* iParam, char* iParam2, char* iParam3)
{
  HTREEITEM lDistribution = mTree.GetRootItem();
  lDistribution = mTree.GetNextSiblingItem(lDistribution);
  lDistribution = mTree.GetNextSiblingItem(lDistribution);

  HTREEITEM lScenario = mTree.GetChildItem(lDistribution);
  for (int i=0; i<iScenario; i++)
  {
    lScenario = mTree.GetNextSiblingItem(lScenario);
  }

  char lBuffer[400];
        mTree.GetItemText(lScenario, (LPTSTR)lBuffer, 400);

  HTREEITEM lChild = mTree.GetChildItem(lScenario);
        mTree.GetItemText(lChild, (LPTSTR)lBuffer, 400);
  if (!strcmp(lBuffer, iParam))
  {
                if (iParam2)
                {
                        HTREEITEM lChild1 = mTree.GetChildItem(lChild);
                        mTree.GetItemText(lChild1, (LPTSTR)lBuffer, 400);
                        if (!strcmp(lBuffer, iParam2))
                        {
                                if (iParam3)
                                {
                                        HTREEITEM lChild2 = mTree.GetChildItem(lChild1);
                                        mTree.GetItemText(lChild2, (LPTSTR)lBuffer, 400);
                                        if (!strcmp(lBuffer, iParam3))
                                        {
                                    return (Distribution*) mTree.GetItemData(lChild2);
                                        }
                                        lChild2 = mTree.GetNextSiblingItem(lChild2);
                                        mTree.GetItemText(lChild2, (LPTSTR)lBuffer, 400);
                                        if (!strcmp(lBuffer, iParam3))
                                        {
                                    return (Distribution*) mTree.GetItemData(lChild2);
                                        }
                                        return 0;
                                }
                    return (Distribution*) mTree.GetItemData(lChild1);
                        }
                        lChild1 = mTree.GetNextSiblingItem(lChild1);
                        mTree.GetItemText(lChild1, (LPTSTR)lBuffer, 400);
                        if (!strcmp(lBuffer, iParam2))
                        {
                                if (iParam3)
                                {
                                        HTREEITEM lChild2 = mTree.GetChildItem(lChild1);
                                        mTree.GetItemText(lChild2, (LPTSTR)lBuffer, 400);
                                        if (!strcmp(lBuffer, iParam3))
                                        {
                                    return (Distribution*) mTree.GetItemData(lChild2);
                                        }
                                        lChild2 = mTree.GetNextSiblingItem(lChild2);
```

```
                                      mTree.GetItemText(lChild2, (LPTSTR)lBuffer, 400);
                                      if (!strcmp(lBuffer, iParam3))
                                      {
                                  return (Distribution*) mTree.GetItemData(lChild2);
                                      }
                                      return 0;
                              }
                  return (Distribution*) mTree.GetItemData(lChild1);
                      }
                      return 0;
              }
  return (Distribution*) mTree.GetItemData(lChild);
}

lChild = mTree.GetNextSiblingItem(lChild);
      mTree.GetItemText(lChild, (LPTSTR)lBuffer, 400);
if (!strcmp(lBuffer, iParam))
{
              if (iParam2)
              {
                      HTREEITEM lChild1 = mTree.GetChildItem(lChild);
                      mTree.GetItemText(lChild1, (LPTSTR)lBuffer, 400);
                      if (!strcmp(lBuffer, iParam2))
                      {
                              if (iParam3)
                              {
                                      HTREEITEM lChild2 = mTree.GetChildItem(lChild1);
                                      mTree.GetItemText(lChild2, (LPTSTR)lBuffer, 400);
                                      if (!strcmp(lBuffer, iParam3))
                                      {
                                  return (Distribution*) mTree.GetItemData(lChild2);
                                      }
                                      lChild2 = mTree.GetNextSiblingItem(lChild2);
                                      mTree.GetItemText(lChild2, (LPTSTR)lBuffer, 400);
                                      if (!strcmp(lBuffer, iParam3))
                                      {
                                  return (Distribution*) mTree.GetItemData(lChild2);
                                      }
                                      return 0;
                              }
                  return (Distribution*) mTree.GetItemData(lChild1);
                      }
                      lChild1 = mTree.GetNextSiblingItem(lChild1);
                      mTree.GetItemText(lChild1, (LPTSTR)lBuffer, 400);
                      if (!strcmp(lBuffer, iParam2))
                      {
                              if (iParam3)
                              {
                                      HTREEITEM lChild2 = mTree.GetChildItem(lChild1);
                                      mTree.GetItemText(lChild2, (LPTSTR)lBuffer, 400);
                                      if (!strcmp(lBuffer, iParam3))
                                      {
                                  return (Distribution*) mTree.GetItemData(lChild2);
                                      }
                                      lChild2 = mTree.GetNextSiblingItem(lChild2);
                                      mTree.GetItemText(lChild2, (LPTSTR)lBuffer, 400);
                                      if (!strcmp(lBuffer, iParam3))
                                      {
                                  return (Distribution*) mTree.GetItemData(lChild2);
                                      }
                                      return 0;
                              }
                  return (Distribution*) mTree.GetItemData(lChild1);
                      }
                      return 0;
              }
  return (Distribution*) mTree.GetItemData(lChild);
}

return 0;
```

```
}

Activity* FrmMain::getActivity(int iScenario)
{
   HTREEITEM lActivity = mTree.GetRootItem();
   HTREEITEM lScene = mTree.GetChildItem(lActivity);
   for (int i=0; i<iScenario; i++)
   {
      lScene = mTree.GetNextSiblingItem(lScene);
   }
   return (Activity*) mTree.GetItemData(lScene);
}

LRESULT FrmMain::OnTime(UINT uMsg, WPARAM wParam, LPARAM lParam, BOOL& bHandled)
{
   static float sE[10000];
   static float sHINDOOR[10000];
   static float sWINDOOR[10000];
   static float sDHINDOOR[10000];
   static float sNHINDOOR[10000];
   static float sSINDOOR[10000];
   static float sOUTDOOR[10000];
   static float sTRANSW[10000];
   static float sTRANSO[10000];
            char lTemp[100];
            HANDLE lFile = 0;

   int lScenario = mContent.mScenario.GetCurSel();
   WorkPair* lWorkPair = sWorkPairs[mTrack+1];

   if (!lWorkPair)
   {
      LOG<12> () << "missing workpairs for track " << mTrack+1;
      mTrack++;
      if (mTrack == CENSUSTRACKS)
      {
                        stopScenario();
      }
      return 1;
   }

   LOG<12> () << "running track " << mTrack+1;
   LOG<12>::begin();
   while (!LOG<12>::end())
   {
      LOG<12>::MESSAGE& lMessage = LOG<12>::next();
      FrmMain::sInstance->output(lMessage.mBuffer);
   }

   switch (lScenario)
   {
      case 0:
         {
            Activity* lActivity = getActivity(lScenario);

            // workers
            Distribution* lDistribution = getDistribution(lScenario, "WORKERS");
                                                if (lDistribution[mTrack].cNHINDOOR &&
                                                        lDistribution[mTrack].cWINDOOR &&
                                                        lDistribution[mTrack].cDHINDOOR &&
                                                        lDistribution[mTrack].cSINDOOR &&
                                                        lDistribution[mTrack].cOUTDOOR &&
                                                        lDistribution[mTrack].cTRANSO)
                                                {
                                                        lFile = createFile("WORK", mTrack);
                                                        if (lFile)
                                                        {
                                                                for (int i=0; i<10000; i++)
                                                                {
```

```
                                                          int lDestination = lWorkPair-
>DEST[RANDOM(lWorkPair->cDEST-1)]-1;

                                                          if (lDistribution[mTrack].TRANSWv[lDestination])
                                                          {
                float Nhindoor = lDistribution[mTrack].NHINDOOR[RANDOM(lDistribution[mTrack].cNHINDOOR-1)];
                                                            float Windoor =
lDistribution[lDestination].WINDOOR[RANDOM(lDistribution[lDestination].cWINDOOR-1)];
                                                            float Dhindoor =
lDistribution[mTrack].DHINDOOR[RANDOM(lDistribution[mTrack].cDHINDOOR-1)];
                                                            float Sindoor =
lDistribution[mTrack].SINDOOR[RANDOM(lDistribution[mTrack].cSINDOOR-1)];
                                                            float Outdoor =
lDistribution[mTrack].OUTDOOR[RANDOM(lDistribution[mTrack].cOUTDOOR-1)];
                                                            float Transo =
lDistribution[mTrack].TRANSO[RANDOM(lDistribution[mTrack].cTRANSO-1)];
                                                            float Transt  =
lDistribution[mTrack].TRANSWt[lDestination];
                                                            float Transv  =
lDistribution[mTrack].TRANSWv[lDestination];

                                                            int lIndex = RANDOM((lActivity->cWORK_S-
7)/7);

                sNHINDOOR[i] = (Nhindoor * (lActivity->WORK_S[lIndex*7+3]+lActivity->WORK_S[lIndex*7+1]-
2*Transt))/ 1440;
                sWINDOOR[i] = (Windoor * lActivity->WORK_S[lIndex*7+0])/ 1440;
                sDHINDOOR[i] = (Dhindoor * lActivity->WORK_S[lIndex*7+2])/ 1440;
                sSINDOOR[i] = (Sindoor * lActivity->WORK_S[lIndex*7+4])/ 1440;
                sOUTDOOR[i] = (Outdoor * lActivity->WORK_S[lIndex*7+5])/ 1440;
                sTRANSO[i] = (Transo * lActivity->WORK_S[lIndex*7+6])/ 1440;
                sTRANSW[i] = (Transv * 2*Transt)/1440;

                                                            sE[i] = sWINDOOR[i] +
                                                                             sTRANSW[i] +
                                                                             sDHINDOOR[i] +
                                                                             sNHINDOOR[i] +
                                                                             sSINDOOR[i] +
                                                                             sOUTDOOR[i] +
                                                                             sTRANSO[i];

                if (sE[i] < 0)
                {
                  int i=12;
                }

                sprintf(lTemp, "%f\n", sE[i]);
                                                            DWORD lLenght = strlen(lTemp);
                                                            DWORD lWritten = strlen(lTemp);
                                                            WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                          }
                                                          else
                                                          {
                                                                  LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                          }
                                                  }
            addSummary(mSummaryWorkers, sE);
            addSummary(mSummaryWorkers_Nhindoor, sNHINDOOR);
            addSummary(mSummaryWorkers_Windoor, sWINDOOR);
            addSummary(mSummaryWorkers_Dhindoor, sDHINDOOR);
            addSummary(mSummaryWorkers_Sindoor, sSINDOOR);
            addSummary(mSummaryWorkers_Outdoor, sOUTDOOR);
            addSummary(mSummaryWorkers_Transo, sTRANSO);
            addSummary(mSummaryWorkers_Transw, sTRANSW);
                                                  CloseHandle(lFile);
                                         }
                                 }
                                 else
                                 {
```

```
                                        LOG<12> () << "Missing distribution for WORKERS of census track "
<< mTrack+1;
                                    }


            // non workers
            lDistribution = getDistribution(lScenario, "NONWORKERS");
            if (lDistribution[mTrack].cNHINDOOR &&
                lDistribution[mTrack].cDHINDOOR &&
                lDistribution[mTrack].cSINDOOR &&
                lDistribution[mTrack].cOUTDOOR &&
                lDistribution[mTrack].cTRANSO)
            {
                // male
                                        lFile = createFile("NW_M", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
                                                        float Nhindoor =
lDistribution[mTrack].NHINDOOR[RANDOM(lDistribution[mTrack].cNHINDOOR-1)];
                                                        float Dhindoor =
lDistribution[mTrack].DHINDOOR[RANDOM(lDistribution[mTrack].cDHINDOOR-1)];
                                                        float Sindoor =
lDistribution[mTrack].SINDOOR[RANDOM(lDistribution[mTrack].cSINDOOR-1)];
                                                        float Outdoor =
lDistribution[mTrack].OUTDOOR[RANDOM(lDistribution[mTrack].cOUTDOOR-1)];
                                                        float Transo =
lDistribution[mTrack].TRANSO[RANDOM(lDistribution[mTrack].cTRANSO-1)];

                                                        int lActivityIndex = RANDOM((lActivity-
>cNW_M_S-5)/5);

                    sDHINDOOR[i] = (Dhindoor * lActivity->NW_M_S[lActivityIndex*5+0])/1440;
                    sNHINDOOR[i] = (Nhindoor * lActivity->NW_M_S[lActivityIndex*5+1])/1440;
                    sSINDOOR[i] = (Sindoor * lActivity->NW_M_S[lActivityIndex*5+2])/1440;
                    sOUTDOOR[i] = (Outdoor * lActivity->NW_M_S[lActivityIndex*5+3])/1440;
                    sTRANSO[i] = (Transo * lActivity->NW_M_S[lActivityIndex*5+4])/1440;

                                                        sE[i] = sDHINDOOR[i] +
                                                                        sNHINDOOR[i] +
                                                                        sSINDOOR[i] +
                                                                        sOUTDOOR[i] +
                                                                        sTRANSO[i];

                                                sprintf(lTemp, "%f\n", sE[i]);
                                                        DWORD lLenght = strlen(lTemp);
                                                        DWORD lWritten = strlen(lTemp);
                                                        WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                }
                  addSummary(mSummaryNonWorkersM, sE);
                  addSummary(mSummaryNonWorkersM_Nhindoor, sNHINDOOR);
                  addSummary(mSummaryNonWorkersM_Dhindoor, sDHINDOOR);
                  addSummary(mSummaryNonWorkersM_Sindoor, sSINDOOR);
                  addSummary(mSummaryNonWorkersM_Outdoor, sOUTDOOR);
                  addSummary(mSummaryNonWorkersM_Transo, sTRANSO);
                                                CloseHandle(lFile);
                                        }

                // female
                                        lFile = createFile("NW_F", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
                                                        float Nhindoor =
lDistribution[mTrack].NHINDOOR[RANDOM(lDistribution[mTrack].cNHINDOOR-1)];
                                                        float Dhindoor =
lDistribution[mTrack].DHINDOOR[RANDOM(lDistribution[mTrack].cDHINDOOR-1)];
```

```
                                                        float Sindoor =
lDistribution[mTrack].SINDOOR[RANDOM(lDistribution[mTrack].cSINDOOR-1)];
                                                        float Outdoor =
lDistribution[mTrack].OUTDOOR[RANDOM(lDistribution[mTrack].cOUTDOOR-1)];
                                                        float Transo =
lDistribution[mTrack].TRANSO[RANDOM(lDistribution[mTrack].cTRANSO-1)];

              int lActivityIndex = RANDOM((lActivity->cNW_F_S-5)/5);

              sDHINDOOR[i] = (Dhindoor * lActivity->NW_F_S[lActivityIndex*5+0])/1440;
              sNHINDOOR[i] =(Nhindoor * lActivity->NW_F_S[lActivityIndex*5+1])/1440;
              sSINDOOR[i] = (Sindoor * lActivity->NW_F_S[lActivityIndex*5+2])/1440;
              sOUTDOOR[i] = (Outdoor * lActivity->NW_F_S[lActivityIndex*5+3])/1440;
              sTRANSO[i] = (Transo * lActivity->NW_F_S[lActivityIndex*5+4])/1440;

                                                        sE[i] = sDHINDOOR[i] +
                                                                      sNHINDOOR[i] +
                                                                      sSINDOOR[i] +
                                                                      sOUTDOOR[i] +
                                                                      sTRANSO[i];

                                                sprintf(lTemp, "%f\n", sE[i]);
                                                        DWORD lLenght = strlen(lTemp);
                                                        DWORD lWritten = strlen(lTemp);
                                                        WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                }
            addSummary(mSummaryNonWorkersF, sE);
            addSummary(mSummaryNonWorkersF_Nhindoor, sNHINDOOR);
            addSummary(mSummaryNonWorkersF_Dhindoor, sDHINDOOR);
            addSummary(mSummaryNonWorkersF_Sindoor, sSINDOOR);
            addSummary(mSummaryNonWorkersF_Outdoor, sOUTDOOR);
            addSummary(mSummaryNonWorkersF_Transo, sTRANSO);
                                                CloseHandle(lFile);
                                        }
        }
        else
        {
          LOG<12> () << "Missing distribution for NONWORKERS of census track " << mTrack+1;
        }
      }
      break;
    case 1:
      {
        Activity* lActivity = getActivity(lScenario);

        // workers
        Distribution* lDistribution = getDistribution(lScenario, "WORKERS");
                                if (lDistribution[mTrack].cHINDOOR &&
                                        lDistribution[mTrack].cWINDOOR &&
                                        lDistribution[mTrack].cSINDOOR &&
                                        lDistribution[mTrack].cOUTDOOR &&
                                        lDistribution[mTrack].cTRANSO)
                                {
                                        lFile = createFile("WORK", mTrack);

                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
                                                        int lDestination = lWorkPair-
>DEST[RANDOM(lWorkPair->cDEST-1)]-1;

                                                        if (lDistribution[mTrack].TRANSWt[lDestination])
                                                        {
                                                          float Hindoor =
lDistribution[mTrack].HINDOOR[RANDOM(lDistribution[mTrack].cHINDOOR-1)];
                                                          float Windoor =
lDistribution[lDestination].WINDOOR[RANDOM(lDistribution[lDestination].cWINDOOR-1)];
                                                          float Sindoor =
lDistribution[mTrack].SINDOOR[RANDOM(lDistribution[mTrack].cSINDOOR-1)];
```

```
                                                            float Outdoor =
lDistribution[mTrack].OUTDOOR[RANDOM(lDistribution[mTrack].cOUTDOOR-1)];
                                                            float Transo =
lDistribution[mTrack].TRANSO[RANDOM(lDistribution[mTrack].cTRANSO-1)];
                                                            float Transt  =
lDistribution[mTrack].TRANSWt[lDestination];
                                                            float Transv  =
lDistribution[mTrack].TRANSWv[lDestination];

                                                            int lIndex = RANDOM((lActivity->cWORK_S-
6)/6);

                sWINDOOR[i] = (Windoor * lActivity->WORK_S[lIndex*6+0])/1440;
                sHINDOOR[i] = (Hindoor *(lActivity->WORK_S[lIndex*6+2]+lActivity->WORK_S[lIndex*6+1]-
2*Transt))/1440;
                sSINDOOR[i] = (Sindoor * lActivity->WORK_S[lIndex*6+3])/1440;
                sOUTDOOR[i] = (Outdoor * lActivity->WORK_S[lIndex*6+4])/1440;
                sTRANSO[i] = (Transo * lActivity->WORK_S[lIndex*6+5])/1440;
                sTRANSW[i] = (Transv * 2*Transt)/1440;

                                                            sE[i] = sWINDOOR[i] +
                                                                            sTRANSW[i] +
                                                                            sHINDOOR[i] +
                                                                            sSINDOOR[i] +
                                                                            sOUTDOOR[i] +
                                                                            sTRANSO[i];

                                                    sprintf(lTemp, "%f\n", sE[i]);
                                                            DWORD lLenght = strlen(lTemp);
                                                            DWORD lWritten = strlen(lTemp);
                                                            WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                          }
                                                          else
                                                          {
                                                                  LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                          }
                                                  }
                                         }
          addSummary(mSummaryWorkers, sE);
          addSummary(mSummaryWorkers_Hindoor, sHINDOOR);
          addSummary(mSummaryWorkers_Windoor, sWINDOOR);
          addSummary(mSummaryWorkers_Sindoor, sSINDOOR);
          addSummary(mSummaryWorkers_Outdoor, sOUTDOOR);
          addSummary(mSummaryWorkers_Transo, sTRANSO);
          addSummary(mSummaryWorkers_Transw, sTRANSW);
                                         CloseHandle(lFile);
                                 }
                                 else
                                 {
                                         LOG<12> () << "Missing distribution for WORKERS of census track "
<< mTrack+1;
                                 }


        // non workers
        lDistribution = getDistribution(lScenario, "NONWORKERS");
        if (lDistribution[mTrack].cHINDOOR &&
          lDistribution[mTrack].cSINDOOR &&
          lDistribution[mTrack].cOUTDOOR &&
          lDistribution[mTrack].cTRANSO)
        {
          // male
                                         lFile = createFile("NW_M", mTrack);
                                         if (lFile)
                                         {
                                                 for (int i=0; i<10000; i++)
                                                 {
                                                          float Hindoor =
lDistribution[mTrack].HINDOOR[RANDOM(lDistribution[mTrack].cHINDOOR-1)];
```

```
                                                                float Sindoor =
lDistribution[mTrack].SINDOOR[RANDOM(lDistribution[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lDistribution[mTrack].OUTDOOR[RANDOM(lDistribution[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lDistribution[mTrack].TRANSO[RANDOM(lDistribution[mTrack].cTRANSO-1)];

           int lIndex = RANDOM((lActivity->cNW_M_S-4)/4);

           sHINDOOR[i] = (Hindoor * lActivity->NW_M_S[lIndex*4+0])/1440;
           sSINDOOR[i] = (Sindoor * lActivity->NW_M_S[lIndex*4+1])/1440;
           sOUTDOOR[i] = (Outdoor * lActivity->NW_M_S[lIndex*4+2])/1440;
           sTRANSO[i] = (Transo * lActivity->NW_M_S[lIndex*4+3])/1440;

                                                                sE[i] = sHINDOOR[i] +
                                                                            sSINDOOR[i] +
                                                                            sOUTDOOR[i] +
                                                                            sTRANSO[i];

                                                          sprintf(lTemp, "%f\n", sE[i]);
                                                                DWORD lLenght = strlen(lTemp);
                                                                DWORD lWritten = strlen(lTemp);
                                                                WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                          }
          addSummary(mSummaryNonWorkersM, sE);
          addSummary(mSummaryNonWorkersM_Hindoor, sHINDOOR);
          addSummary(mSummaryNonWorkersM_Sindoor, sSINDOOR);
          addSummary(mSummaryNonWorkersM_Outdoor, sOUTDOOR);
          addSummary(mSummaryNonWorkersM_Transo, sTRANSO);
                                                          CloseHandle(lFile);
                                                    }

        // female
                                                    lFile = createFile("NW_F", mTrack);
                                                    if (lFile)
                                                    {
                                                          for (int i=0; i<10000; i++)
                                                          {
                                                                float Hindoor =
lDistribution[mTrack].HINDOOR[RANDOM(lDistribution[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lDistribution[mTrack].SINDOOR[RANDOM(lDistribution[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lDistribution[mTrack].OUTDOOR[RANDOM(lDistribution[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lDistribution[mTrack].TRANSO[RANDOM(lDistribution[mTrack].cTRANSO-1)];

           int lIndex = RANDOM((lActivity->cNW_F_S-4)/4);

           sHINDOOR[i] = (Hindoor * lActivity->NW_F_S[lIndex*4+0])/1440;
           sSINDOOR[i] = (Sindoor * lActivity->NW_F_S[lIndex*4+1])/1440;
           sOUTDOOR[i] = (Outdoor * lActivity->NW_F_S[lIndex*4+2])/1440;
           sTRANSO[i] = (Transo * lActivity->NW_F_S[lIndex*4+3])/1440;

                                                                sE[i] = sHINDOOR[i] +
                                                                            sSINDOOR[i] +
                                                                            sOUTDOOR[i] +
                                                                            sTRANSO[i];

                                                          sprintf(lTemp, "%f\n", sE[i]);
                                                                DWORD lLenght = strlen(lTemp);
                                                                DWORD lWritten = strlen(lTemp);
                                                                WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                          }
          addSummary(mSummaryNonWorkersF, sE);
          addSummary(mSummaryNonWorkersF_Hindoor, sHINDOOR);
          addSummary(mSummaryNonWorkersF_Sindoor, sSINDOOR);
          addSummary(mSummaryNonWorkersF_Outdoor, sOUTDOOR);
          addSummary(mSummaryNonWorkersF_Transo, sTRANSO);
                                                          CloseHandle(lFile);
```

```
                                        }
        }
        else
        {
          LOG<12> () << "Missing distribution for NONWORKERS of census track " << mTrack+1;
        }
      }
      break;
    case 2:
      {
        Activity* lActivity = getActivity(lScenario);

        Distribution* lDistribution1 = getDistribution(lScenario, "WORKERS", "WEEKDAY");
        Distribution* lDistribution2 = getDistribution(lScenario, "WORKERS", "WEEKEND");
                                if (lDistribution1[mTrack].cNHINDOOR &&
                                        lDistribution1[mTrack].cWINDOOR &&
                                        lDistribution1[mTrack].cDHINDOOR &&
                                        lDistribution1[mTrack].cSINDOOR &&
                                        lDistribution1[mTrack].cOUTDOOR &&
                                        lDistribution1[mTrack].cTRANSO &&
                                        lDistribution2[mTrack].cNHINDOOR &&
                                        lDistribution2[mTrack].cDHINDOOR &&
                                        lDistribution2[mTrack].cSINDOOR &&
                                        lDistribution2[mTrack].cOUTDOOR &&
                                        lDistribution2[mTrack].cTRANSO)
                                {
                // workers male
                                        lFile = createFile("WORK_M", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
              float E1 = 0;

                                                        int lDestination = lWorkPair-
>DEST[RANDOM(lWorkPair->cDEST-1)]-1;

              if (lDistribution1[mTrack].TRANSWt[lDestination])
                                                        {
                                                          float Nhindoor =
lDistribution1[mTrack].NHINDOOR[RANDOM(lDistribution1[mTrack].cNHINDOOR-1)];
                                                          float Windoor =
lDistribution1[lDestination].WINDOOR[RANDOM(lDistribution1[lDestination].cWINDOOR-1)];
                                                          float Dhindoor =
lDistribution1[mTrack].DHINDOOR[RANDOM(lDistribution1[mTrack].cDHINDOOR-1)];
                                                          float Sindoor =
lDistribution1[mTrack].SINDOOR[RANDOM(lDistribution1[mTrack].cSINDOOR-1)];
                                                          float Outdoor =
lDistribution1[mTrack].OUTDOOR[RANDOM(lDistribution1[mTrack].cOUTDOOR-1)];
                                                          float Transo =
lDistribution1[mTrack].TRANSO[RANDOM(lDistribution1[mTrack].cTRANSO-1)];
                                                          float Transt  =
lDistribution1[mTrack].TRANSWt[lDestination];
                                                          float Transv  =
lDistribution1[mTrack].TRANSWv[lDestination];

                                                          int lIndex = RANDOM(lActivity->cWORK_S/7);

                sWINDOOR[i] = (Windoor * lActivity->WORK_S[lIndex*7+0])/1440;
                sDHINDOOR[i] = (Dhindoor * lActivity->WORK_S[lIndex*7+2])/1440;
                sNHINDOOR[i] = (Nhindoor * (lActivity->WORK_S[lIndex*7+3]+lActivity->WORK_S[lIndex*7+1]-
2*Transt))/1440;
                sSINDOOR[i] = (Sindoor * lActivity->WORK_S[lIndex*7+4])/1440;
                sOUTDOOR[i] = (Outdoor * lActivity->WORK_S[lIndex*7+5])/1440;
                sTRANSO[i] = (Transo * lActivity->WORK_S[lIndex*7+6])/1440;
                sTRANSW[i] = (Transv * 2*Transt)/1440;

                                                          E1 =    sWINDOOR[i] +
                                                                          sTRANSW[i] +
                                                                          sDHINDOOR[i] +
```

```
                                                                                            sNHINDOOR[i] +
                                                                                            sSINDOOR[i] +
                                                                                            sOUTDOOR[i] +
                                                                                            sTRANSO[i];
                                                                      }
                                                                      else
                                                                      {
                                                                               LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                    break;
                                                                      }

                                                                      float E2 = 0;
                                                                      for (int j=0; j<8; j++)
                                                                      {
                                                                               float Nhindoor =
lDistribution2[mTrack].NHINDOOR[RANDOM(lDistribution2[mTrack].cNHINDOOR-1)];
                                                                               float Dhindoor =
lDistribution2[mTrack].DHINDOOR[RANDOM(lDistribution2[mTrack].cDHINDOOR-1)];
                                                                               float Sindoor =
lDistribution2[mTrack].SINDOOR[RANDOM(lDistribution2[mTrack].cSINDOOR-1)];
                                                                               float Outdoor =
lDistribution2[mTrack].OUTDOOR[RANDOM(lDistribution2[mTrack].cOUTDOOR-1)];
                    float Transo = lDistribution2[mTrack].TRANSO[RANDOM(lDistribution2[mTrack].cTRANSO-1)];

                                                                               int lIndex = RANDOM(lActivity-
>cNW_M_S/5);

                    sNHINDOOR[i] += (Nhindoor * lActivity->NW_M_S[lIndex*5+1])/1440;
                    sDHINDOOR[i] += (Dhindoor * lActivity->NW_M_S[lIndex*5+0])/1440;
                    sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*5+2])/1440;
                    sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*5+3])/1440;
                    sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*5+4])/1440;

                                                                               E2 += (
                                                                                          (Dhindoor * lActivity-
>NW_M_S[lIndex*5+0]) +
                                                                                          (Nhindoor * lActivity-
>NW_M_S[lIndex*5+1]) +
                                                                                          (Sindoor * lActivity-
>NW_M_S[lIndex*5+2]) +
                                                                                          (Outdoor * lActivity-
>NW_M_S[lIndex*5+3]) +
                                                                                          (Transo * lActivity-
>NW_M_S[lIndex*5+4])
                                                                                           )
                                                                                           / 1440;
                                                                      }
                                                                      E2/=8;
                  sNHINDOOR[i] /= 9.0;
                  sDHINDOOR[i] /= 9.0;
                  sSINDOOR[i] /= 9.0;
                  sOUTDOOR[i] /= 9.0;
                  sTRANSO[i] /= 9.0;

                  sE[i] = E1*0.74+E2*0.26;

                                                                      sprintf(lTemp, "%f\n", sE[i]);
                                                                      DWORD lLenght = strlen(lTemp);
                                                                      DWORD lWritten = strlen(lTemp);
                                                                      WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                            }
               addSummary(mSummaryWorkersM, sE);
               addSummary(mSummaryWorkersM_Nhindoor, sNHINDOOR);
               addSummary(mSummaryWorkersM_Windoor, sWINDOOR);
               addSummary(mSummaryWorkersM_Dhindoor, sDHINDOOR);
               addSummary(mSummaryWorkersM_Sindoor, sSINDOOR);
               addSummary(mSummaryWorkersM_Outdoor, sOUTDOOR);
               addSummary(mSummaryWorkersM_Transo, sTRANSO);
               addSummary(mSummaryWorkersM_Transw, sTRANSW);
```

```
                                                CloseHandle(lFile);
                                        }

                // workers female
                                        lFile = createFile("WORK_F", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
              float E1 = 0;

                                                        int lDestination = lWorkPair-
>DEST[RANDOM(lWorkPair->cDEST-1)]-1;

                                                        if (lDistribution1[mTrack].TRANSWt[lDestination])
                                                        {
                float Nhindoor = lDistribution1[mTrack].NHINDOOR[RANDOM(lDistribution1[mTrack].cNHINDOOR-
1)];
                                                            float Windoor =
lDistribution1[lDestination].WINDOOR[RANDOM(lDistribution1[lDestination].cWINDOOR-1)];
                                                            float Dhindoor =
lDistribution1[mTrack].DHINDOOR[RANDOM(lDistribution1[mTrack].cDHINDOOR-1)];
                                                            float Sindoor =
lDistribution1[mTrack].SINDOOR[RANDOM(lDistribution1[mTrack].cSINDOOR-1)];
                                                            float Outdoor =
lDistribution1[mTrack].OUTDOOR[RANDOM(lDistribution1[mTrack].cOUTDOOR-1)];
                                                            float Transo =
lDistribution1[mTrack].TRANSO[RANDOM(lDistribution1[mTrack].cTRANSO-1)];
                                                            float Transt  =
lDistribution1[mTrack].TRANSWt[lDestination];
                                                            float Transv  =
lDistribution1[mTrack].TRANSWv[lDestination];

                int lIndex = RANDOM(lActivity->cWORK_S/7);

                sWINDOOR[i] = (Windoor * lActivity->WORK_S[lIndex*7+0])/1440;
                sDHINDOOR[i] = (Dhindoor * lActivity->WORK_S[lIndex*7+2])/1440;
                sNHINDOOR[i] = (Nhindoor * (lActivity->WORK_S[lIndex*7+3]+lActivity->WORK_S[lIndex*7+1]-
2*Transt))/1440;
                sSINDOOR[i] = (Sindoor * lActivity->WORK_S[lIndex*7+4])/1440;
                sOUTDOOR[i] = (Outdoor * lActivity->WORK_S[lIndex*7+5])/1440;
                sTRANSO[i] = (Transo * lActivity->WORK_S[lIndex*7+6])/1440;
                sTRANSW[i] = (Transv * 2*Transt)/1440;

                                                            E1 = (
                                                                            sWINDOOR[i] +
                                                                            sTRANSW[i] +
                                                                            sDHINDOOR[i] +
                                                                            sNHINDOOR[i] +
                                                                            sSINDOOR[i] +
                                                                            sOUTDOOR[i] +
                                                                            sTRANSO[i]
                                                                            )
                                                                            / 1440;
              }
                                                        else
                                                        {
                                                                LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                                break;
                                                        }

                                                        float E2 = 0;
                                                        for (int j=0; j<8; j++)
                                                        {
                                                                float Nhindoor =
lDistribution2[mTrack].NHINDOOR[RANDOM(lDistribution2[mTrack].cNHINDOOR-1)];
                                                                float Dhindoor =
lDistribution2[mTrack].DHINDOOR[RANDOM(lDistribution2[mTrack].cDHINDOOR-1)];
```

```
                                                            float Sindoor =
lDistribution2[mTrack].SINDOOR[RANDOM(lDistribution2[mTrack].cSINDOOR-1)];
                                                            float Outdoor =
lDistribution2[mTrack].OUTDOOR[RANDOM(lDistribution2[mTrack].cOUTDOOR-1)];
                                                            float Transo =
lDistribution2[mTrack].TRANSO[RANDOM(lDistribution2[mTrack].cTRANSO-1)];

                                                            int lIndex = RANDOM(lActivity-
>cNW_F_S/5);

           sDHINDOOR[i] += (Dhindoor * lActivity->NW_F_S[lIndex*5+0])/1440;
           sNHINDOOR[i] += (Nhindoor * lActivity->NW_F_S[lIndex*5+1])/1440;
           sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*5+2])/1440;
           sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*5+3])/1440;
           sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*5+4])/1440;

                                                            E2 += (
                                                                  (Dhindoor * lActivity-
>NW_F_S[lIndex*5+0]) +
                                                                  (Nhindoor * lActivity-
>NW_F_S[lIndex*5+1]) +
                                                                  (Sindoor * lActivity-
>NW_F_S[lIndex*5+2]) +
                                                                  (Outdoor * lActivity-
>NW_F_S[lIndex*5+3]) +
                                                                  (Transo * lActivity-
>NW_F_S[lIndex*5+4])
                                                                   )
                                                                   / 1440;
                                                      }
                                                      E2/=8;
          sNHINDOOR[i] /= 9.0;
          sDHINDOOR[i] /= 9.0;
          sSINDOOR[i] /= 9.0;
          sOUTDOOR[i] /= 9.0;
          sTRANSO[i] /= 9.0;

          sE[i] = E1*0.74+E2*0.26;

                                                      sprintf(lTemp, "%f\n", sE[i]);
                                                      DWORD lLenght = strlen(lTemp);
                                                      DWORD lWritten = strlen(lTemp);
                                                      WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                }

         addSummary(mSummaryWorkersF, sE);
         addSummary(mSummaryWorkersF_Nhindoor, sNHINDOOR);
         addSummary(mSummaryWorkersF_Windoor, sWINDOOR);
         addSummary(mSummaryWorkersF_Dhindoor, sDHINDOOR);
         addSummary(mSummaryWorkersF_Sindoor, sSINDOOR);
         addSummary(mSummaryWorkersF_Outdoor, sOUTDOOR);
         addSummary(mSummaryWorkersF_Transo, sTRANSO);
         addSummary(mSummaryWorkersF_Transw, sTRANSW);
                                                CloseHandle(lFile);
                                          }
                                    }
                                    else
                                    {
                                          LOG<12> () << "Missing distribution for WORKERS of census track "
<< mTrack+1;
                                    }


      lDistribution1 = getDistribution(lScenario, "NONWORKERS", "WEEKDAY");
      lDistribution2 = getDistribution(lScenario, "NONWORKERS", "WEEKEND");
                                    if (lDistribution1[mTrack].cNHINDOOR &&
                                          lDistribution1[mTrack].cDHINDOOR &&
                                          lDistribution1[mTrack].cSINDOOR &&
                                          lDistribution1[mTrack].cOUTDOOR &&
                                          lDistribution1[mTrack].cTRANSO &&
```

```
                                        lDistribution2[mTrack].cNHINDOOR &&
                                        lDistribution2[mTrack].cDHINDOOR &&
                                        lDistribution2[mTrack].cSINDOOR &&
                                        lDistribution2[mTrack].cOUTDOOR &&
                                        lDistribution2[mTrack].cTRANSO)
                                {
                // nonworkers male
                                        lFile = createFile("NW_M", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
                                                        float E1 = 0;
              sNHINDOOR[i] = 0;
              sDHINDOOR[i] = 0;
              sSINDOOR[i] = 0;
              sOUTDOOR[i] = 0;
              sTRANSO[i] = 0;

                                                        for (int j=0; j<23; j++)
                                                        {
                                                                float Nhindoor =
lDistribution1[mTrack].NHINDOOR[RANDOM(lDistribution1[mTrack].cNHINDOOR-1)];
                                                                float Dhindoor =
lDistribution1[mTrack].DHINDOOR[RANDOM(lDistribution1[mTrack].cDHINDOOR-1)];
                                                                float Sindoor =
lDistribution1[mTrack].SINDOOR[RANDOM(lDistribution1[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lDistribution1[mTrack].OUTDOOR[RANDOM(lDistribution1[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lDistribution1[mTrack].TRANSO[RANDOM(lDistribution1[mTrack].cTRANSO-1)];

                                                                int lIndex = RANDOM(lActivity-
>cNW_M_S/5);

                sDHINDOOR[i] += (Dhindoor * lActivity->NW_M_S[lIndex*5+0])/1440;
                sNHINDOOR[i] += (Nhindoor * lActivity->NW_M_S[lIndex*5+1])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*5+2])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*5+3])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*5+4])/1440;

                                                                E1 += (
                                                                                (Dhindoor *
lActivity->NW_M_S[lIndex*5+0]) +
                                                                                (Nhindoor *
lActivity->NW_M_S[lIndex*5+1]) +
                                                                                (Sindoor * lActivity-
>NW_M_S[lIndex*5+2]) +
                                                                                (Outdoor * lActivity-
>NW_M_S[lIndex*5+3]) +
                                                                                (Transo * lActivity-
>NW_M_S[lIndex*5+4])
                                                                                )
                                                                                / 1440;
                                                        }
                                                        E1/=23;

                                                        float E2 = 0;
                                                        for (int j=0; j<8; j++)
                                                        {
                                                                float Nhindoor =
lDistribution2[mTrack].NHINDOOR[RANDOM(lDistribution2[mTrack].cNHINDOOR-1)];
                                                                float Dhindoor =
lDistribution2[mTrack].DHINDOOR[RANDOM(lDistribution2[mTrack].cDHINDOOR-1)];
                                                                float Sindoor =
lDistribution2[mTrack].SINDOOR[RANDOM(lDistribution2[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lDistribution2[mTrack].OUTDOOR[RANDOM(lDistribution2[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lDistribution2[mTrack].TRANSO[RANDOM(lDistribution2[mTrack].cTRANSO-1)];
```

```
                                                                int lIndex = RANDOM(lActivity-
>cNW_M_S/5);

                sDHINDOOR[i] += (Dhindoor * lActivity->NW_M_S[lIndex*5+0])/1440;
                sNHINDOOR[i] += (Nhindoor * lActivity->NW_M_S[lIndex*5+1])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*5+2])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*5+3])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*5+4])/1440;

                                                                E2 += (
                                                                         (Dhindoor * lActivity-
>NW_M_S[lIndex*5+0]) +
                                                                         (Nhindoor * lActivity-
>NW_M_S[lIndex*5+1]) +
                                                                         (Sindoor * lActivity-
>NW_M_S[lIndex*5+2]) +
                                                                         (Outdoor * lActivity-
>NW_M_S[lIndex*5+3]) +
                                                                         (Transo * lActivity-
>NW_M_S[lIndex*5+4])
                                                                          )
                                                                          / 1440;
                                                        }
                                                        E2/=8;
              sNHINDOOR[i] /= 31.0;
              sDHINDOOR[i] /= 31.0;
              sSINDOOR[i] /= 31.0;
              sOUTDOOR[i] /= 31.0;
              sTRANSO[i] /= 31.0;

              sE[i] = E1*0.74+E2*0.26;

                                                        sprintf(lTemp, "%f\n", sE[i]);
                                                        DWORD lLenght = strlen(lTemp);
                                                        DWORD lWritten = strlen(lTemp);
                                                        WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                }

            addSummary(mSummaryNonWorkersM, sE);
            addSummary(mSummaryNonWorkersM_Nhindoor, sNHINDOOR);
            addSummary(mSummaryNonWorkersM_Dhindoor, sDHINDOOR);
            addSummary(mSummaryNonWorkersM_Sindoor, sSINDOOR);
            addSummary(mSummaryNonWorkersM_Outdoor, sOUTDOOR);
            addSummary(mSummaryNonWorkersM_Transo, sTRANSO);
                                                CloseHandle(lFile);
                                        }

                // nonworkers female
                                        lFile = createFile("NW_F", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
                                                        float E1 = 0;
              sNHINDOOR[i] = 0;
              sDHINDOOR[i] = 0;
              sSINDOOR[i] = 0;
              sOUTDOOR[i] = 0;
              sTRANSO[i] = 0;

                                                        for (int j=0; j<23; j++)
                                                        {
                                                                float Nhindoor =
lDistribution1[mTrack].NHINDOOR[RANDOM(lDistribution1[mTrack].cNHINDOOR-1)];
                                                                float Dhindoor =
lDistribution1[mTrack].DHINDOOR[RANDOM(lDistribution1[mTrack].cDHINDOOR-1)];
                                                                float Sindoor =
lDistribution1[mTrack].SINDOOR[RANDOM(lDistribution1[mTrack].cSINDOOR-1)];
```

```
                                                                        float Outdoor =
lDistribution1[mTrack].OUTDOOR[RANDOM(lDistribution1[mTrack].cOUTDOOR-1)];
                                                                        float Transo =
lDistribution1[mTrack].TRANSO[RANDOM(lDistribution1[mTrack].cTRANSO-1)];

                  int lIndex = RANDOM(lActivity->cNW_F_S/5);

                  sDHINDOOR[i] += (Dhindoor * lActivity->NW_F_S[lIndex*5+0])/1440;
                  sNHINDOOR[i] += (Nhindoor * lActivity->NW_F_S[lIndex*5+1])/1440;
                  sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*5+2])/1440;
                  sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*5+3])/1440;
                  sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*5+4])/1440;

                                                                        E1 += (
                                                                                          (Dhindoor *
lActivity->NW_F_S[lIndex*5+0]) +
                                                                                          (Nhindoor *
lActivity->NW_F_S[lIndex*5+1]) +
                                                                                          (Sindoor * lActivity-
>NW_F_S[lIndex*5+2]) +
                                                                                          (Outdoor * lActivity-
>NW_F_S[lIndex*5+3]) +
                                                                                          (Transo * lActivity-
>NW_F_S[lIndex*5+4])
                                                                                          )
                                                                                          / 1440;
                                                               }
                                                               E1/=23;


                                                               float E2 = 0;
                                                               for (int j=0; j<8; j++)
                                                               {
                                                                        float Nhindoor =
lDistribution2[mTrack].NHINDOOR[RANDOM(lDistribution2[mTrack].cNHINDOOR-1)];
                                                                        float Dhindoor =
lDistribution2[mTrack].DHINDOOR[RANDOM(lDistribution2[mTrack].cDHINDOOR-1)];
                                                                        float Sindoor =
lDistribution2[mTrack].SINDOOR[RANDOM(lDistribution2[mTrack].cSINDOOR-1)];
                                                                        float Outdoor =
lDistribution2[mTrack].OUTDOOR[RANDOM(lDistribution2[mTrack].cOUTDOOR-1)];
                                                                        float Transo =
lDistribution2[mTrack].TRANSO[RANDOM(lDistribution2[mTrack].cTRANSO-1)];

                  int lIndex = RANDOM(lActivity->cNW_F_S/5);

                  sDHINDOOR[i] += (Dhindoor * lActivity->NW_F_S[lIndex*5+0])/1440;
                  sNHINDOOR[i] += (Nhindoor * lActivity->NW_F_S[lIndex*5+1])/1440;
                  sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*5+2])/1440;
                  sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*5+3])/1440;
                  sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*5+4])/1440;

                                                                        E2 += (
                                                                                  (Dhindoor * lActivity-
>NW_F_S[lIndex*5+0]) +
                                                                                  (Nhindoor * lActivity-
>NW_F_S[lIndex*5+1]) +
                                                                                  (Sindoor * lActivity-
>NW_F_S[lIndex*5+2]) +
                                                                                  (Outdoor * lActivity-
>NW_F_S[lIndex*5+3]) +
                                                                                  (Transo * lActivity-
>NW_F_S[lIndex*5+4])
                                                                                   )
                                                                                   / 1440;
                                                               }
                                                               E2/=8;

                sNHINDOOR[i] /= 31.0;
                sDHINDOOR[i] /= 31.0;
```

```
              sSINDOOR[i] /= 31.0;
              sOUTDOOR[i] /= 31.0;
              sTRANSO[i] /= 31.0;

              sE[i] = E1*0.74+E2*0.26;

                                                          sprintf(lTemp, "%f\n", sE[i]);
                                                          DWORD lLenght = strlen(lTemp);
                                                          DWORD lWritten = strlen(lTemp);
                                                          WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                  }
            addSummary(mSummaryNonWorkersF, sE);
            addSummary(mSummaryNonWorkersF_Nhindoor, sNHINDOOR);
            addSummary(mSummaryNonWorkersF_Dhindoor, sDHINDOOR);
            addSummary(mSummaryNonWorkersF_Sindoor, sSINDOOR);
            addSummary(mSummaryNonWorkersF_Outdoor, sOUTDOOR);
            addSummary(mSummaryNonWorkersF_Transo, sTRANSO);
                                                  CloseHandle(lFile);
                                          }
                                  }
                                  else
                                  {
                                          LOG<12> () << "Missing distribution for WORKERS of census track " 
<< mTrack+1;
                                  }
      }
      break;
    case 3:
      {
        Activity* lActivity = getActivity(lScenario);

        Distribution* lDistribution1 = getDistribution(lScenario, "WORKERS", "WEEKDAY");
        Distribution* lDistribution2 = getDistribution(lScenario, "WORKERS", "WEEKEND");
                                  if (lDistribution1[mTrack].cHINDOOR &&
                                          lDistribution1[mTrack].cWINDOOR &&
                                          lDistribution1[mTrack].cSINDOOR &&
                                          lDistribution1[mTrack].cOUTDOOR &&
                                          lDistribution1[mTrack].cTRANSO &&
                                          lDistribution2[mTrack].cHINDOOR &&
                                          lDistribution2[mTrack].cSINDOOR &&
                                          lDistribution2[mTrack].cOUTDOOR &&
                                          lDistribution2[mTrack].cTRANSO)
                                  {
                // workers male
                                          lFile = createFile("WORK_M", mTrack);
                                          if (lFile)
                                          {
                                                  for (int i=0; i<10000; i++)
                                                  {
              float E1 = 0;

                                                          int lDestination = lWorkPair-
>DEST[RANDOM(lWorkPair->cDEST-1)]-1;

              if (lDistribution1[mTrack].TRANSWt[lDestination])
                                                          {
                                                            float Hindoor = 
lDistribution1[mTrack].HINDOOR[RANDOM(lDistribution1[mTrack].cHINDOOR-1)];
                                                            float Windoor = 
lDistribution1[lDestination].WINDOOR[RANDOM(lDistribution1[lDestination].cWINDOOR-1)];
                                                            float Sindoor = 
lDistribution1[mTrack].SINDOOR[RANDOM(lDistribution1[mTrack].cSINDOOR-1)];
                                                            float Outdoor = 
lDistribution1[mTrack].OUTDOOR[RANDOM(lDistribution1[mTrack].cOUTDOOR-1)];
                                                            float Transo  = 
lDistribution1[mTrack].TRANSO[RANDOM(lDistribution1[mTrack].cTRANSO-1)];
                                                            float Transt  = 
lDistribution1[mTrack].TRANSWt[lDestination];
                                                            float Transv  = 
lDistribution1[mTrack].TRANSWv[lDestination];
```

```
                                                            int lIndex = RANDOM(lActivity->cWORK_S/6);

            sHINDOOR[i] = (Hindoor * (lActivity->WORK_S[lIndex*6+2]+lActivity->WORK_S[lIndex*6+1]-
2*Transt))/1440;
            sWINDOOR[i] = (Windoor * lActivity->WORK_S[lIndex*6+0])/1440;
            sSINDOOR[i] = (Sindoor * lActivity->WORK_S[lIndex*6+3])/1440;
            sOUTDOOR[i] = (Outdoor * lActivity->WORK_S[lIndex*6+4])/1440;
            sTRANSO[i] = (Transo * lActivity->WORK_S[lIndex*6+5])/1440;
            sTRANSW[i] = (Transv * 2*Transt)/1440;

                                                            E1 =    sWINDOOR[i] +
                                                                            sTRANSW[i] +
                                                                            sHINDOOR[i] +
                                                                            sSINDOOR[i] +
                                                                            sOUTDOOR[i] +
                                                                            sTRANSO[i];

          }
                                                          else
                                                          {
                                                                LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                                break;
                                                          }

          float E2 = 0;
                                                          for (int j=0; j<8; j++)
                                                          {
                                                                float Hindoor =
lDistribution2[mTrack].HINDOOR[RANDOM(lDistribution2[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lDistribution2[mTrack].SINDOOR[RANDOM(lDistribution2[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lDistribution2[mTrack].OUTDOOR[RANDOM(lDistribution2[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lDistribution2[mTrack].TRANSO[RANDOM(lDistribution2[mTrack].cTRANSO-1)];

                                                                int lIndex = RANDOM(lActivity-
>cNW_M_S/4);

            sHINDOOR[i] += (Hindoor * lActivity->NW_M_S[lIndex*4+0])/1440;
            sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*4+1])/1440;
            sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*4+2])/1440;
            sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*4+3])/1440;

                                                                E2 += (
                                                                       (Hindoor * lActivity-
>NW_M_S[lIndex*4+0]) +
                                                                       (Sindoor * lActivity-
>NW_M_S[lIndex*4+1]) +
                                                                       (Outdoor * lActivity-
>NW_M_S[lIndex*4+2]) +
                                                                       (Transo * lActivity-
>NW_M_S[lIndex*4+3])
                                                                        )
                                                                        / 1440;
                                                          }
                                                          E2/=8;

          sHINDOOR[i] /= 9.0;
          sSINDOOR[i] /= 9.0;
          sOUTDOOR[i] /= 9.0;
          sTRANSO[i] /= 9.0;

          sE[i] = E1*0.74+E2*0.26;

                                                          sprintf(lTemp, "%f\n", sE[i]);
                                                          DWORD lLenght = strlen(lTemp);
                                                          DWORD lWritten = strlen(lTemp);
```

```
                                                        WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                }
                addSummary(mSummaryWorkersM, sE);
                addSummary(mSummaryWorkersM_Hindoor, sHINDOOR);
                addSummary(mSummaryWorkersM_Windoor, sWINDOOR);
                addSummary(mSummaryWorkersM_Sindoor, sSINDOOR);
                addSummary(mSummaryWorkersM_Outdoor, sOUTDOOR);
                addSummary(mSummaryWorkersM_Transo, sTRANSO);
                addSummary(mSummaryWorkersM_Transw, sTRANSW);
                                                CloseHandle(lFile);
                                        }

                    // workers female
                                        lFile = createFile("WORK_F", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
                  float E1 = 0;

                                                        int lDestination = lWorkPair-
>DEST[RANDOM(lWorkPair->cDEST-1)]-1;

                                                        if (lDistribution1[mTrack].TRANSWt[lDestination])
                                                        {
                    float Hindoor = lDistribution1[mTrack].HINDOOR[RANDOM(lDistribution1[mTrack].cHINDOOR-1)];
                                                          float Windoor =
lDistribution1[lDestination].WINDOOR[RANDOM(lDistribution1[lDestination].cWINDOOR-1)];
                                                          float Sindoor =
lDistribution1[mTrack].SINDOOR[RANDOM(lDistribution1[mTrack].cSINDOOR-1)];
                                                          float Outdoor =
lDistribution1[mTrack].OUTDOOR[RANDOM(lDistribution1[mTrack].cOUTDOOR-1)];
                                                          float Transo =
lDistribution1[mTrack].TRANSO[RANDOM(lDistribution1[mTrack].cTRANSO-1)];
                                                          float Transt  =
lDistribution1[mTrack].TRANSWt[lDestination];
                                                          float Transv  =
lDistribution1[mTrack].TRANSWv[lDestination];

                                                          int lIndex = RANDOM(lActivity->cWORK_S/6);

                    sHINDOOR[i] = (Hindoor * (lActivity->WORK_S[lIndex*6+2]+lActivity->WORK_S[lIndex*6+1]-
2*Transt))/1440;
                    sWINDOOR[i] = (Windoor * lActivity->WORK_S[lIndex*6+0])/1440;
                    sSINDOOR[i] = (Sindoor * lActivity->WORK_S[lIndex*6+3])/1440;
                    sOUTDOOR[i] = (Outdoor * lActivity->WORK_S[lIndex*6+4])/1440;
                    sTRANSO[i] = (Transo * lActivity->WORK_S[lIndex*6+5])/1440;
                    sTRANSW[i] = (Transv * 2*Transt)/1440;

                    E1 =    sWINDOOR[i] +
                                                                        sTRANSW[i] +
                                                                        sHINDOOR[i] +
                                                                        sSINDOOR[i] +
                                                                        sOUTDOOR[i] +
                                                                        sTRANSO[i];
                                                        }
                                                        else
                                                        {
                                                                LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                                break;
                                                        }

                                                        float E2 = 0;
                                                        for (int j=0; j<8; j++)
                                                        {
                                                                float Hindoor =
lDistribution2[mTrack].HINDOOR[RANDOM(lDistribution2[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lDistribution2[mTrack].SINDOOR[RANDOM(lDistribution2[mTrack].cSINDOOR-1)];
```

```
                                float Outdoor = 
lDistribution2[mTrack].OUTDOOR[RANDOM(lDistribution2[mTrack].cOUTDOOR-1)];
                                float Transo = 
lDistribution2[mTrack].TRANSO[RANDOM(lDistribution2[mTrack].cTRANSO-1)];

        int lIndex = RANDOM(lActivity->cNW_F_S/4);

        sHINDOOR[i] += (Hindoor * lActivity->NW_F_S[lIndex*4+0])/1440;
        sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*4+1])/1440;
        sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*4+2])/1440;
        sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*4+3])/1440;

                                E2 += (
                                    (Hindoor * lActivity-
>NW_F_S[lIndex*4+0]) +
                                    (Sindoor * lActivity-
>NW_F_S[lIndex*4+1]) +
                                    (Outdoor * lActivity-
>NW_F_S[lIndex*4+2]) +
                                    (Transo * lActivity-
>NW_F_S[lIndex*4+3])
                                     )
                                     / 1440;
                            }
                            E2/=8;

       sHINDOOR[i] /= 9.0;
       sSINDOOR[i] /= 9.0;
       sOUTDOOR[i] /= 9.0;
       sTRANSO[i] /= 9.0;

       sE[i] = E1*0.74+E2*0.26;

                            sprintf(lTemp, "%f\n", sE[i]);
                            DWORD lLenght = strlen(lTemp);
                            DWORD lWritten = strlen(lTemp);
                            WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                        }
      addSummary(mSummaryWorkersF, sE);
      addSummary(mSummaryWorkersF_Hindoor, sHINDOOR);
      addSummary(mSummaryWorkersF_Windoor, sWINDOOR);
      addSummary(mSummaryWorkersF_Sindoor, sSINDOOR);
      addSummary(mSummaryWorkersF_Outdoor, sOUTDOOR);
      addSummary(mSummaryWorkersF_Transo, sTRANSO);
      addSummary(mSummaryWorkersF_Transw, sTRANSW);
                        CloseHandle(lFile);
                    }
                }
                else
                {
                    LOG<12> () << "Missing distribution for WORKERS of census track " 
<< mTrack+1;
                }


    lDistribution1 = getDistribution(lScenario, "NONWORKERS", "WEEKDAY");
    lDistribution2 = getDistribution(lScenario, "NONWORKERS", "WEEKEND");
                if (lDistribution1[mTrack].cHINDOOR &&
                    lDistribution1[mTrack].cSINDOOR &&
                    lDistribution1[mTrack].cOUTDOOR &&
                    lDistribution1[mTrack].cTRANSO &&
                    lDistribution2[mTrack].cHINDOOR &&
                    lDistribution2[mTrack].cSINDOOR &&
                    lDistribution2[mTrack].cOUTDOOR &&
                    lDistribution2[mTrack].cTRANSO)
                {
        // nonworkers male
                    lFile = createFile("NW_M", mTrack);
                    if (lFile)
                    {
```

```
                                                        for (int i=0; i<10000; i++)
                                                        {
                                                                float E1 = 0;
                sHINDOOR[i] = 0;
                sSINDOOR[i] = 0;
                sOUTDOOR[i] = 0;
                sTRANSO[i] = 0;

                                                                for (int j=0; j<23; j++)
                                                                {
                                                                        float Hindoor =
lDistribution1[mTrack].HINDOOR[RANDOM(lDistribution1[mTrack].cHINDOOR-1)];
                                                                        float Sindoor =
lDistribution1[mTrack].SINDOOR[RANDOM(lDistribution1[mTrack].cSINDOOR-1)];
                                                                        float Outdoor =
lDistribution1[mTrack].OUTDOOR[RANDOM(lDistribution1[mTrack].cOUTDOOR-1)];
                                                                        float Transo =
lDistribution1[mTrack].TRANSO[RANDOM(lDistribution1[mTrack].cTRANSO-1)];

                                                                        int lIndex = RANDOM(lActivity-
>cNW_M_S/4);

                  sHINDOOR[i] += (Hindoor * lActivity->NW_M_S[lIndex*4+0])/1440;
                  sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*4+1])/1440;
                  sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*4+2])/1440;
                  sTRANSO[i]+= (Transo * lActivity->NW_M_S[lIndex*4+3])/1440;

                                                                        E1 += (
                                                                                        (Hindoor * lActivity-
>NW_M_S[lIndex*4+0]) +
                                                                                        (Sindoor * lActivity-
>NW_M_S[lIndex*4+1]) +
                                                                                        (Outdoor * lActivity-
>NW_M_S[lIndex*4+2]) +
                                                                                        (Transo * lActivity-
>NW_M_S[lIndex*4+3])
                                                                                        )
                                                                                        / 1440;
                                                                }
                                                                E1/=23;

                                                                float E2 = 0;
                                                                for (int j=0; j<8; j++)
                                                                {
                                                                        float Hindoor =
lDistribution2[mTrack].HINDOOR[RANDOM(lDistribution2[mTrack].cHINDOOR-1)];
                                                                        float Sindoor =
lDistribution2[mTrack].SINDOOR[RANDOM(lDistribution2[mTrack].cSINDOOR-1)];
                                                                        float Outdoor =
lDistribution2[mTrack].OUTDOOR[RANDOM(lDistribution2[mTrack].cOUTDOOR-1)];
                                                                        float Transo =
lDistribution2[mTrack].TRANSO[RANDOM(lDistribution2[mTrack].cTRANSO-1)];

                  int lIndex = RANDOM(lActivity->cNW_M_S/4);

                  sHINDOOR[i] += (Hindoor * lActivity->NW_M_S[lIndex*4+0])/1440;
                  sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*4+1])/1440;
                  sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*4+2])/1440;
                  sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*4+3])/1440;

                                                                        E2 += (
                                                                                (Hindoor * lActivity-
>NW_M_S[lIndex*4+0]) +
                                                                                (Sindoor * lActivity-
>NW_M_S[lIndex*4+1]) +
                                                                                (Outdoor * lActivity-
>NW_M_S[lIndex*4+2]) +
                                                                                (Transo * lActivity-
>NW_M_S[lIndex*4+3])
                                                                                 )
```

```
                                                                            / 1440;
                                                          }
                                                          E2/=8;

              sHINDOOR[i] /= 31.0;
              sSINDOOR[i] /= 31.0;
              sOUTDOOR[i] /= 31.0;
              sTRANSO[i] /= 31.0;

              sE[i] = E1*0.74+E2*0.26;

              sprintf(lTemp, "%f\n", sE[i]);
                                                          DWORD lLenght = strlen(lTemp);
                                                          DWORD lWritten = strlen(lTemp);
                                                          WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                  }
            addSummary(mSummaryNonWorkersM, sE);
            addSummary(mSummaryNonWorkersM_Hindoor, sHINDOOR);
            addSummary(mSummaryNonWorkersM_Sindoor, sSINDOOR);
            addSummary(mSummaryNonWorkersM_Outdoor, sOUTDOOR);
            addSummary(mSummaryNonWorkersM_Transo, sTRANSO);
                                                  CloseHandle(lFile);
                                         }

                // nonworkers female
                                         lFile = createFile("NW_F", mTrack);
                                         if (lFile)
                                         {
                                                  for (int i=0; i<10000; i++)
                                                  {
                                                          float E1 = 0;
              sHINDOOR[i] = 0;
              sSINDOOR[i] = 0;
              sOUTDOOR[i] = 0;
              sTRANSO[i] = 0;

                                                          for (int j=0; j<23; j++)
                                                          {
                                                                  float Hindoor =
lDistribution1[mTrack].HINDOOR[RANDOM(lDistribution1[mTrack].cHINDOOR-1)];
                                                                  float Sindoor =
lDistribution1[mTrack].SINDOOR[RANDOM(lDistribution1[mTrack].cSINDOOR-1)];
                                                                  float Outdoor =
lDistribution1[mTrack].OUTDOOR[RANDOM(lDistribution1[mTrack].cOUTDOOR-1)];
                                                                  float Transo =
lDistribution1[mTrack].TRANSO[RANDOM(lDistribution1[mTrack].cTRANSO-1)];

                                                                  int lIndex = RANDOM(lActivity-
>cNW_F_S/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_F_S[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*4+3])/1440;

                                                                  E1 += (
                                                                                   (Hindoor * lActivity-
>NW_F_S[lIndex*4+0]) +
                                                                                   (Sindoor * lActivity-
>NW_F_S[lIndex*4+1]) +
                                                                                   (Outdoor * lActivity-
>NW_F_S[lIndex*4+2]) +
                                                                                   (Transo * lActivity-
>NW_F_S[lIndex*4+3])
                                                                                   )
                                                                                   / 1440;
                                                          }
                                                          E1/=23;
```

```
                                                        float E2 = 0;
                                                        for (int j=0; j<8; j++)
                                                        {
                                                                float Hindoor =
lDistribution2[mTrack].HINDOOR[RANDOM(lDistribution2[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lDistribution2[mTrack].SINDOOR[RANDOM(lDistribution2[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lDistribution2[mTrack].OUTDOOR[RANDOM(lDistribution2[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lDistribution2[mTrack].TRANSO[RANDOM(lDistribution2[mTrack].cTRANSO-1)];

                                                                int lIndex = RANDOM(lActivity-
>cNW_F_S/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_F_S[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*4+3])/1440;

                                                                E2 += (
                                                                        (Hindoor * lActivity-
>NW_F_S[lIndex*4+0]) +
                                                                        (Sindoor * lActivity-
>NW_F_S[lIndex*4+1]) +
                                                                        (Outdoor * lActivity-
>NW_F_S[lIndex*4+2]) +
                                                                        (Transo * lActivity-
>NW_F_S[lIndex*4+3])
                                                                         )
                                                                         / 1440;
                                                        }
                                                        E2/=8;

              sHINDOOR[i] /= 31.0;
              sSINDOOR[i] /= 31.0;
              sOUTDOOR[i] /= 31.0;
              sTRANSO[i] /= 31.0;

              sE[i] = E1*0.74+E2*0.26;

                                                        sprintf(lTemp, "%f\n", sE[i]);
                                                        DWORD lLenght = strlen(lTemp);
                                                        DWORD lWritten = strlen(lTemp);
                                                        WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                }
            addSummary(mSummaryNonWorkersF, sE);
            addSummary(mSummaryNonWorkersF_Hindoor, sHINDOOR);
            addSummary(mSummaryNonWorkersF_Sindoor, sSINDOOR);
            addSummary(mSummaryNonWorkersF_Outdoor, sOUTDOOR);
            addSummary(mSummaryNonWorkersF_Transo, sTRANSO);
                                                CloseHandle(lFile);
                                        }
                                }
                                else
                                {
                                        LOG<12> () << "Missing distribution for WORKERS of census track "
<< mTrack+1;
                                }
                        }
      break;
    case 4:
      {
        Activity* lActivity = getActivity(lScenario);

                                Distribution* lWeekDaySummer = getDistribution(lScenario, "WORKERS",
"WEEKDAY", "SUMMER");
        Distribution* lWeekEndSummer = getDistribution(lScenario, "WORKERS", "WEEKEND", "SUMMER");
                                Distribution* lWeekDayWinter = getDistribution(lScenario, "WORKERS",
"WEEKDAY", "WINTER");
```

```
        Distribution* lWeekEndWinter = getDistribution(lScenario, "WORKERS", "WEEKEND", "WINTER");
                                 if (lWeekDaySummer[mTrack].cNHINDOOR &&
                                         lWeekDaySummer[mTrack].cWINDOOR &&
                                         lWeekDaySummer[mTrack].cDHINDOOR &&
                                         lWeekDaySummer[mTrack].cSINDOOR &&
                                         lWeekDaySummer[mTrack].cOUTDOOR &&
                                         lWeekDaySummer[mTrack].cTRANSO &&
                                         lWeekEndSummer[mTrack].cNHINDOOR &&
                                         lWeekEndSummer[mTrack].cDHINDOOR &&
                                         lWeekEndSummer[mTrack].cSINDOOR &&
                                         lWeekEndSummer[mTrack].cOUTDOOR &&
                                         lWeekEndSummer[mTrack].cTRANSO &&
          lWeekDayWinter[mTrack].cNHINDOOR &&
                                         lWeekDayWinter[mTrack].cWINDOOR &&
                                         lWeekDayWinter[mTrack].cDHINDOOR &&
                                         lWeekDayWinter[mTrack].cSINDOOR &&
                                         lWeekDayWinter[mTrack].cOUTDOOR &&
                                         lWeekDayWinter[mTrack].cTRANSO &&
                                         lWeekEndWinter[mTrack].cNHINDOOR &&
                                         lWeekEndWinter[mTrack].cDHINDOOR &&
                                         lWeekEndWinter[mTrack].cSINDOOR &&
                                         lWeekEndWinter[mTrack].cOUTDOOR &&
                                         lWeekEndWinter[mTrack].cTRANSO)
                                 {
                // workers male
                                         lFile = createFile("WORK_M", mTrack);
                                         if (lFile)
                                         {
                                                  for (int i=0; i<10000; i++)
                                                  {
                                                          int lDestination = lWorkPair-
>DEST[RANDOM(lWorkPair->cDEST-1)]-1;  // JSTIER ???
                                                          int lWorkerIndex = RANDOM(lActivity-
>cWORK_S/7);

              sNHINDOOR[i] = 0;
              sWINDOOR[i] = 0;
              sDHINDOOR[i] = 0;
              sSINDOOR[i] = 0;
              sOUTDOOR[i] = 0;
              sTRANSO[i] = 0;
              sTRANSW[i] = 0;

              //Part 1 Summer
                                                          float E1a=0;
                                                          {
                                                                  if
(lWeekDaySummer[mTrack].TRANSWt[lDestination])
                                                                  {
                                                                    float Nhindoor =
lWeekDaySummer[mTrack].NHINDOOR[RANDOM(lWeekDaySummer[mTrack].cNHINDOOR-1)];
                                                                    float Windoor =
lWeekDaySummer[lDestination].WINDOOR[RANDOM(lWeekDaySummer[lDestination].cWINDOOR-1)];
                                                                    float Dhindoor =
lWeekDaySummer[mTrack].DHINDOOR[RANDOM(lWeekDaySummer[mTrack].cDHINDOOR-1)];
                                                                    float Sindoor =
lWeekDaySummer[mTrack].SINDOOR[RANDOM(lWeekDaySummer[mTrack].cSINDOOR-1)];
                                                                    float Outdoor =
lWeekDaySummer[mTrack].OUTDOOR[RANDOM(lWeekDaySummer[mTrack].cOUTDOOR-1)];
                                                                    float Transo =
lWeekDaySummer[mTrack].TRANSO[RANDOM(lWeekDaySummer[mTrack].cTRANSO-1)];
                                                              float Transt  =
lWeekDaySummer[mTrack].TRANSWt[lDestination];
                                                              float Transv  =
lWeekDaySummer[mTrack].TRANSWv[lDestination];

                  sNHINDOOR[i] += (Nhindoor * (lActivity->WORK_S[lWorkerIndex*7+3]+lActivity-
>WORK_S[lWorkerIndex*7+1]-2*Transt))/1440;
                  sWINDOOR[i] += (Windoor * lActivity->WORK_S[lWorkerIndex*7+0])/1440;
                  sDHINDOOR[i] += (Dhindoor * lActivity->WORK_S[lWorkerIndex*7+2])/1440;
```

```
                  sSINDOOR[i] += (Sindoor * lActivity->WORK_S[lWorkerIndex*7+4])/1440;
                  sOUTDOOR[i] += (Outdoor * lActivity->WORK_S[lWorkerIndex*7+5])/1440;
                  sTRANSO[i] += (Transo * lActivity->WORK_S[lWorkerIndex*7+6])/1440;
                  sTRANSW[i] += (Transv * 2*Transt)/1440;

                                                                    E1a =  sWINDOOR[i] +
                                                                                     sTRANSO[i] +
                                                                                     sDHINDOOR[i] +
                                                                                     sNHINDOOR[i] +
                                                                                     sSINDOOR[i] +
                                                                                     sOUTDOOR[i] +
                                                                                     sTRANSW[i];

                                                                  }
                                                                  else
                                                                  {
                                                                          LOG<12> () << "Missing
TRANSW for " << mTrack+1 << " to " << lDestination+1;

                                                                          break;
                                                                  }
                                                          }

              float E1b = 0;

              for (int j=0; j<53; j++)
                                                          {
                                                                  float Nhindoor =
lWeekEndSummer[mTrack].NHINDOOR[RANDOM(lWeekEndSummer[mTrack].cNHINDOOR-1)];
                                                                  float Dhindoor =
lWeekEndSummer[mTrack].DHINDOOR[RANDOM(lWeekEndSummer[mTrack].cDHINDOOR-1)];
                                                                  float Sindoor =
lWeekEndSummer[mTrack].SINDOOR[RANDOM(lWeekEndSummer[mTrack].cSINDOOR-1)];
                                                                  float Outdoor =
lWeekEndSummer[mTrack].OUTDOOR[RANDOM(lWeekEndSummer[mTrack].cOUTDOOR-1)];
                                                                  float Transo =
lWeekEndSummer[mTrack].TRANSO[RANDOM(lWeekEndSummer[mTrack].cTRANSO-1)];

                                                          int lIndex = RANDOM(lActivity->cNW_M_S/5);

                sNHINDOOR[i] += (Nhindoor * lActivity->NW_M_S[lIndex*5+1])/1440;
                sDHINDOOR[i] += (Dhindoor * lActivity->NW_M_S[lIndex*5+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*5+2])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*5+3])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*5+4])/1440;

                                                                  E1b += (
                                                                           (Dhindoor * lActivity-
>NW_M_S[lIndex*5+0]) +
                                                                           (Nhindoor * lActivity-
>NW_M_S[lIndex*5+1]) +
                                                                           (Sindoor * lActivity-
>NW_M_S[lIndex*5+2]) +
                                                                           (Outdoor * lActivity-
>NW_M_S[lIndex*5+3]) +
                                                                           (Transo * lActivity-
>NW_M_S[lIndex*5+4])
                                                                            )
                                                                            / 1440;
                                                          }
                                                          E1b/=53;

                                                          float E2a=0;

                                                          if
(lWeekDayWinter[mTrack].TRANSWt[lDestination])
                                                          {
                                                                  float Nhindoor =
lWeekDayWinter[mTrack].NHINDOOR[RANDOM(lWeekDayWinter[mTrack].cNHINDOOR-1)];
                                                                  float Windoor =
lWeekDayWinter[lDestination].WINDOOR[RANDOM(lWeekDayWinter[lDestination].cWINDOOR-1)];
```

```
                                                                float Dhindoor =
lWeekDayWinter[mTrack].DHINDOOR[RANDOM(lWeekDayWinter[mTrack].cDHINDOOR-1)];
                                                                float Sindoor =
lWeekDayWinter[mTrack].SINDOOR[RANDOM(lWeekDayWinter[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekDayWinter[mTrack].OUTDOOR[RANDOM(lWeekDayWinter[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekDayWinter[mTrack].TRANSO[RANDOM(lWeekDayWinter[mTrack].cTRANSO-1)];
                                                          float Transt  =
lWeekDayWinter[mTrack].TRANSWt[lDestination];
                                                          float Transv  =
lWeekDayWinter[mTrack].TRANSWv[lDestination];

                sNHINDOOR[i] += (Nhindoor * (lActivity->WORK_S[lWorkerIndex*7+3]+lActivity-
>WORK_S[lWorkerIndex*7+1]-2*Transt))/1440;
                sWINDOOR[i] += (Windoor * lActivity->WORK_S[lWorkerIndex*7+0])/1440;
                sDHINDOOR[i] += (Dhindoor * lActivity->WORK_S[lWorkerIndex*7+2])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->WORK_S[lWorkerIndex*7+4])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->WORK_S[lWorkerIndex*7+5])/1440;
                sTRANSO[i] += (Transo * lActivity->WORK_S[lWorkerIndex*7+6])/1440;
                sTRANSW[i] += (Transv * 2*Transt)/1440;

                                                                int lIndex = RANDOM(lActivity-
>cWORK_S/7);

                                                                E2a = (
                                                                                (Windoor * lActivity-
>WORK_S[lWorkerIndex*7+0]) +
                                                                                (Transv * 2*Transt)
+
                                                                                (Dhindoor *
lActivity->WORK_S[lWorkerIndex*7+2]) +
                                                                                (Nhindoor *
(lActivity->WORK_S[lWorkerIndex*7+3]+lActivity->WORK_S[lWorkerIndex*7+1]-2*Transt)) +
                                                                                (Sindoor * lActivity-
>WORK_S[lWorkerIndex*7+4]) +
                                                                                (Outdoor * lActivity-
>WORK_S[lWorkerIndex*7+5]) +
                                                                                (Transo * lActivity-
>WORK_S[lWorkerIndex*7+6])
                                                                                )
                                                                                / 1440;
                                                        }
                                                        else
                                                        {
                                                                LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                                break;
                                                        }

                                                        float E2b = 0;

                                                        for (int j=0; j<51; j++)
                                                        {
                                                                float Nhindoor =
lWeekEndWinter[mTrack].NHINDOOR[RANDOM(lWeekEndWinter[mTrack].cNHINDOOR-1)];
                                                                float Dhindoor =
lWeekEndWinter[mTrack].DHINDOOR[RANDOM(lWeekEndWinter[mTrack].cDHINDOOR-1)];
                                                                float Sindoor =
lWeekEndWinter[mTrack].SINDOOR[RANDOM(lWeekEndWinter[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekEndWinter[mTrack].OUTDOOR[RANDOM(lWeekEndWinter[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekEndWinter[mTrack].TRANSO[RANDOM(lWeekEndWinter[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_M_S/5);

                sNHINDOOR[i] += (Nhindoor * lActivity->NW_M_S[lIndex*5+1])/1440;
                sDHINDOOR[i] += (Dhindoor * lActivity->NW_M_S[lIndex*5+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*5+2])/1440;
```

```
                sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*5+3])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*5+4])/1440;

                                                                E2b += (
                                                                         (Dhindoor * lActivity-
>NW_M_S[lIndex*5+0]) +
                                                                         (Nhindoor * lActivity-
>NW_M_S[lIndex*5+1]) +
                                                                         (Sindoor * lActivity-
>NW_M_S[lIndex*5+2]) +
                                                                         (Outdoor * lActivity-
>NW_M_S[lIndex*5+3]) +
                                                                         (Transo * lActivity-
>NW_M_S[lIndex*5+4])
                                                                          )
                                                                          / 1440;
                                                        }
                                                        E2b/=51;

              sNHINDOOR[i] /= (2+53+51);
              sWINDOOR[i] /= (2);
              sDHINDOOR[i] /= (2+53+51);
              sSINDOOR[i] /= (2+53+51);
              sOUTDOOR[i] /= (2+53+51);
              sTRANSO[i] /= (2+53+51);
              sTRANSW[i] /= (2);

              sE[i] = (E1a*0.72+E1b*0.28)/2.0+(E2a*0.72+E2b*0.28)/2.0;

                                                        sprintf(lTemp, "%f\n", sE[i]);
                                                        DWORD lLenght = strlen(lTemp);
                                                        DWORD lWritten = strlen(lTemp);
                                                        WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                }
            addSummary(mSummaryWorkersM_Nhindoor, sNHINDOOR);
            addSummary(mSummaryWorkersM_Windoor, sWINDOOR);
            addSummary(mSummaryWorkersM_Dhindoor, sDHINDOOR);
            addSummary(mSummaryWorkersM_Sindoor, sSINDOOR);
            addSummary(mSummaryWorkersM_Outdoor, sOUTDOOR);
            addSummary(mSummaryWorkersM_Transo, sTRANSO);
            addSummary(mSummaryWorkersM_Transw, sTRANSW);
            addSummary(mSummaryWorkersM, sE);
                                                CloseHandle(lFile);
                                        }

                // workers female
                                        lFile = createFile("WORK_F", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
                                                        int lWorkerIndex = RANDOM(lActivity-
>cWORK_S/7);
                                                int lDestination = lWorkPair->DEST[RANDOM(lWorkPair-
>cDEST-1)]-1;  // JSTIER ???

              sNHINDOOR[i] = 0;
              sWINDOOR[i] = 0;
              sDHINDOOR[i] = 0;
              sSINDOOR[i] = 0;
              sOUTDOOR[i] = 0;
              sTRANSO[i] = 0;
              sTRANSW[i] = 0;

              float E1a=0;
                                                        if
(lWeekDaySummer[mTrack].TRANSWt[lDestination])
                                                        {
                                                                float Nhindoor =
lWeekDaySummer[mTrack].NHINDOOR[RANDOM(lWeekDaySummer[mTrack].cNHINDOOR-1)];
```

```
                                                                float Windoor =
lWeekDaySummer[lDestination].WINDOOR[RANDOM(lWeekDaySummer[lDestination].cWINDOOR-1)];
                                                                float Dhindoor =
lWeekDaySummer[mTrack].DHINDOOR[RANDOM(lWeekDaySummer[mTrack].cDHINDOOR-1)];
                                                                float Sindoor =
lWeekDaySummer[mTrack].SINDOOR[RANDOM(lWeekDaySummer[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekDaySummer[mTrack].OUTDOOR[RANDOM(lWeekDaySummer[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekDaySummer[mTrack].TRANSO[RANDOM(lWeekDaySummer[mTrack].cTRANSO-1)];
                                                          float Transt  =
lWeekDaySummer[mTrack].TRANSWt[lDestination];
                                                          float Transv  =
lWeekDaySummer[mTrack].TRANSWv[lDestination];

            sNHINDOOR[i] += (Nhindoor * (lActivity->WORK_S[lWorkerIndex*7+3]+lActivity-
>WORK_S[lWorkerIndex*7+1]-2*Transt))/1440;
            sWINDOOR[i] += (Windoor * lActivity->WORK_S[lWorkerIndex*7+0])/1440;
            sDHINDOOR[i] += (Dhindoor * lActivity->WORK_S[lWorkerIndex*7+2])/1440;
            sSINDOOR[i] += (Sindoor * lActivity->WORK_S[lWorkerIndex*7+4])/1440;
            sOUTDOOR[i] += (Outdoor * lActivity->WORK_S[lWorkerIndex*7+5])/1440;
            sTRANSO[i] += (Transo * lActivity->WORK_S[lWorkerIndex*7+6])/1440;
            sTRANSW[i] += (Transv * 2*Transt)/1440;

                                                                E1a = (
                                                                            (Windoor * lActivity-
>WORK_S[lWorkerIndex*7+0]) +
                                                                            (Transv * 2*Transt)
+
                                                                            (Dhindoor *
lActivity->WORK_S[lWorkerIndex*7+2]) +
                                                                            (Nhindoor *
(lActivity->WORK_S[lWorkerIndex*7+3]+lActivity->WORK_S[lWorkerIndex*7+1]-2*Transt)) +
                                                                            (Sindoor * lActivity-
>WORK_S[lWorkerIndex*7+4]) +
                                                                            (Outdoor * lActivity-
>WORK_S[lWorkerIndex*7+5]) +
                                                                            (Transo * lActivity-
>WORK_S[lWorkerIndex*7+6])
                                                                            )
                                                                            / 1440;
                                                          }
                                                          else
                                                          {
                                                                LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                                break;
                                                          }

                                                          float E1b = 0;
                                                          for (int j=0; j<53; j++)
                                                          {
                                                                float Nhindoor =
lWeekEndSummer[mTrack].NHINDOOR[RANDOM(lWeekEndSummer[mTrack].cNHINDOOR-1)];
                                                                float Dhindoor =
lWeekEndSummer[mTrack].DHINDOOR[RANDOM(lWeekEndSummer[mTrack].cDHINDOOR-1)];
                                                                float Sindoor =
lWeekEndSummer[mTrack].SINDOOR[RANDOM(lWeekEndSummer[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekEndSummer[mTrack].OUTDOOR[RANDOM(lWeekEndSummer[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekEndSummer[mTrack].TRANSO[RANDOM(lWeekEndSummer[mTrack].cTRANSO-1)];

            int lIndex = RANDOM(lActivity->cNW_F_S/5);

            sNHINDOOR[i] += (Nhindoor * lActivity->NW_F_S[lIndex*5+1])/1440;
            sDHINDOOR[i] += (Dhindoor * lActivity->NW_F_S[lIndex*5+0])/1440;
            sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*5+2])/1440;
            sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*5+3])/1440;
            sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*5+4])/1440;
```

```
                                                                        E1b += (
                                                                                (Dhindoor * lActivity-
>NW_F_S[lIndex*5+0]) +
                                                                                (Nhindoor * lActivity-
>NW_F_S[lIndex*5+1]) +
                                                                                (Sindoor * lActivity-
>NW_F_S[lIndex*5+2]) +
                                                                                (Outdoor * lActivity-
>NW_F_S[lIndex*5+3]) +
                                                                                (Transo * lActivity-
>NW_F_S[lIndex*5+4])
                                                                                 )
                                                                                 / 1440;
                                                                }
                                                                E1b/=53;

                                                                float E2a=0;
                                                                if
(lWeekDayWinter[mTrack].TRANSWt[lDestination])
                                                                {
                                                                        float Nhindoor =
lWeekDayWinter[mTrack].NHINDOOR[RANDOM(lWeekDayWinter[mTrack].cNHINDOOR-1)];
                                                                        float Windoor =
lWeekDayWinter[lDestination].WINDOOR[RANDOM(lWeekDayWinter[lDestination].cWINDOOR-1)];
                                                                        float Dhindoor =
lWeekDayWinter[mTrack].DHINDOOR[RANDOM(lWeekDayWinter[mTrack].cDHINDOOR-1)];
                                                                        float Sindoor =
lWeekDayWinter[mTrack].SINDOOR[RANDOM(lWeekDayWinter[mTrack].cSINDOOR-1)];
                                                                        float Outdoor =
lWeekDayWinter[mTrack].OUTDOOR[RANDOM(lWeekDayWinter[mTrack].cOUTDOOR-1)];
                                                                        float Transo =
lWeekDayWinter[mTrack].TRANSO[RANDOM(lWeekDayWinter[mTrack].cTRANSO-1)];
                                                                  float Transt  =
lWeekDayWinter[mTrack].TRANSWt[lDestination];
                                                                  float Transv  =
lWeekDayWinter[mTrack].TRANSWv[lDestination];

                sNHINDOOR[i] += (Nhindoor * (lActivity->WORK_S[lWorkerIndex*7+3]+lActivity-
>WORK_S[lWorkerIndex*7+1]-2*Transt))/1440;
                sWINDOOR[i] += (Windoor * lActivity->WORK_S[lWorkerIndex*7+0])/1440;
                sDHINDOOR[i] += (Dhindoor * lActivity->WORK_S[lWorkerIndex*7+2])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->WORK_S[lWorkerIndex*7+4])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->WORK_S[lWorkerIndex*7+5])/1440;
                sTRANSO[i] += (Transo * lActivity->WORK_S[lWorkerIndex*7+6])/1440;
                sTRANSW[i] += (Transv * 2*Transt)/1440;

                                                                        E2a = (
                                                                                       (Windoor * lActivity-
>WORK_S[lWorkerIndex*7+0]) +
                                                                                       (Transv * 2*Transt)
+
                                                                                       (Dhindoor *
lActivity->WORK_S[lWorkerIndex*7+2]) +
                                                                                       (Nhindoor *
(lActivity->WORK_S[lWorkerIndex*7+3]+lActivity->WORK_S[lWorkerIndex*7+1]-2*Transt)) +
                                                                                       (Sindoor * lActivity-
>WORK_S[lWorkerIndex*7+4]) +
                                                                                       (Outdoor * lActivity-
>WORK_S[lWorkerIndex*7+5]) +
                                                                                       (Transo * lActivity-
>WORK_S[lWorkerIndex*7+6])
                                                                                       )
                                                                                       / 1440;
              }
                                                                else
                                                                {
                                                                        LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                                        break;
```

```
                                                          }

                                                          float E2b = 0;
              for (int j=0; j<51; j++)
                                                          {
                                                                  float Nhindoor =
lWeekEndWinter[mTrack].NHINDOOR[RANDOM(lWeekEndWinter[mTrack].cNHINDOOR-1)];
                                                                  float Dhindoor =
lWeekEndWinter[mTrack].DHINDOOR[RANDOM(lWeekEndWinter[mTrack].cDHINDOOR-1)];
                                                                  float Sindoor =
lWeekEndWinter[mTrack].SINDOOR[RANDOM(lWeekEndWinter[mTrack].cSINDOOR-1)];
                                                                  float Outdoor =
lWeekEndWinter[mTrack].OUTDOOR[RANDOM(lWeekEndWinter[mTrack].cOUTDOOR-1)];
                                                                  float Transo =
lWeekEndWinter[mTrack].TRANSO[RANDOM(lWeekEndWinter[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_M_S/5);

                sNHINDOOR[i] += (Nhindoor * lActivity->NW_F_S[lIndex*5+1]);
                sDHINDOOR[i] += (Dhindoor * lActivity->NW_F_S[lIndex*5+0]);
                sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*5+2]);
                sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*5+3]);
                sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*5+4]);

                                                                  E2b += (
                                                                           (Dhindoor * lActivity-
>NW_F_S[lIndex*5+0]) +

                                                                           (Nhindoor * lActivity-
>NW_F_S[lIndex*5+1]) +

                                                                           (Sindoor * lActivity-
>NW_F_S[lIndex*5+2]) +

                                                                           (Outdoor * lActivity-
>NW_F_S[lIndex*5+3]) +

                                                                           (Transo * lActivity-
>NW_F_S[lIndex*5+4])

                                                                            )
                                                                            / 1440;
                                                          }
                                                          E2b/=51;

              sNHINDOOR[i] /= (2+53+51);
              sWINDOOR[i] /= (2);
              sDHINDOOR[i] /= (2+53+51);
              sSINDOOR[i] /= (2+53+51);
              sOUTDOOR[i] /= (2+53+51);
              sTRANSO[i] /= (2+53+51);
              sTRANSW[i] /= (2);

              sE[i] = (E1a*0.72+E1b*0.28)/2.0+(E2a*0.72+E2b*0.28)/2.0;

                                                          sprintf(lTemp, "%f\n", sE[i]);
                                                          DWORD lLenght = strlen(lTemp);
                                                          DWORD lWritten = strlen(lTemp);
                                                          WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                  }
            addSummary(mSummaryWorkersF_Nhindoor, sNHINDOOR);
            addSummary(mSummaryWorkersF_Windoor, sWINDOOR);
            addSummary(mSummaryWorkersF_Dhindoor, sDHINDOOR);
            addSummary(mSummaryWorkersF_Sindoor, sSINDOOR);
            addSummary(mSummaryWorkersF_Outdoor, sOUTDOOR);
            addSummary(mSummaryWorkersF_Transo, sTRANSO);
            addSummary(mSummaryWorkersF_Transw, sTRANSW);
            addSummary(mSummaryWorkersF, sE);
                                                  CloseHandle(lFile);
                                          }
                                  }


                                  lWeekDaySummer = getDistribution(lScenario, "NONWORKERS", "WEEKDAY",
"SUMMER");
```

```
    lWeekEndSummer = getDistribution(lScenario, "NONWORKERS", "WEEKEND", "SUMMER");
                lWeekDayWinter = getDistribution(lScenario, "NONWORKERS", "WEEKDAY",
"WINTER");
    lWeekEndWinter = getDistribution(lScenario, "NONWORKERS", "WEEKEND", "WINTER");
                if (lWeekDaySummer[mTrack].cNHINDOOR &&
                    lWeekDaySummer[mTrack].cDHINDOOR &&
                    lWeekDaySummer[mTrack].cSINDOOR &&
                    lWeekDaySummer[mTrack].cOUTDOOR &&
                    lWeekDaySummer[mTrack].cTRANSO &&
                    lWeekEndSummer[mTrack].cNHINDOOR &&
                    lWeekEndSummer[mTrack].cDHINDOOR &&
                    lWeekEndSummer[mTrack].cSINDOOR &&
                    lWeekEndSummer[mTrack].cOUTDOOR &&
                    lWeekEndSummer[mTrack].cTRANSO &&
                    lWeekDayWinter[mTrack].cNHINDOOR &&
                    lWeekDayWinter[mTrack].cDHINDOOR &&
                    lWeekDayWinter[mTrack].cSINDOOR &&
                    lWeekDayWinter[mTrack].cOUTDOOR &&
                    lWeekDayWinter[mTrack].cTRANSO &&
                    lWeekEndWinter[mTrack].cNHINDOOR &&
                    lWeekEndWinter[mTrack].cDHINDOOR &&
                    lWeekEndWinter[mTrack].cSINDOOR &&
                    lWeekEndWinter[mTrack].cOUTDOOR &&
                    lWeekEndWinter[mTrack].cTRANSO)
                {
        // nonworkers male
                    lFile = createFile("NW_M", mTrack);
                    if (lFile)
                    {
                        for (int i=0; i<10000; i++)
                        {
       sNHINDOOR[i] = 0;
       sWINDOOR[i] = 0;
       sDHINDOOR[i] = 0;
       sSINDOOR[i] = 0;
       sOUTDOOR[i] = 0;
       sTRANSO[i] = 0;

       float E1a = 0;

                            for (int j=0; j<133; j++)
                            {
                                float Nhindoor =
lWeekDaySummer[mTrack].NHINDOOR[RANDOM(lWeekDaySummer[mTrack].cNHINDOOR-1)];
                                float Dhindoor =
lWeekDaySummer[mTrack].DHINDOOR[RANDOM(lWeekDaySummer[mTrack].cDHINDOOR-1)];
                                float Sindoor =
lWeekDaySummer[mTrack].SINDOOR[RANDOM(lWeekDaySummer[mTrack].cSINDOOR-1)];
                                float Outdoor =
lWeekDaySummer[mTrack].OUTDOOR[RANDOM(lWeekDaySummer[mTrack].cOUTDOOR-1)];
        float Transo =
lWeekDaySummer[mTrack].TRANSO[RANDOM(lWeekDaySummer[mTrack].cTRANSO-1)];

        int lIndex = RANDOM(lActivity->cNW_M_S/5);

        sDHINDOOR[i] += (Dhindoor * lActivity->NW_M_S[lIndex*5+0])/1440;
        sNHINDOOR[i] += (Nhindoor * lActivity->NW_M_S[lIndex*5+1])/1440;
        sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*5+2])/1440;
        sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*5+3])/1440;
        sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*5+4])/1440;

                                E1a += (
                                        (Dhindoor *
lActivity->NW_M_S[lIndex*5+0]) +
                                        (Nhindoor *
lActivity->NW_M_S[lIndex*5+1]) +
                                        (Sindoor * lActivity-
>NW_M_S[lIndex*5+2]) +
                                        (Outdoor * lActivity-
>NW_M_S[lIndex*5+3]) +
```

```
                                                                                         (Transso * lActivity-
>NW_M_S[lIndex*5+4])
                                                                                         )
                                                                                         / 1440;
                                                                     }
                                                                     E1a/=133;

                        float E1b = 0;

                                                                     for (int j=0; j<53; j++)
                                                                     {
                                                                            float Nhindoor =
lWeekEndSummer[mTrack].NHINDOOR[RANDOM(lWeekEndSummer[mTrack].cNHINDOOR-1)];
                                                                            float Dhindoor =
lWeekEndSummer[mTrack].DHINDOOR[RANDOM(lWeekEndSummer[mTrack].cDHINDOOR-1)];
                                                                            float Sindoor =
lWeekEndSummer[mTrack].SINDOOR[RANDOM(lWeekEndSummer[mTrack].cSINDOOR-1)];
                                                                            float Outdoor =
lWeekEndSummer[mTrack].OUTDOOR[RANDOM(lWeekEndSummer[mTrack].cOUTDOOR-1)];
                                                                            float Transo =
lWeekEndSummer[mTrack].TRANSO[RANDOM(lWeekEndSummer[mTrack].cTRANSO-1)];

                          int lIndex = RANDOM(lActivity->cNW_M_S/5);

                          sDHINDOOR[i] += (Dhindoor * lActivity->NW_M_S[lIndex*5+0])/1440;
                          sNHINDOOR[i] += (Nhindoor * lActivity->NW_M_S[lIndex*5+1])/1440;
                          sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*5+2])/1440;
                          sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*5+3])/1440;
                          sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*5+4])/1440;

                                                                            E1b += (
                                                                                   (Dhindoor * lActivity-
>NW_M_S[lIndex*5+0]) +
                                                                                   (Nhindoor * lActivity-
>NW_M_S[lIndex*5+1]) +
                                                                                   (Sindoor * lActivity-
>NW_M_S[lIndex*5+2]) +
                                                                                   (Outdoor * lActivity-
>NW_M_S[lIndex*5+3]) +
                                                                                   (Transo * lActivity-
>NW_M_S[lIndex*5+4])
                                                                                    )
                                                                                    / 1440;
                                                                     }
                                                                     E1b/=53;

                                                                     float E2a = 0;

                                                                     for (int j=0; j<128; j++)
                                                                     {
                                                                            float Nhindoor =
lWeekDayWinter[mTrack].NHINDOOR[RANDOM(lWeekDayWinter[mTrack].cNHINDOOR-1)];
                                                                            float Dhindoor =
lWeekDayWinter[mTrack].DHINDOOR[RANDOM(lWeekDayWinter[mTrack].cDHINDOOR-1)];
                                                                            float Sindoor =
lWeekDayWinter[mTrack].SINDOOR[RANDOM(lWeekDayWinter[mTrack].cSINDOOR-1)];
                                                                            float Outdoor =
lWeekDayWinter[mTrack].OUTDOOR[RANDOM(lWeekDayWinter[mTrack].cOUTDOOR-1)];
                                                                            float Transo =
lWeekDayWinter[mTrack].TRANSO[RANDOM(lWeekDayWinter[mTrack].cTRANSO-1)];

                          int lIndex = RANDOM(lActivity->cNW_M_S/5);

                          sDHINDOOR[i] += (Dhindoor * lActivity->NW_M_S[lIndex*5+0])/1440;
                          sNHINDOOR[i] += (Nhindoor * lActivity->NW_M_S[lIndex*5+1])/1440;
                          sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*5+2])/1440;
                          sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*5+3])/1440;
                          sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*5+4])/1440;

                                                                            E2a += (
```

```
                                                                                                    (Dhindoor *
lActivity->NW_M_S[lIndex*5+0]) +
                                                                                                    (Nhindoor *
lActivity->NW_M_S[lIndex*5+1]) +
                                                                                                    (Sindoor * lActivity-
>NW_M_S[lIndex*5+2]) +
                                                                                                    (Outdoor * lActivity-
>NW_M_S[lIndex*5+3]) +
                                                                                                    (Transo * lActivity-
>NW_M_S[lIndex*5+4])
                                                                                                    )
                                                                                                    / 1440;
                                                                              }
                                                                              E2a/=128;

                                                                              float E2b = 0;

                                                                              for (int j=0; j<51; j++)
                                                                              {
                                                                                      float Nhindoor =
lWeekEndWinter[mTrack].NHINDOOR[RANDOM(lWeekEndWinter[mTrack].cNHINDOOR-1)];
                                                                                      float Dhindoor =
lWeekEndWinter[mTrack].DHINDOOR[RANDOM(lWeekEndWinter[mTrack].cDHINDOOR-1)];
                                                                                      float Sindoor =
lWeekEndWinter[mTrack].SINDOOR[RANDOM(lWeekEndWinter[mTrack].cSINDOOR-1)];
                                                                                      float Outdoor =
lWeekEndWinter[mTrack].OUTDOOR[RANDOM(lWeekEndWinter[mTrack].cOUTDOOR-1)];
                                                                                      float Transo =
lWeekEndWinter[mTrack].TRANSO[RANDOM(lWeekEndWinter[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_M_S/5);

                sDHINDOOR[i] += (Dhindoor * lActivity->NW_M_S[lIndex*5+0])/1440;
                sNHINDOOR[i] += (Nhindoor * lActivity->NW_M_S[lIndex*5+1])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*5+2])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*5+3])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*5+4])/1440;

                                                                                      E2b += (
                                                                                               (Dhindoor * lActivity-
>NW_M_S[lIndex*5+0]) +
                                                                                               (Nhindoor * lActivity-
>NW_M_S[lIndex*5+1]) +
                                                                                               (Sindoor * lActivity-
>NW_M_S[lIndex*5+2]) +
                                                                                               (Outdoor * lActivity-
>NW_M_S[lIndex*5+3]) +
                                                                                               (Transo * lActivity-
>NW_M_S[lIndex*5+4])
                                                                                                )
                                                                                                / 1440;
                                                                              }
                                                                              E2b/=51;

              sNHINDOOR[i] /= (133+53+128+51);
              sDHINDOOR[i] /= (133+53+128+51);
              sSINDOOR[i] /= (133+53+128+51);
              sOUTDOOR[i] /= (133+53+128+51);
              sTRANSO[i] /= (133+53+128+51);

              sE[i] = (E1a*0.72+E1b*0.28)/2.0+(E2a*0.72+E2b*0.28)/2.0;

                                                                              sprintf(lTemp, "%f\n", sE[i]);
                                                                              DWORD lLenght = strlen(lTemp);
                                                                              DWORD lWritten = strlen(lTemp);
                                                                              WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                                      }

            addSummary(mSummaryNonWorkersM_Nhindoor, sNHINDOOR);
            addSummary(mSummaryNonWorkersM_Dhindoor, sDHINDOOR);
```

```
                    addSummary(mSummaryNonWorkersM_Sindoor, sSINDOOR);
                    addSummary(mSummaryNonWorkersM_Outdoor, sOUTDOOR);
                    addSummary(mSummaryNonWorkersM_Transo, sTRANSO);
                    addSummary(mSummaryNonWorkersM, sE);
                                                                CloseHandle(lFile);
                                                    }

                        // nonworkers female
                                                    lFile = createFile("NW_F", mTrack);
                                                    if (lFile)
                                                    {
                                                                for (int i=0; i<10000; i++)
                                                                {
                      sNHINDOOR[i] = 0;
                      sWINDOOR[i] = 0;
                      sDHINDOOR[i] = 0;
                      sSINDOOR[i] = 0;
                      sOUTDOOR[i] = 0;
                      sTRANSO[i] = 0;
                      sTRANSW[i] = 0;

                                                                            float E1a = 0;
                                                                            for (int j=0; j<133; j++)
                                                                            {
                                                                                        float Nhindoor =
lWeekDaySummer[mTrack].NHINDOOR[RANDOM(lWeekDaySummer[mTrack].cNHINDOOR-1)];
                                                                                        float Dhindoor =
lWeekDaySummer[mTrack].DHINDOOR[RANDOM(lWeekDaySummer[mTrack].cDHINDOOR-1)];
                                                                                        float Sindoor =
lWeekDaySummer[mTrack].SINDOOR[RANDOM(lWeekDaySummer[mTrack].cSINDOOR-1)];
                                                                                        float Outdoor =
lWeekDaySummer[mTrack].OUTDOOR[RANDOM(lWeekDaySummer[mTrack].cOUTDOOR-1)];
                                                                                        float Transo =
lWeekDaySummer[mTrack].TRANSO[RANDOM(lWeekDaySummer[mTrack].cTRANSO-1)];

                        int lIndex = RANDOM(lActivity->cNW_F_S/5);

                        sNHINDOOR[i] += (Nhindoor * lActivity->NW_F_S[lIndex*5+1])/1440;
                        sDHINDOOR[i] += (Dhindoor * lActivity->NW_F_S[lIndex*5+0])/1440;
                        sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*5+2])/1440;
                        sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*5+3])/1440;
                        sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*5+4])/1440;

                                                                                        E1a += (
                                                                                                    (Dhindoor *
lActivity->NW_F_S[lIndex*5+0]) +
                                                                                                    (Nhindoor *
lActivity->NW_F_S[lIndex*5+1]) +
                                                                                                    (Sindoor * lActivity-
>NW_F_S[lIndex*5+2]) +
                                                                                                    (Outdoor * lActivity-
>NW_F_S[lIndex*5+3]) +
                                                                                                    (Transo * lActivity-
>NW_F_S[lIndex*5+4])
                                                                                                    )
                                                                                                    / 1440;
                                                                            }
                                                                            E1a/=133;

                                                                            float E1b = 0;
                                                                            for (int j=0; j<53; j++)
                                                                            {
                                                                                        float Nhindoor =
lWeekEndSummer[mTrack].NHINDOOR[RANDOM(lWeekEndSummer[mTrack].cNHINDOOR-1)];
                                                                                        float Dhindoor =
lWeekEndSummer[mTrack].DHINDOOR[RANDOM(lWeekEndSummer[mTrack].cDHINDOOR-1)];
                                                                                        float Sindoor =
lWeekEndSummer[mTrack].SINDOOR[RANDOM(lWeekEndSummer[mTrack].cSINDOOR-1)];
                                                                                        float Outdoor =
lWeekEndSummer[mTrack].OUTDOOR[RANDOM(lWeekEndSummer[mTrack].cOUTDOOR-1)];
```

```
                                                                                float Transo =
lWeekEndSummer[mTrack].TRANSO[RANDOM(lWeekEndSummer[mTrack].cTRANSO-1)];

                    int lIndex = RANDOM(lActivity->cNW_F_S/5);

                    sNHINDOOR[i] += (Nhindoor * lActivity->NW_F_S[lIndex*5+1])/1440;
                    sDHINDOOR[i] += (Dhindoor * lActivity->NW_F_S[lIndex*5+0])/1440;
                    sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*5+2])/1440;
                    sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*5+3])/1440;
                    sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*5+4])/1440;

                                                                                E1b += (
                                                                                           (Dhindoor * lActivity-
>NW_F_S[lIndex*5+0]) +
                                                                                           (Nhindoor * lActivity-
>NW_F_S[lIndex*5+1]) +
                                                                                           (Sindoor * lActivity-
>NW_F_S[lIndex*5+2]) +
                                                                                           (Outdoor * lActivity-
>NW_F_S[lIndex*5+3]) +
                                                                                           (Transo * lActivity-
>NW_F_S[lIndex*5+4])
                                                                                            )
                                                                                            / 1440;
                                                                      }
                                                                      E1b/=53;

                                                                      float E2a = 0;
                                                                      for (int j=0; j<128; j++)
                                                                      {
                                                                                float Nhindoor =
lWeekDayWinter[mTrack].NHINDOOR[RANDOM(lWeekDayWinter[mTrack].cNHINDOOR-1)];
                                                                                float Dhindoor =
lWeekDayWinter[mTrack].DHINDOOR[RANDOM(lWeekDayWinter[mTrack].cDHINDOOR-1)];
                                                                                float Sindoor =
lWeekDayWinter[mTrack].SINDOOR[RANDOM(lWeekDayWinter[mTrack].cSINDOOR-1)];
                                                                                float Outdoor =
lWeekDayWinter[mTrack].OUTDOOR[RANDOM(lWeekDayWinter[mTrack].cOUTDOOR-1)];
                                                                                float Transo =
lWeekDayWinter[mTrack].TRANSO[RANDOM(lWeekDayWinter[mTrack].cTRANSO-1)];

                    int lIndex = RANDOM(lActivity->cNW_F_S/5);

                    sNHINDOOR[i] += (Nhindoor * lActivity->NW_F_S[lIndex*5+1])/1440;
                    sDHINDOOR[i] += (Dhindoor * lActivity->NW_F_S[lIndex*5+0])/1440;
                    sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*5+2])/1440;
                    sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*5+3])/1440;
                    sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*5+4])/1440;

                                                                                E2a += (
                                                                                                  (Dhindoor *
lActivity->NW_F_S[lIndex*5+0]) +
                                                                                                  (Nhindoor *
lActivity->NW_F_S[lIndex*5+1]) +
                                                                                                  (Sindoor * lActivity-
>NW_F_S[lIndex*5+2]) +
                                                                                                  (Outdoor * lActivity-
>NW_F_S[lIndex*5+3]) +
                                                                                                  (Transo * lActivity-
>NW_F_S[lIndex*5+4])
                                                                                                  )
                                                                                                  / 1440;
                                                                      }
                                                                      E2a/=128;

                                                                      float E2b = 0;
                                                                      for (int j=0; j<51; j++)
                                                                      {
                                                                                float Nhindoor =
lWeekEndWinter[mTrack].NHINDOOR[RANDOM(lWeekEndWinter[mTrack].cNHINDOOR-1)];
```

```
                                                                  float Dhindoor =
lWeekEndWinter[mTrack].DHINDOOR[RANDOM(lWeekEndWinter[mTrack].cDHINDOOR-1)];
                                                                  float Sindoor =
lWeekEndWinter[mTrack].SINDOOR[RANDOM(lWeekEndWinter[mTrack].cSINDOOR-1)];
                                                                  float Outdoor =
lWeekEndWinter[mTrack].OUTDOOR[RANDOM(lWeekEndWinter[mTrack].cOUTDOOR-1)];
                                                                  float Transo =
lWeekEndWinter[mTrack].TRANSO[RANDOM(lWeekEndWinter[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_F_S/5);

                sNHINDOOR[i] += (Nhindoor * lActivity->NW_F_S[lIndex*5+1])/1440;
                sDHINDOOR[i] += (Dhindoor * lActivity->NW_F_S[lIndex*5+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*5+2])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*5+3])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*5+4])/1440;

                                                                  E2b += (
                                                                           (Dhindoor * lActivity-
>NW_F_S[lIndex*5+0]) +
                                                                           (Nhindoor * lActivity-

>NW_F_S[lIndex*5+1]) +
                                                                           (Sindoor * lActivity-

>NW_F_S[lIndex*5+2]) +
                                                                           (Outdoor * lActivity-

>NW_F_S[lIndex*5+3]) +
                                                                           (Transo * lActivity-

>NW_F_S[lIndex*5+4])
                                                                            )
                                                                            / 1440;
                                                          }
                                                          E2b/=51;

              sNHINDOOR[i] /= (133+53+128+51);
              sDHINDOOR[i] /= (133+53+128+51);
              sSINDOOR[i] /= (133+53+128+51);
              sOUTDOOR[i] /= (133+53+128+51);
              sTRANSO[i] /= (133+53+128+51);

              sE[i] = (E1a*0.72+E1b*0.28)/2.0+(E2a*0.72+E2b*0.28)/2.0;

              sprintf(lTemp, "%f\n", sE[i]);
                                                          DWORD lLenght = strlen(lTemp);
                                                          DWORD lWritten = strlen(lTemp);
                                                          WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                  }

            addSummary(mSummaryNonWorkersF_Nhindoor, sNHINDOOR);
            addSummary(mSummaryNonWorkersF_Dhindoor, sDHINDOOR);
            addSummary(mSummaryNonWorkersF_Sindoor, sSINDOOR);
            addSummary(mSummaryNonWorkersF_Outdoor, sOUTDOOR);
            addSummary(mSummaryNonWorkersF_Transo, sTRANSO);
            addSummary(mSummaryNonWorkersF, sE);
                                                  CloseHandle(lFile);
                                         }
                                 }
                                 else
                                 {
                                         LOG<12> () << "Missing distribution for WORKERS of census track "
<< mTrack+1;
                                 }
      }
      break;
    case 5:
      {
        Activity* lActivity = getActivity(lScenario);

                                 Distribution* lWeekDaySummer = getDistribution(lScenario, "WORKERS",
"WEEKDAY", "SUMMER");
        Distribution* lWeekEndSummer = getDistribution(lScenario, "WORKERS", "WEEKEND", "SUMMER");
```

```
                                Distribution* lWeekDayWinter = getDistribution(lScenario, "WORKERS",
"WEEKDAY", "WINTER");
        Distribution* lWeekEndWinter = getDistribution(lScenario, "WORKERS", "WEEKEND", "WINTER");
                                if (lWeekDaySummer[mTrack].cHINDOOR &&
                                        lWeekDaySummer[mTrack].cWINDOOR &&
                                        lWeekDaySummer[mTrack].cSINDOOR &&
                                        lWeekDaySummer[mTrack].cOUTDOOR &&
                                        lWeekDaySummer[mTrack].cTRANSO &&
                                        lWeekEndSummer[mTrack].cHINDOOR &&
                                        lWeekEndSummer[mTrack].cSINDOOR &&
                                        lWeekEndSummer[mTrack].cOUTDOOR &&
                                        lWeekEndSummer[mTrack].cTRANSO)
                                {
                // workers male
                                        lFile = createFile("WORK_M", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
              sHINDOOR[i] = 0;
              sWINDOOR[i] = 0;
              sSINDOOR[i] = 0;
              sOUTDOOR[i] = 0;
              sTRANSO[i] = 0;
              sTRANSW[i] = 0;

                                                int lIndex = RANDOM(lActivity->cWORK_S/6);
                                                        int lDestination = lWorkPair-
>DEST[RANDOM(lWorkPair->cDEST-1)]-1;  // JSTIER ???

              //Part 1 Summer
                                                        float E1a=0;
                                                        if
(lWeekDaySummer[mTrack].TRANSWt[lDestination])
                                                        {
                                                                float Hindoor =
lWeekDaySummer[mTrack].HINDOOR[RANDOM(lWeekDaySummer[mTrack].cHINDOOR-1)];
                                                                float Windoor =
lWeekDaySummer[lDestination].WINDOOR[RANDOM(lWeekDaySummer[lDestination].cWINDOOR-1)];
                                                                float Sindoor =
lWeekDaySummer[mTrack].SINDOOR[RANDOM(lWeekDaySummer[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekDaySummer[mTrack].OUTDOOR[RANDOM(lWeekDaySummer[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekDaySummer[mTrack].TRANSO[RANDOM(lWeekDaySummer[mTrack].cTRANSO-1)];
                                                          float Transt =
lWeekDaySummer[mTrack].TRANSWt[lDestination];
                                                          float Transv =
lWeekDaySummer[mTrack].TRANSWv[lDestination];

                sWINDOOR[i] += (Windoor * lActivity->WORK_S[lIndex*6+0])/1440;
                sHINDOOR[i] += (Hindoor * (lActivity->WORK_S[lIndex*6+2]+lActivity->WORK_S[lIndex*6+1]-
2*Transt))/1440;
                sSINDOOR[i] += (Sindoor * lActivity->WORK_S[lIndex*6+3])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->WORK_S[lIndex*6+4])/1440;
                sTRANSO[i] += (Transo * lActivity->WORK_S[lIndex*6+5])/1440;
                sTRANSW[i] += (Transv * 2*Transt)/1440;

                                                                E1a = (
                                                                                (Windoor * lActivity-
>WORK_S[lIndex*6+0]) +
                                                                                (Transv * 2*Transt)
+
                                                                                (Hindoor * (lActivity-
>WORK_S[lIndex*6+2]+lActivity->WORK_S[lIndex*6+1]-2*Transt)) +
                                                                                (Sindoor * lActivity-
>WORK_S[lIndex*6+3]) +
                                                                                (Outdoor * lActivity-
>WORK_S[lIndex*6+4]) +
```

```
                                                                                        (Transco * lActivity-
>WORK_S[lIndex*6+5])
                                                                                        )
                                                                                        / 1440;
                                                                  }
                                                                  else
                                                                  {
                                                                          LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                                          break;
                                                                  }

            float E1b = 0;
                                                                  for (int j=0; j<53; j++)
                                                                  {
                                                                          float Hindoor =
lWeekEndSummer[mTrack].HINDOOR[RANDOM(lWeekEndSummer[mTrack].cHINDOOR-1)];
                                                                          float Sindoor =
lWeekEndSummer[mTrack].SINDOOR[RANDOM(lWeekEndSummer[mTrack].cSINDOOR-1)];
                                                                          float Outdoor =
lWeekEndSummer[mTrack].OUTDOOR[RANDOM(lWeekEndSummer[mTrack].cOUTDOOR-1)];
                                                                          float Transo =
lWeekEndSummer[mTrack].TRANSO[RANDOM(lWeekEndSummer[mTrack].cTRANSO-1)];

                                                                          int lIndex = RANDOM(lActivity-
>cNW_M_S/4);

              sHINDOOR[i] += (Hindoor * lActivity->NW_M_S[lIndex*4+0])/1440;
              sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*4+1])/1440;
              sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*4+2])/1440;
              sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*4+3])/1440;

                                                                          E1b += (
                                                                                  (Hindoor * lActivity-
>NW_M_S[lIndex*4+0]) +
                                                                                  (Sindoor * lActivity-
>NW_M_S[lIndex*4+1]) +
                                                                                  (Outdoor * lActivity-
>NW_M_S[lIndex*4+2]) +
                                                                                  (Transo * lActivity-
>NW_M_S[lIndex*4+3])
                                                                                   )
                                                                                   / 1440;
                                                                  }
                                                                  E1b/=53;

            // Part 2 Winter
                                                                  float E2a=0;
                                                                  if
(lWeekDayWinter[mTrack].TRANSWt[lDestination])
                                                                  {
                                                                          float Hindoor =
lWeekDayWinter[mTrack].HINDOOR[RANDOM(lWeekDayWinter[mTrack].cHINDOOR-1)];
                                                                          float Windoor =
lWeekDayWinter[lDestination].WINDOOR[RANDOM(lWeekDayWinter[lDestination].cWINDOOR-1)];
                                                                          float Sindoor =
lWeekDayWinter[mTrack].SINDOOR[RANDOM(lWeekDayWinter[mTrack].cSINDOOR-1)];
                                                                          float Outdoor =
lWeekDayWinter[mTrack].OUTDOOR[RANDOM(lWeekDayWinter[mTrack].cOUTDOOR-1)];
                                                                          float Transo =
lWeekDayWinter[mTrack].TRANSO[RANDOM(lWeekDayWinter[mTrack].cTRANSO-1)];
                                                                    float Transt  =
lWeekDayWinter[mTrack].TRANSWt[lDestination];
                                                                    float Transv  =
lWeekDayWinter[mTrack].TRANSWv[lDestination];

              sHINDOOR[i] += (Hindoor * (lActivity->WORK_W[lIndex*6+2]+lActivity->WORK_W[lIndex*6+1]-
2*Transt))/1440;
              sWINDOOR[i] += (Windoor * lActivity->WORK_W[lIndex*6+0])/1440;
              sSINDOOR[i] += (Sindoor * lActivity->WORK_W[lIndex*6+3])/1440;
```

```
                sOUTDOOR[i] += (Outdoor * lActivity->WORK_W[lIndex*6+4])/1440;
                sTRANSO[i] += (Transo * lActivity->WORK_W[lIndex*6+5])/1440;
                sTRANSW[i] += (Transv * 2*Transt)/1440;

                                                                  E2a = (
                                                                                   (Windoor * lActivity-
>WORK_W[lIndex*6+0]) +
                                                                                   (Transv * 2*Transt)
+
                                                                                   (Hindoor * (lActivity-
>WORK_W[lIndex*6+2]+lActivity->WORK_W[lIndex*6+1]-2*Transt)) +
                                                                                   (Sindoor * lActivity-
>WORK_W[lIndex*6+3]) +
                                                                                   (Outdoor * lActivity-
>WORK_W[lIndex*6+4]) +
                                                                                   (Transo * lActivity-
>WORK_W[lIndex*6+5])
                                                                                   )
                                                                                   / 1440;
                                                          }
                                                          else
                                                          {
                                                                  LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                                  break;
                                                          }

              float E2b = 0;
                                                          for (int j=0; j<51; j++)
                                                          {
                                                                  float Hindoor =
lWeekEndWinter[mTrack].HINDOOR[RANDOM(lWeekEndWinter[mTrack].cHINDOOR-1)];
                                                                  float Sindoor =
lWeekEndWinter[mTrack].SINDOOR[RANDOM(lWeekEndWinter[mTrack].cSINDOOR-1)];
                                                                  float Outdoor =
lWeekEndWinter[mTrack].OUTDOOR[RANDOM(lWeekEndWinter[mTrack].cOUTDOOR-1)];
                                                                  float Transo =
lWeekEndWinter[mTrack].TRANSO[RANDOM(lWeekEndWinter[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_M_W/4);

                sHINDOOR[i] = (Hindoor * lActivity->NW_M_W[lIndex*4+0])/1440;
                sSINDOOR[i] = (Sindoor * lActivity->NW_M_W[lIndex*4+1])/1440;
                sOUTDOOR[i] = (Outdoor * lActivity->NW_M_W[lIndex*4+2])/1440;
                sTRANSO[i] = (Transo * lActivity->NW_M_W[lIndex*4+3])/1440;

                                                                  E2b += (
                                                                           (Hindoor * lActivity-
>NW_M_W[lIndex*4+0]) +
                                                                           (Sindoor * lActivity-
>NW_M_W[lIndex*4+1]) +
                                                                           (Outdoor * lActivity-
>NW_M_W[lIndex*4+3]) +
                                                                           (Transo * lActivity-
>NW_M_W[lIndex*4+3])
                                                                            )
                                                                            / 1440;
                                                          }
                                                          E2b/=51;

              sHINDOOR[i] /= (2+53+51);
              sWINDOOR[i] /= (2);
              sSINDOOR[i] /= (2+53+51);
              sOUTDOOR[i] /= (2+53+51);
              sTRANSO[i] /= (2+53+51);
              sTRANSW[i] /= (2);

              sE[i] = (E1a*0.72+E1b*0.28)/2.0+(E2a*0.72+E2b*0.28)/2.0;

                                                          sprintf(lTemp, "%f\n", sE[i]);
```

```
                                                        DWORD lLenght = strlen(lTemp);
                                                        DWORD lWritten = strlen(lTemp);
                                                        WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                }
            addSummary(mSummaryWorkersM_Hindoor, sHINDOOR);
            addSummary(mSummaryWorkersM_Windoor, sWINDOOR);
            addSummary(mSummaryWorkersM_Sindoor, sSINDOOR);
            addSummary(mSummaryWorkersM_Outdoor, sOUTDOOR);
            addSummary(mSummaryWorkersM_Transw, sTRANSW);
            addSummary(mSummaryWorkersM_Transo, sTRANSO);
            addSummary(mSummaryWorkersM, sE);
                                                CloseHandle(lFile);
                                        }

                // workers female
                                        lFile = createFile("WORK_F", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
              sHINDOOR[i] = 0;
              sWINDOOR[i] = 0;
              sSINDOOR[i] = 0;
              sOUTDOOR[i] = 0;
              sTRANSO[i] = 0;
              sTRANSW[i] = 0;

              int lDestination = lWorkPair->DEST[RANDOM(lWorkPair->cDEST-1)]-1;  // JSTIER ???
                                                int lIndex = RANDOM(lActivity->cWORK_S/6);

              // Part 1 Summer
                                                        float E1a=0;
                                                        if
(lWeekDaySummer[mTrack].TRANSWt[lDestination])
                                                        {
                                                                float Hindoor =
lWeekDaySummer[mTrack].HINDOOR[RANDOM(lWeekDaySummer[mTrack].cHINDOOR-1)];
                                                                float Windoor =
lWeekDaySummer[lDestination].WINDOOR[RANDOM(lWeekDaySummer[lDestination].cWINDOOR-1)];
                                                                float Sindoor =
lWeekDaySummer[mTrack].SINDOOR[RANDOM(lWeekDaySummer[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekDaySummer[mTrack].OUTDOOR[RANDOM(lWeekDaySummer[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekDaySummer[mTrack].TRANSO[RANDOM(lWeekDaySummer[mTrack].cTRANSO-1)];
                                                          float Transt  =
lWeekDaySummer[mTrack].TRANSWt[lDestination];
                                                          float Transv  =
lWeekDaySummer[mTrack].TRANSWv[lDestination];

                sHINDOOR[i] += (Hindoor * (lActivity->WORK_S[lIndex*6+2]+lActivity->WORK_W[lIndex*6+1]-
2*Transt))/1440;
                sWINDOOR[i] += (Windoor * lActivity->WORK_S[lIndex*6+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->WORK_S[lIndex*6+3])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->WORK_S[lIndex*6+4])/1440;
                sTRANSO[i] += (Transo * lActivity->WORK_S[lIndex*6+5])/1440;
                sTRANSW[i] += (Transv * 2*Transt)/1440;

                E1a = (
                                                                                (Windoor * lActivity-
>WORK_S[lIndex*6+0]) +
                                                                                (Transv * 2*Transt)
+
                                                                                (Hindoor * (lActivity-
>WORK_S[lIndex*6+2]+lActivity->WORK_S[lIndex*6+1]-2*Transt)) +
                                                                                (Sindoor * lActivity-
>WORK_S[lIndex*6+3]) +
                                                                                (Outdoor * lActivity-
>WORK_S[lIndex*6+4]) +
```

```
                                                                                (Transo * lActivity-
>WORK_S[lIndex*6+5])
                                                                                )
                                                                                / 1440;
              }
                                                        else
                                                        {
                                                                LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                                break;
                                                        }

                                                        float E1b = 0;
                                                        for (int j=0; j<53; j++)
                                                        {
                                                                float Hindoor =
lWeekEndSummer[mTrack].HINDOOR[RANDOM(lWeekEndSummer[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lWeekEndSummer[mTrack].SINDOOR[RANDOM(lWeekEndSummer[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekEndSummer[mTrack].OUTDOOR[RANDOM(lWeekEndSummer[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekEndSummer[mTrack].TRANSO[RANDOM(lWeekEndSummer[mTrack].cTRANSO-1)];

                                                                int lIndex = RANDOM(lActivity-
>cNW_F_S/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_F_S[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*4+3])/1440;

                                                                E1b += (
                                                                          (Hindoor * lActivity-
>NW_F_S[lIndex*4+0]) +
                                                                          (Sindoor * lActivity-
>NW_F_S[lIndex*4+1]) +
                                                                          (Outdoor * lActivity-
>NW_F_S[lIndex*4+2]) +
                                                                          (Transo * lActivity-
>NW_F_S[lIndex*4+3])
                                                                           )
                                                                           / 1440;
                                                        }
                                                        E1b/=53;

              // Part 2 Winter
                                                        float E2a=0;
                                                        if
(lWeekDayWinter[mTrack].TRANSWt[lDestination])
                                                        {
                                                                float Hindoor =
lWeekDayWinter[mTrack].HINDOOR[RANDOM(lWeekDayWinter[mTrack].cHINDOOR-1)];
                                                                float Windoor =
lWeekDayWinter[lDestination].WINDOOR[RANDOM(lWeekDayWinter[lDestination].cWINDOOR-1)];
                                                                float Sindoor =
lWeekDayWinter[mTrack].SINDOOR[RANDOM(lWeekDayWinter[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekDayWinter[mTrack].OUTDOOR[RANDOM(lWeekDayWinter[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekDayWinter[mTrack].TRANSO[RANDOM(lWeekDayWinter[mTrack].cTRANSO-1)];
                                                          float Transt  =
lWeekDayWinter[mTrack].TRANSWt[lDestination];
                                                          float Transv  =
lWeekDayWinter[mTrack].TRANSWv[lDestination];

                sHINDOOR[i] += (Hindoor * (lActivity->WORK_W[lIndex*6+2]+lActivity->WORK_W[lIndex*6+1]-
2*Transt))/1440;
                sWINDOOR[i] += (Windoor * lActivity->WORK_W[lIndex*6+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->WORK_W[lIndex*6+3])/1440;
```

```
                sOUTDOOR[i] += (Outdoor * lActivity->WORK_W[lIndex*6+4])/1440;
                sTRANSO[i] += (Transo * lActivity->WORK_W[lIndex*6+5])/1440;
                sTRANSW[i] += (Transv * 2*Transt)/1440;

                E2a = (
                                                                              (Windoor * lActivity-
>WORK_W[lIndex*6+0]) +
                                                                              (Transv * 2*Transt)
+
                                                                              (Hindoor * (lActivity-
>WORK_W[lIndex*6+2]+lActivity->WORK_W[lIndex*6+1]-2*Transt)) +
                                                                              (Sindoor * lActivity-
>WORK_W[lIndex*6+3]) +
                                                                              (Outdoor * lActivity-
>WORK_W[lIndex*6+4]) +
                                                                              (Transo * lActivity-
>WORK_W[lIndex*6+5])
                                                                              )
                                                                              / 1440;
                                                          }
                                                          else
                                                          {
                                                                LOG<12> () << "Missing TRANSW for "
<< mTrack+1 << " to " << lDestination+1;
                                                                break;
                                                          }

                                                          float E2b = 0;
                                                          for (int j=0; j<51; j++)
                                                          {
                                                                float Hindoor =
lWeekEndWinter[mTrack].HINDOOR[RANDOM(lWeekEndWinter[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lWeekEndWinter[mTrack].SINDOOR[RANDOM(lWeekEndWinter[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekEndWinter[mTrack].OUTDOOR[RANDOM(lWeekEndWinter[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekEndWinter[mTrack].TRANSO[RANDOM(lWeekEndWinter[mTrack].cTRANSO-1)];

                                                                int lIndex = RANDOM(lActivity-
>cNW_F_W/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_F_W[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_F_W[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_F_W[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_F_W[lIndex*4+3])/1440;

                                                                E2b += (
                                                                       (Hindoor * lActivity-
>NW_F_W[lIndex*4+0]) +
                                                                       (Sindoor * lActivity-
>NW_F_W[lIndex*4+1]) +
                                                                       (Outdoor * lActivity-
>NW_F_W[lIndex*4+3]) +
                                                                       (Transo * lActivity-
>NW_F_W[lIndex*4+3])
                                                                        )
                                                                        / 1440;
                                                          }
                                                          E2b/=51;

              sHINDOOR[i] /= (2+53+51);
              sWINDOOR[i] /= (2);
              sSINDOOR[i] /= (2+53+51);
              sOUTDOOR[i] /= (2+53+51);
              sTRANSO[i] /= (2+53+51);
              sTRANSW[i] /= (2);

              sE[i] = (E1a*0.72+E1b*0.28)/2.0+(E2a*0.72+E2b*0.28)/2.0;
```

```
                    sprintf(lTemp, "%f\n", sE[i]);
                                                        DWORD lLenght = strlen(lTemp);
                                                        DWORD lWritten = strlen(lTemp);
                                                        WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                }
                  addSummary(mSummaryWorkersF_Hindoor, sHINDOOR);
                  addSummary(mSummaryWorkersF_Windoor, sWINDOOR);
                  addSummary(mSummaryWorkersF_Sindoor, sSINDOOR);
                  addSummary(mSummaryWorkersF_Outdoor, sOUTDOOR);
                  addSummary(mSummaryWorkersF_Transw, sTRANSW);
                  addSummary(mSummaryWorkersF_Transo, sTRANSO);
                  addSummary(mSummaryWorkersF, sE);
                                                CloseHandle(lFile);
                                        }
                                }

                                lWeekDaySummer = getDistribution(lScenario, "NONWORKERS", "WEEKDAY",
"SUMMER");
        lWeekEndSummer = getDistribution(lScenario, "NONWORKERS", "WEEKEND", "SUMMER");
                                lWeekDayWinter = getDistribution(lScenario, "NONWORKERS", "WEEKDAY",
"WINTER");
        lWeekEndWinter = getDistribution(lScenario, "NONWORKERS", "WEEKEND", "WINTER");
                                if (lWeekDaySummer[mTrack].cHINDOOR &&
                                        lWeekDaySummer[mTrack].cSINDOOR &&
                                        lWeekDaySummer[mTrack].cOUTDOOR &&
                                        lWeekDaySummer[mTrack].cTRANSO &&
                                        lWeekEndSummer[mTrack].cHINDOOR &&
                                        lWeekEndSummer[mTrack].cSINDOOR &&
                                        lWeekEndSummer[mTrack].cOUTDOOR &&
                                        lWeekEndSummer[mTrack].cTRANSO &&
                                        lWeekDayWinter[mTrack].cHINDOOR &&
                                        lWeekDayWinter[mTrack].cSINDOOR &&
                                        lWeekDayWinter[mTrack].cOUTDOOR &&
                                        lWeekDayWinter[mTrack].cTRANSO &&
                                        lWeekEndWinter[mTrack].cHINDOOR &&
                                        lWeekEndWinter[mTrack].cSINDOOR &&
                                        lWeekEndWinter[mTrack].cOUTDOOR &&
                                        lWeekEndWinter[mTrack].cTRANSO)
                                {
                    // nonworkers male
                                        lFile = createFile("NW_M", mTrack);
                                        if (lFile)
                                        {
                                                for (int i=0; i<10000; i++)
                                                {
                    sHINDOOR[i] = 0;
                    sSINDOOR[i] = 0;
                    sOUTDOOR[i] = 0;
                    sTRANSO[i] = 0;

                    float E1a = 0;
                                                for (int j=0; j<133; j++)
                                                        {
                                                                float Hindoor =
lWeekDaySummer[mTrack].HINDOOR[RANDOM(lWeekDaySummer[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lWeekDaySummer[mTrack].SINDOOR[RANDOM(lWeekDaySummer[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekDaySummer[mTrack].OUTDOOR[RANDOM(lWeekDaySummer[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekDaySummer[mTrack].TRANSO[RANDOM(lWeekDaySummer[mTrack].cTRANSO-1)];

                      int lIndex = RANDOM(lActivity->cNW_M_S/4);

                      sHINDOOR[i] += (Hindoor * lActivity->NW_M_S[lIndex*4+0])/1440;
                      sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*4+1])/1440;
                      sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*4+2])/1440;
                      sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*4+3])/1440;

                                                                E1a += (
```

```
                                                                                  (Hindoor * lActivity-
>NW_M_S[lIndex*4+0]) +
                                                                                  (Sindoor * lActivity-
>NW_M_S[lIndex*4+1]) +
                                                                                  (Outdoor * lActivity-
>NW_M_S[lIndex*4+2]) +
                                                                                  (Transo * lActivity-
>NW_M_S[lIndex*4+3])
                                                                                  )
                                                                                  / 1440;
                                                          }
                                                          E1a/=133;

              float E1b = 0;
                                                          for (int j=0; j<53; j++)
                                                          {
                                                                  float Hindoor =
lWeekEndSummer[mTrack].HINDOOR[RANDOM(lWeekEndSummer[mTrack].cHINDOOR-1)];
                                                                  float Sindoor =
lWeekEndSummer[mTrack].SINDOOR[RANDOM(lWeekEndSummer[mTrack].cSINDOOR-1)];
                                                                  float Outdoor =
lWeekEndSummer[mTrack].OUTDOOR[RANDOM(lWeekEndSummer[mTrack].cOUTDOOR-1)];
                                                                  float Transo =
lWeekEndSummer[mTrack].TRANSO[RANDOM(lWeekEndSummer[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_M_S/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_M_S[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_M_S[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_M_S[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_M_S[lIndex*4+3])/1440;

                                                                  E1b += (
                                                                           (Hindoor * lActivity-
>NW_M_S[lIndex*4+0]) +
                                                                           (Sindoor * lActivity-
>NW_M_S[lIndex*4+1]) +
                                                                           (Outdoor * lActivity-
>NW_M_S[lIndex*4+2]) +
                                                                           (Transo * lActivity-
>NW_M_S[lIndex*4+3])
                                                                            )
                                                                            / 1440;
                                                          }
                                                          E1b/=53;

                                                          float E2a = 0;
                                                          for (int j=0; j<128; j++)
                                                          {
                                                                  float Hindoor =
lWeekDayWinter[mTrack].HINDOOR[RANDOM(lWeekDayWinter[mTrack].cHINDOOR-1)];
                                                                  float Sindoor =
lWeekDayWinter[mTrack].SINDOOR[RANDOM(lWeekDayWinter[mTrack].cSINDOOR-1)];
                                                                  float Outdoor =
lWeekDayWinter[mTrack].OUTDOOR[RANDOM(lWeekDayWinter[mTrack].cOUTDOOR-1)];
                                                                  float Transo =
lWeekDayWinter[mTrack].TRANSO[RANDOM(lWeekDayWinter[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_M_S/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_M_W[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_M_W[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_M_W[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_M_W[lIndex*4+3])/1440;

                E2a += (
                                                                                  (Hindoor * lActivity-
>NW_M_W[lIndex*4+0]) +
                                                                                  (Sindoor * lActivity-
>NW_M_W[lIndex*4+1]) +
```

```
                                                                                   (Outdoor * lActivity-
>NW_M_W[lIndex*4+2]) +
                                                                                   (Transo * lActivity-
>NW_M_W[lIndex*4+3])
                                                                                   )
                                                                                   / 1440;
                                                          }
                                                          E2a/=128;

              float E2b = 0;
                                                          for (int j=0; j<51; j++)
                                                          {
                                                                  float Hindoor =
lWeekEndWinter[mTrack].HINDOOR[RANDOM(lWeekEndWinter[mTrack].cHINDOOR-1)];
                                                                  float Sindoor =
lWeekEndWinter[mTrack].SINDOOR[RANDOM(lWeekEndWinter[mTrack].cSINDOOR-1)];
                                                                  float Outdoor =
lWeekEndWinter[mTrack].OUTDOOR[RANDOM(lWeekEndWinter[mTrack].cOUTDOOR-1)];
                                                                  float Transo =
lWeekEndWinter[mTrack].TRANSO[RANDOM(lWeekEndWinter[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_M_S/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_M_W[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_M_W[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_M_W[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_M_W[lIndex*4+3])/1440;

                                                                  E2b += (
                                                                           (Hindoor * lActivity-
>NW_M_W[lIndex*4+0]) +
                                                                           (Sindoor * lActivity-
>NW_M_W[lIndex*4+1]) +
                                                                           (Outdoor * lActivity-
>NW_M_W[lIndex*4+2]) +
                                                                           (Transo * lActivity-
>NW_M_W[lIndex*4+3])
                                                                            )
                                                                            / 1440;
                                                          }
                                                          E2b/=51;

                                                          sHINDOOR[i] /= (133+53+128+51);
              sSINDOOR[i] /= (133+53+128+51);
              sOUTDOOR[i] /= (133+53+128+51);
              sTRANSO[i] /= (133+53+128+51);

              sE[i] = (E1a*0.72+E1b*0.28)/2.0+(E2a*0.72+E2b*0.28)/2.0;

                                                          sprintf(lTemp, "%f\n", sE[i]);
                                                          DWORD lLenght = strlen(lTemp);
                                                          DWORD lWritten = strlen(lTemp);
                                                          WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                  }
            addSummary(mSummaryNonWorkersM_Hindoor, sHINDOOR);
            addSummary(mSummaryNonWorkersM_Sindoor, sSINDOOR);
            addSummary(mSummaryNonWorkersM_Outdoor, sOUTDOOR);
            addSummary(mSummaryNonWorkersM_Transo, sTRANSO);
            addSummary(mSummaryNonWorkersM, sE);
                                                  CloseHandle(lFile);
                                         }

                // nonworkers female
                                         lFile = createFile("NW_F", mTrack);
                                         if (lFile)
                                         {
                                                  for (int i=0; i<10000; i++)
                                                  {
              sHINDOOR[i] = 0;
              sSINDOOR[i] = 0;
```

```
              sOUTDOOR[i] = 0;
              sTRANSO[i] = 0;

                                                        float E1a = 0;
                                                        for (int j=0; j<133; j++)
                                                        {
                                                                float Hindoor =
lWeekDaySummer[mTrack].HINDOOR[RANDOM(lWeekDaySummer[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lWeekDaySummer[mTrack].SINDOOR[RANDOM(lWeekDaySummer[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekDaySummer[mTrack].OUTDOOR[RANDOM(lWeekDaySummer[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekDaySummer[mTrack].TRANSO[RANDOM(lWeekDaySummer[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_F_S/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_F_S[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*4+3])/1440;

                                                                E1a += (
                                                                                (Hindoor * lActivity-
>NW_F_S[lIndex*4+0]) +
                                                                                (Sindoor * lActivity-
>NW_F_S[lIndex*4+1]) +
                                                                                (Outdoor * lActivity-
>NW_F_S[lIndex*4+2]) +
                                                                                (Transo * lActivity-
>NW_F_S[lIndex*4+3])
                                                                                )
                                                                                / 1440;
                                                        }
                                                        E1a/=133;


              float E1b = 0;
                                                        for (int j=0; j<53; j++)
                                                        {
                                                                float Hindoor =
lWeekEndSummer[mTrack].HINDOOR[RANDOM(lWeekEndSummer[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lWeekEndSummer[mTrack].SINDOOR[RANDOM(lWeekEndSummer[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekEndSummer[mTrack].OUTDOOR[RANDOM(lWeekEndSummer[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekEndSummer[mTrack].TRANSO[RANDOM(lWeekEndSummer[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_F_S/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_F_S[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_F_S[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_F_S[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_F_S[lIndex*4+3])/1440;

                                                                E1b += (
                                                                         (Hindoor * lActivity-
>NW_F_S[lIndex*4+0]) +
                                                                         (Sindoor * lActivity-
>NW_F_S[lIndex*4+1]) +
                                                                         (Outdoor * lActivity-
>NW_F_S[lIndex*4+2]) +
                                                                         (Transo * lActivity-
>NW_F_S[lIndex*4+3])
                                                                          )
                                                                          / 1440;
                                                        }
                                                        E1b/=53;
```

```
                                                        float E2a = 0;
                                                        for (int j=0; j<128; j++)
                                                        {
                                                                float Hindoor =
lWeekDayWinter[mTrack].HINDOOR[RANDOM(lWeekDayWinter[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lWeekDayWinter[mTrack].SINDOOR[RANDOM(lWeekDayWinter[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekDayWinter[mTrack].OUTDOOR[RANDOM(lWeekDayWinter[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekDayWinter[mTrack].TRANSO[RANDOM(lWeekDayWinter[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_F_S/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_F_W[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_F_W[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_F_W[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_F_W[lIndex*4+3])/1440;

                                                                E2a += (
                                                                                (Hindoor * lActivity-
>NW_F_W[lIndex*4+0]) +
                                                                                (Sindoor * lActivity-
>NW_F_W[lIndex*4+1]) +
                                                                                (Outdoor * lActivity-
>NW_F_W[lIndex*4+2]) +
                                                                                (Transo * lActivity-
>NW_F_W[lIndex*4+3])
                                                                                )
                                                                                / 1440;
                                                        }
                                                        E2a/=128;


                                                        float E2b = 0;
                                                        for (int j=0; j<51; j++)
                                                        {
                                                                float Hindoor =
lWeekEndWinter[mTrack].HINDOOR[RANDOM(lWeekEndWinter[mTrack].cHINDOOR-1)];
                                                                float Sindoor =
lWeekEndWinter[mTrack].SINDOOR[RANDOM(lWeekEndWinter[mTrack].cSINDOOR-1)];
                                                                float Outdoor =
lWeekEndWinter[mTrack].OUTDOOR[RANDOM(lWeekEndWinter[mTrack].cOUTDOOR-1)];
                                                                float Transo =
lWeekEndWinter[mTrack].TRANSO[RANDOM(lWeekEndWinter[mTrack].cTRANSO-1)];

                int lIndex = RANDOM(lActivity->cNW_F_S/4);

                sHINDOOR[i] += (Hindoor * lActivity->NW_F_W[lIndex*4+0])/1440;
                sSINDOOR[i] += (Sindoor * lActivity->NW_F_W[lIndex*4+1])/1440;
                sOUTDOOR[i] += (Outdoor * lActivity->NW_F_W[lIndex*4+2])/1440;
                sTRANSO[i] += (Transo * lActivity->NW_F_W[lIndex*4+3])/1440;

                                                                E2b += (
                                                                         (Hindoor * lActivity-
>NW_F_W[lIndex*4+0]) +
                                                                         (Sindoor * lActivity-
>NW_F_W[lIndex*4+1]) +
                                                                         (Outdoor * lActivity-
>NW_F_W[lIndex*4+2]) +
                                                                         (Transo * lActivity-
>NW_F_W[lIndex*4+3])
                                                                          )
                                                                          / 1440;
                                                        }
                                                        E2b/=51;

                                                        sHINDOOR[i] /= (133+53+128+51);
              sSINDOOR[i] /= (133+53+128+51);
              sOUTDOOR[i] /= (133+53+128+51);
```

```
              sTRANSO[i] /= (133+53+128+51);

              sE[i] = (E1a*0.72+E1b*0.28)/2.0+(E2a*0.72+E2b*0.28)/2.0;

                                                          sprintf(lTemp, "%f\n", sE[i]);
                                                          DWORD lLenght = strlen(lTemp);
                                                          DWORD lWritten = strlen(lTemp);
                                                          WriteFile(lFile, lTemp, lLenght, &lWritten, 0);
                                                  }

            addSummary(mSummaryNonWorkersF_Hindoor, sHINDOOR);
            addSummary(mSummaryNonWorkersF_Sindoor, sSINDOOR);
            addSummary(mSummaryNonWorkersF_Outdoor, sOUTDOOR);
            addSummary(mSummaryNonWorkersF_Transo, sTRANSO);
            addSummary(mSummaryNonWorkersF, sE);
                                                  CloseHandle(lFile);
                                         }
                                 }
                                 else
                                 {
                                         LOG<12> () << "Missing distribution for WORKERS of census track "
<< mTrack+1;
                                 }
      }
      break;
  }

  mTrack++;

  if (mTrack == CENSUSTRACKS)
  {
                stopScenario();
  }
  return 1;
}

void FrmMain::output(char* iBuffer)
{
  mContent.mOutput.InsertString(0, iBuffer);
}

HANDLE FrmMain::createFile(char* iBuffer, int iID)
{
        char lBuffer[400];
  if (iID != -1)
  {
          sprintf(lBuffer, "%s%d.csv", iBuffer, iID+1);
  }
  else
  {
          sprintf(lBuffer, "%s.csv", iBuffer);
  }
        HANDLE hFile = CreateFile(lBuffer,
                                                           GENERIC_WRITE,
                                                           FILE_SHARE_READ,
                                                           NULL,
                                                           OPEN_ALWAYS,
                                                           FILE_ATTRIBUTE_NORMAL,
                                                           NULL);

        if (hFile == INVALID_HANDLE_VALUE)
        {
                LPVOID lpMsgBuf;
                FormatMessage(FORMAT_MESSAGE_ALLOCATE_BUFFER |
                                        FORMAT_MESSAGE_FROM_SYSTEM,
                                        NULL,
                                        GetLastError(),
                                        MAKELANGID(LANG_NEUTRAL, SUBLANG_DEFAULT),
                                        (LPTSTR) &lpMsgBuf,
                                        0, NULL );
```

```
                LOG<12> () << (char*)lpMsgBuf;
        }

        return hFile;
};

void FrmMain::loadActivity(HTREEITEM iItem)
{
  HANDLE lHandle;
  WIN32_FIND_DATA lData;

  lHandle = FindFirstFile("*.*",&lData);
  do
  {
    if (lHandle != INVALID_HANDLE_VALUE)
    {
      if (lData.dwFileAttributes & FILE_ATTRIBUTE_DIRECTORY)
      {
        if (lData.cFileName[0] != '.')
        {
          void* lUser = 0;

          if (lData.cFileName[0] == 'S')
          {
            lUser = new Activity();
          }

          HTREEITEM lItem = addItem(iItem, lData.cFileName, 1, lUser);
          PUSHDIR(lData.cFileName)
          loadActivity(lItem);
          POPDIR;
        }
      }
      else
      {
        Activity* lWork = (Activity*)mTree.GetItemData(iItem);

        HANDLE hFile = CreateFile(lData.cFileName,
                                  GENERIC_READ,
                                  FILE_SHARE_READ,
                                  NULL,
                                  OPEN_EXISTING,
                                  FILE_ATTRIBUTE_NORMAL,
                                  NULL);

        if (!strncmp(lData.cFileName, "NW_F_S", strlen("NW_F_S")))
        {
          loadCSV(hFile, lWork->NW_F_S, lWork->cNW_F_S);
        }
        else if (!strncmp(lData.cFileName, "NW_M_S", strlen("NW_M_S")))
        {
          loadCSV(hFile, lWork->NW_M_S, lWork->cNW_M_S);
        }
        else if (!strncmp(lData.cFileName, "WORK_S", strlen("WORK_S")))
        {
          loadCSV(hFile, lWork->WORK_S, lWork->cWORK_S);
        }
        else if (!strncmp(lData.cFileName, "NW_F_W", strlen("NW_F_W")))
        {
          loadCSV(hFile, lWork->NW_F_W, lWork->cNW_F_W);
        }
        else if (!strncmp(lData.cFileName, "NW_M_W", strlen("NW_M_W")))
        {
          loadCSV(hFile, lWork->NW_M_W, lWork->cNW_M_W);
        }
        else if (!strncmp(lData.cFileName, "WORK_W", strlen("WORK_W")))
        {
          loadCSV(hFile, lWork->WORK_W, lWork->cWORK_W);
        }
```

```
            HTREEITEM lItem = addItem(iItem, lData.cFileName, 0, 0);
            DWORD lSize= GetFileSize(hFile,0);
            CloseHandle(hFile);
         }
      }
   }
   while (FindNextFile(lHandle,&lData));
   FindClose(lHandle);
}

void FrmMain::loadWorkPairs(HTREEITEM iItem)
{
   HANDLE lHandle;
   WIN32_FIND_DATA lData;

   lHandle = FindFirstFile("*.*",&lData);
   do
   {
      if (lHandle != INVALID_HANDLE_VALUE)
      {
         if (! (lData.dwFileAttributes & FILE_ATTRIBUTE_DIRECTORY))
         {
            HANDLE hFile = CreateFile(lData.cFileName,
                                      GENERIC_READ,
                                      FILE_SHARE_READ,
                                      NULL,
                                      OPEN_EXISTING,
                                      FILE_ATTRIBUTE_NORMAL,
                                      NULL);

            WorkPair* lPair = new WorkPair();
            loadCSV(hFile, lPair->DEST, lPair->cDEST);

            int lIndex;
            sscanf(lData.cFileName, "CT%d", &lIndex);
            sWorkPairs[lIndex] = lPair;

            HTREEITEM lItem = addItem(iItem, lData.cFileName, 0, lPair);
            DWORD lSize= GetFileSize(hFile,0);
            CloseHandle(hFile);
         }
      }
   }
   while (FindNextFile(lHandle,&lData));
   FindClose(lHandle);
}

int compare(const void *long1, const void *long2)
{
   //return ( *(int*)a - *(int*)b );
   float* lV1 = (float*) long1;
   float* lV2 = (float*) long2;

   if (*lV1 > *lV2)
   {
      return 1;
   }
   else if (*lV1 < *lV2)
   {
      return -1;
   }

   return 0;
}

void FrmMain::addSummary(HANDLE iSummary, float iE[])
{
            qsort(iE, 10000, sizeof(float), compare);

   float lMean = 0;
```

```
for (int i=0; i<10000; i++)
{
   lMean+= iE[i];
}
lMean/= 10000;

float lDeviation = 0;
for (int i=0; i<10000; i++)
{
   lDeviation += (iE[i]-lMean)*(iE[i]-lMean);
}
lDeviation /= 9999;

float lPercent;
float lTemp = iE[4999];
//
int lU1 = 0;
int lL1 = 0;
lPercent = sPercent1;
for (lU1=4999; lU1<10000; lU1++)
{
   if (iE[lU1] > lTemp*(1.0+lPercent))
   {
      break;
   }
}
for (lL1=4999; lL1>=0; lL1--)
{
   if (iE[lL1] < lTemp*(1.0-lPercent))
   {
      break;
   }
}

int lU2 = 0;
int lL2 = 0;
lPercent = sPercent2;
for (lU2=4999; lU2<10000; lU2++)
{
   if (iE[lU2] > lTemp*(1.0+lPercent))
   {
      break;
   }
}
for (lL2=4999; lL2>=0; lL2--)
{
   if (iE[lL2] < lTemp*(1.0-lPercent))
   {
      break;
   }
}

int lU3 = 0;
int lL3 = 0;
lPercent = sPercent3;
for (lU3=4999; lU3<10000; lU3++)
{
   if (iE[lU3] > lTemp*(1.0+lPercent))
   {
      break;
   }
}
for (lL3=4999; lL3>=0; lL3--)
{
   if (iE[lL3] < lTemp*(1.0-lPercent))
   {
      break;
   }
}
```

```
   char lBuffer[400];
   sprintf(lBuffer, "%d %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %d %d %d %d %d %d\n",
               mTrack+1,
               lMean,
               sqrt(lDeviation),
               iE[0], iE[9999],
               iE[100], iE[500],
               iE[1000], iE[2000], iE[3000], iE[4000], iE[5000], iE[6000], iE[7000], iE[8000], iE[9000],
               iE[9500], iE[9900],
               lL1+1, lU1+1, lL2+1, lU2+1, lL3+1, lU3+1);
            DWORD lLenght = strlen(lBuffer);
            DWORD lWritten = strlen(lBuffer);
            WriteFile(iSummary, lBuffer, lLenght, &lWritten, 0);
}

void FrmMain::loadDist(HTREEITEM iItem)
{
   HANDLE lHandle;
   WIN32_FIND_DATA lData;

   lHandle = FindFirstFile("*.*",&lData);
   do
   {
      if (lHandle != INVALID_HANDLE_VALUE)
      {
         if (lData.dwFileAttributes & FILE_ATTRIBUTE_DIRECTORY)
         {
            if (lData.cFileName[0] != '.')
            {
               void* lUser = 0;

               lUser = new Distribution[CENSUSTRACKS];
               HTREEITEM lItem = addItem(iItem, lData.cFileName, 1, lUser);
               PUSHDIR(lData.cFileName)
               loadDist(lItem);
               POPDIR;
            }
         }
         else
         {
            Distribution* lTrack = (Distribution*)mTree.GetItemData(iItem);

            HANDLE hFile = CreateFile(lData.cFileName,
                                 GENERIC_READ,
                                 FILE_SHARE_READ,
                                 NULL,
                                 OPEN_EXISTING,
                                 FILE_ATTRIBUTE_NORMAL,
                                 NULL);

            if (!strncmp(lData.cFileName, "HindoorCT", strlen("HindoorCT")))
            {
               int lIndex;
               sscanf(lData.cFileName, "HindoorCT%d", &lIndex);
               loadXYZ(hFile, lTrack[lIndex-1].HINDOOR, lTrack[lIndex-1].cHINDOOR);
            }
            else if (!strncmp(lData.cFileName, "DhindoorCT", strlen("DhindoorCT")))
            {
               int lIndex;
               sscanf(lData.cFileName, "DhindoorCT%d", &lIndex);
               loadXYZ(hFile, lTrack[lIndex-1].DHINDOOR, lTrack[lIndex-1].cDHINDOOR);
            }
            else if (!strncmp(lData.cFileName, "NhindoorCT", strlen("NhindoorCT")))
            {
               int lIndex;
               sscanf(lData.cFileName, "NhindoorCT%d", &lIndex);
               loadXYZ(hFile, lTrack[lIndex-1].NHINDOOR, lTrack[lIndex-1].cNHINDOOR);
            }
            else if (!strncmp(lData.cFileName, "OutsideCT", strlen("OutsideCT")))
            {
```

```
                    int lIndex;
                    sscanf(lData.cFileName, "OutsideCT%d", &lIndex);
                    loadXYZ(hFile, lTrack[lIndex-1].OUTDOOR, lTrack[lIndex-1].cOUTDOOR);
                }
                else if (!strncmp(lData.cFileName, "SindoorCT", strlen("SindoorCT")))
                {
                    int lIndex;
                    sscanf(lData.cFileName, "SindoorCT%d", &lIndex);
                    loadXYZ(hFile, lTrack[lIndex-1].SINDOOR, lTrack[lIndex-1].cSINDOOR);
                }
                else if (!strncmp(lData.cFileName, "WindoorCT", strlen("WindoorCT")))
                {
                    int lIndex;
                    sscanf(lData.cFileName, "WindoorCT%d", &lIndex);
                    loadXYZ(hFile, lTrack[lIndex-1].WINDOOR, lTrack[lIndex-1].cWINDOOR);
                }
                else if (!strncmp(lData.cFileName, "TransoCT", strlen("TransoCT")))
                {
                    int lIndex;
                    sscanf(lData.cFileName, "TransoCT%d", &lIndex);
                    loadTrans(hFile, lTrack[lIndex-1].TRANSO, lTrack[lIndex-1].cTRANSO);
                }
                else if (!strncmp(lData.cFileName, "Transw", strlen("Transw")))
                {
                    loadTransW(hFile, lTrack);
                }

                DWORD lSize= GetFileSize(hFile,0);
                CloseHandle(hFile);

                HTREEITEM lItem = addItem(iItem, lData.cFileName, 0, 0);
            }
        }
    }
    while (FindNextFile(lHandle,&lData));
    FindClose(lHandle);
}

void FrmMain::clearDist(HTREEITEM iItem)
{
    HTREEITEM lChild = mTree.GetChildItem(iItem);
    while (lChild)
    {
        clearDist(lChild);
        HTREEITEM lTemp = mTree.GetNextSiblingItem(lChild);
        if (mTree.GetItemData(lChild))
        {
            Distribution* lTracks = (Distribution*) mTree.GetItemData(lChild);
            delete [] lTracks;
        }
        mTree.DeleteItem(lChild);
        lChild = lTemp;
    }
}

void FrmMain::startScenario()
{
                char lPath[400];
                strcpy(lPath, mRoot);
                strcat(lPath, "\\OUTPUT\\");

    char lBuffer[400];
    lBuffer[0] = 400;
                sprintf(lBuffer, "CT mean std min max 1%% 5%% 10%% 20%% 30%% 40%% 50%% 60%% 70%% 80%%
90%% 95%% 99%% L1 U1 L2 U2 L3 U3\n");
                DWORD lLenght = strlen(lBuffer);
                DWORD lWritten = strlen(lBuffer);

    int lIndex = mContent.mScenario.GetCurSel();
    switch (lIndex)
```

```
{
  case 0:
    {
                              strcat(lPath, "SCEN1");
            _chdir(lPath);

            mSummaryWorkers = createFile("SUMMARY_WORK", -1);
      mSummaryWorkers_Nhindoor = createFile("SUMMARY_WORK_NHINDOOR", -1);
      mSummaryWorkers_Windoor = createFile("SUMMARY_WORK_WINDOOR", -1);
      mSummaryWorkers_Dhindoor = createFile("SUMMARY_WORK_DHINDOOR", -1);
      mSummaryWorkers_Sindoor = createFile("SUMMARY_WORK_SINDOOR", -1);
      mSummaryWorkers_Outdoor = createFile("SUMMARY_WORK_OUTDOOR", -1);
      mSummaryWorkers_Transo = createFile("SUMMARY_WORK_TRANSO", -1);
      mSummaryWorkers_Transw = createFile("SUMMARY_WORK_TRANSW", -1);
      WriteFile(mSummaryWorkers, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Nhindoor, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Windoor, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Dhindoor, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Sindoor, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Outdoor, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Transo, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Transw, lBuffer, lLenght, &lWritten, 0);

            mSummaryNonWorkersF = createFile("SUMMARY_NW_F", -1);
      mSummaryNonWorkersF_Nhindoor = createFile("SUMMARY_NW_F_NHINDOOR", -1);
      mSummaryNonWorkersF_Dhindoor = createFile("SUMMARY_NW_F_DHINDOOR", -1);
      mSummaryNonWorkersF_Sindoor = createFile("SUMMARY_NW_F_SINDOOR", -1);
      mSummaryNonWorkersF_Outdoor = createFile("SUMMARY_NW_F_OUTDOOR", -1);
      mSummaryNonWorkersF_Transo = createFile("SUMMARY_NW_F_TRANSO", -1);
            WriteFile(mSummaryNonWorkersF, lBuffer, lLenght, &lWritten, 0);
            WriteFile(mSummaryNonWorkersF_Nhindoor, lBuffer, lLenght, &lWritten, 0);
            WriteFile(mSummaryNonWorkersF_Dhindoor, lBuffer, lLenght, &lWritten, 0);
            WriteFile(mSummaryNonWorkersF_Sindoor, lBuffer, lLenght, &lWritten, 0);
            WriteFile(mSummaryNonWorkersF_Outdoor, lBuffer, lLenght, &lWritten, 0);
            WriteFile(mSummaryNonWorkersF_Transo, lBuffer, lLenght, &lWritten, 0);

      mSummaryNonWorkersM = createFile("SUMMARY_NW_M", -1);
      mSummaryNonWorkersM_Nhindoor = createFile("SUMMARY_NW_M_NHINDOOR", -1);
      mSummaryNonWorkersM_Dhindoor = createFile("SUMMARY_NW_M_DHINDOOR", -1);
      mSummaryNonWorkersM_Sindoor = createFile("SUMMARY_NW_M_SINDOOR", -1);
      mSummaryNonWorkersM_Outdoor = createFile("SUMMARY_NW_M_OUTDOOR", -1);
      mSummaryNonWorkersM_Transo = createFile("SUMMARY_NW_M_TRANSO", -1);
            WriteFile(mSummaryNonWorkersM, lBuffer, lLenght, &lWritten, 0);
            WriteFile(mSummaryNonWorkersM_Nhindoor, lBuffer, lLenght, &lWritten, 0);
            WriteFile(mSummaryNonWorkersM_Dhindoor, lBuffer, lLenght, &lWritten, 0);
            WriteFile(mSummaryNonWorkersM_Sindoor, lBuffer, lLenght, &lWritten, 0);
            WriteFile(mSummaryNonWorkersM_Outdoor, lBuffer, lLenght, &lWritten, 0);
            WriteFile(mSummaryNonWorkersM_Transo, lBuffer, lLenght, &lWritten, 0);

      LOG<12> () << "running scenario 1";
    }
    break;
  case 1:
    {
                              strcat(lPath, "SCEN2");
            _chdir(lPath);

            mSummaryWorkers = createFile("SUMMARY_WORK", -1);
      mSummaryWorkers_Hindoor = createFile("SUMMARY_WORK_HINDOOR", -1);
      mSummaryWorkers_Windoor = createFile("SUMMARY_WORK_WINDOOR", -1);
      mSummaryWorkers_Sindoor = createFile("SUMMARY_WORK_SINDOOR", -1);
      mSummaryWorkers_Outdoor = createFile("SUMMARY_WORK_OUTDOOR", -1);
      mSummaryWorkers_Transo = createFile("SUMMARY_WORK_TRANSO", -1);
      mSummaryWorkers_Transw = createFile("SUMMARY_WORK_TRANSW", -1);
      WriteFile(mSummaryWorkers, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Hindoor, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Windoor, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Sindoor, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Outdoor, lBuffer, lLenght, &lWritten, 0);
      WriteFile(mSummaryWorkers_Transo, lBuffer, lLenght, &lWritten, 0);
```

```
        WriteFile(mSummaryWorkers_Transw, lBuffer, lLenght, &lWritten, 0);

                mSummaryNonWorkersF = createFile("SUMMARY_NW_F", -1);
        mSummaryNonWorkersF_Hindoor = createFile("SUMMARY_NW_F_HINDOOR", -1);
        mSummaryNonWorkersF_Sindoor = createFile("SUMMARY_NW_F_SINDOOR", -1);
        mSummaryNonWorkersF_Outdoor = createFile("SUMMARY_NW_F_OUTDOOR", -1);
        mSummaryNonWorkersF_Transo = createFile("SUMMARY_NW_F_TRANSO", -1);
                WriteFile(mSummaryNonWorkersF, lBuffer, lLenght, &lWritten, 0);
                WriteFile(mSummaryNonWorkersF_Hindoor, lBuffer, lLenght, &lWritten, 0);
                WriteFile(mSummaryNonWorkersF_Sindoor, lBuffer, lLenght, &lWritten, 0);
                WriteFile(mSummaryNonWorkersF_Outdoor, lBuffer, lLenght, &lWritten, 0);
                WriteFile(mSummaryNonWorkersF_Transo, lBuffer, lLenght, &lWritten, 0);

        mSummaryNonWorkersM = createFile("SUMMARY_NW_M", -1);
        mSummaryNonWorkersM_Hindoor = createFile("SUMMARY_NW_M_HINDOOR", -1);
        mSummaryNonWorkersM_Sindoor = createFile("SUMMARY_NW_M_SINDOOR", -1);
        mSummaryNonWorkersM_Outdoor = createFile("SUMMARY_NW_M_OUTDOOR", -1);
        mSummaryNonWorkersM_Transo = createFile("SUMMARY_NW_M_TRANSO", -1);
                WriteFile(mSummaryNonWorkersM, lBuffer, lLenght, &lWritten, 0);
                WriteFile(mSummaryNonWorkersM_Hindoor, lBuffer, lLenght, &lWritten, 0);
                WriteFile(mSummaryNonWorkersM_Sindoor, lBuffer, lLenght, &lWritten, 0);
                WriteFile(mSummaryNonWorkersM_Outdoor, lBuffer, lLenght, &lWritten, 0);
                WriteFile(mSummaryNonWorkersM_Transo, lBuffer, lLenght, &lWritten, 0);

        LOG<12> () << "running scenario 2";
      }
      break;
    case 2:
      {
                                        strcat(lPath, "SCEN3");
                _chdir(lPath);

        mSummaryWorkersF = createFile("SUMMARY_WORK_F", -1);
        mSummaryWorkersF_Nhindoor = createFile("SUMMARY_WORK_F_NHINDOOR", -1);
        mSummaryWorkersF_Windoor = createFile("SUMMARY_WORK_F_WINDOOR", -1);
        mSummaryWorkersF_Dhindoor = createFile("SUMMARY_WORK_F_DHINDOOR", -1);
        mSummaryWorkersF_Sindoor = createFile("SUMMARY_WORK_F_SINDOOR", -1);
        mSummaryWorkersF_Outdoor = createFile("SUMMARY_WORK_F_OUTDOOR", -1);
        mSummaryWorkersF_Transo = createFile("SUMMARY_WORK_F_TRANSO", -1);
        mSummaryWorkersF_Transw = createFile("SUMMARY_WORK_F_TRANSW", -1);
        WriteFile(mSummaryWorkersF, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Nhindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Windoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Dhindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Sindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Outdoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Transo, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Transw, lBuffer, lLenght, &lWritten, 0);

        mSummaryWorkersM = createFile("SUMMARY_WORK_M", -1);
        mSummaryWorkersM_Nhindoor = createFile("SUMMARY_WORK_M_NHINDOOR", -1);
        mSummaryWorkersM_Windoor = createFile("SUMMARY_WORK_M_WINDOOR", -1);
        mSummaryWorkersM_Dhindoor = createFile("SUMMARY_WORK_M_DHINDOOR", -1);
        mSummaryWorkersM_Sindoor = createFile("SUMMARY_WORK_M_SINDOOR", -1);
        mSummaryWorkersM_Outdoor = createFile("SUMMARY_WORK_M_OUTDOOR", -1);
        mSummaryWorkersM_Transo = createFile("SUMMARY_WORK_M_TRANSO", -1);
        mSummaryWorkersM_Transw = createFile("SUMMARY_WORK_M_TRANSW", -1);
        WriteFile(mSummaryWorkersM, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Nhindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Windoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Dhindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Sindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Outdoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Transo, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Transw, lBuffer, lLenght, &lWritten, 0);

        mSummaryNonWorkersF = createFile("SUMMARY_NW_F", -1);
        mSummaryNonWorkersF_Nhindoor = createFile("SUMMARY_NW_F_NHINDOOR", -1);
        mSummaryNonWorkersF_Dhindoor = createFile("SUMMARY_NW_F_DHINDOOR", -1);
        mSummaryNonWorkersF_Sindoor = createFile("SUMMARY_NW_F_SINDOOR", -1);
```

```
    mSummaryNonWorkersF_Outdoor = createFile("SUMMARY_NW_F_OUTDOOR", -1);
    mSummaryNonWorkersF_Transo = createFile("SUMMARY_NW_F_TRANSO", -1);
          WriteFile(mSummaryNonWorkersF, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Nhindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Dhindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Sindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Outdoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Transo, lBuffer, lLenght, &lWritten, 0);

    mSummaryNonWorkersM = createFile("SUMMARY_NW_M", -1);
    mSummaryNonWorkersM_Nhindoor = createFile("SUMMARY_NW_M_NHINDOOR", -1);
    mSummaryNonWorkersM_Dhindoor = createFile("SUMMARY_NW_M_DHINDOOR", -1);
    mSummaryNonWorkersM_Sindoor = createFile("SUMMARY_NW_M_SINDOOR", -1);
    mSummaryNonWorkersM_Outdoor = createFile("SUMMARY_NW_M_OUTDOOR", -1);
    mSummaryNonWorkersM_Transo = createFile("SUMMARY_NW_M_TRANSO", -1);
          WriteFile(mSummaryNonWorkersM, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Nhindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Dhindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Sindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Outdoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Transo, lBuffer, lLenght, &lWritten, 0);

    LOG<12> () << "running scenario 3";
  }
  break;
case 3:
  {
                            strcat(lPath, "SCEN4");
          _chdir(lPath);

          mSummaryWorkersM = createFile("SUMMARY_WORK_M", -1);
    mSummaryWorkersM_Hindoor = createFile("SUMMARY_WORK_M_HINDOOR", -1);
    mSummaryWorkersM_Windoor = createFile("SUMMARY_WORK_M_WINDOOR", -1);
    mSummaryWorkersM_Sindoor = createFile("SUMMARY_WORK_M_SINDOOR", -1);
    mSummaryWorkersM_Outdoor = createFile("SUMMARY_WORK_M_OUTDOOR", -1);
    mSummaryWorkersM_Transo = createFile("SUMMARY_WORK_M_TRANSO", -1);
    mSummaryWorkersM_Transw = createFile("SUMMARY_WORK_M_TRANSW", -1);
          WriteFile(mSummaryWorkersM, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Hindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Windoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Sindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Outdoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Transo, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Transw, lBuffer, lLenght, &lWritten, 0);

          mSummaryWorkersF = createFile("SUMMARY_WORK_F", -1);
    mSummaryWorkersF_Hindoor = createFile("SUMMARY_WORK_F_HINDOOR", -1);
    mSummaryWorkersF_Windoor = createFile("SUMMARY_WORK_F_WINDOOR", -1);
    mSummaryWorkersF_Sindoor = createFile("SUMMARY_WORK_F_SINDOOR", -1);
    mSummaryWorkersF_Outdoor = createFile("SUMMARY_WORK_F_OUTDOOR", -1);
    mSummaryWorkersF_Transo = createFile("SUMMARY_WORK_F_TRANSO", -1);
    mSummaryWorkersF_Transw = createFile("SUMMARY_WORK_F_TRANSW", -1);
          WriteFile(mSummaryWorkersF, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Hindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Windoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Sindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Outdoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Transo, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Transw, lBuffer, lLenght, &lWritten, 0);

          mSummaryNonWorkersF = createFile("SUMMARY_NW_F", -1);
    mSummaryNonWorkersF_Hindoor = createFile("SUMMARY_NW_F_HINDOOR", -1);
    mSummaryNonWorkersF_Sindoor = createFile("SUMMARY_NW_F_SINDOOR", -1);
    mSummaryNonWorkersF_Outdoor = createFile("SUMMARY_NW_F_OUTDOOR", -1);
    mSummaryNonWorkersF_Transo = createFile("SUMMARY_NW_F_TRANSO", -1);
          WriteFile(mSummaryNonWorkersF, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Hindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Sindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Outdoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Transo, lBuffer, lLenght, &lWritten, 0);
```

```
              mSummaryNonWorkersM = createFile("SUMMARY_NW_M", -1);
        mSummaryNonWorkersM_Hindoor = createFile("SUMMARY_NW_M_HINDOOR", -1);
        mSummaryNonWorkersM_Sindoor = createFile("SUMMARY_NW_M_SINDOOR", -1);
        mSummaryNonWorkersM_Outdoor = createFile("SUMMARY_NW_M_OUTDOOR", -1);
        mSummaryNonWorkersM_Transo = createFile("SUMMARY_NW_M_TRANSO", -1);
              WriteFile(mSummaryNonWorkersM, lBuffer, lLenght, &lWritten, 0);
              WriteFile(mSummaryNonWorkersM_Hindoor, lBuffer, lLenght, &lWritten, 0);
              WriteFile(mSummaryNonWorkersM_Sindoor, lBuffer, lLenght, &lWritten, 0);
              WriteFile(mSummaryNonWorkersM_Outdoor, lBuffer, lLenght, &lWritten, 0);
              WriteFile(mSummaryNonWorkersM_Transo, lBuffer, lLenght, &lWritten, 0);

        LOG<12> () << "running scenario 4";
      }
      break;
    case 4:
      {
                                  strcat(lPath, "SCEN5");
              _chdir(lPath);

        mSummaryWorkersF = createFile("SUMMARY_WORK_F", -1);
        mSummaryWorkersF_Nhindoor = createFile("SUMMARY_WORK_F_NHINDOOR", -1);
        mSummaryWorkersF_Windoor = createFile("SUMMARY_WORK_F_WINDOOR", -1);
        mSummaryWorkersF_Dhindoor = createFile("SUMMARY_WORK_F_DHINDOOR", -1);
        mSummaryWorkersF_Sindoor = createFile("SUMMARY_WORK_F_SINDOOR", -1);
        mSummaryWorkersF_Outdoor = createFile("SUMMARY_WORK_F_OUTDOOR", -1);
        mSummaryWorkersF_Transo = createFile("SUMMARY_WORK_F_TRANSO", -1);
        mSummaryWorkersF_Transw = createFile("SUMMARY_WORK_F_TRANSW", -1);
        WriteFile(mSummaryWorkersF, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Nhindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Windoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Dhindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Sindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Outdoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Transo, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersF_Transw, lBuffer, lLenght, &lWritten, 0);

        mSummaryWorkersM = createFile("SUMMARY_WORK_M", -1);
        mSummaryWorkersM_Nhindoor = createFile("SUMMARY_WORK_M_NHINDOOR", -1);
        mSummaryWorkersM_Windoor = createFile("SUMMARY_WORK_M_WINDOOR", -1);
        mSummaryWorkersM_Dhindoor = createFile("SUMMARY_WORK_M_DHINDOOR", -1);
        mSummaryWorkersM_Sindoor = createFile("SUMMARY_WORK_M_SINDOOR", -1);
        mSummaryWorkersM_Outdoor = createFile("SUMMARY_WORK_M_OUTDOOR", -1);
        mSummaryWorkersM_Transo = createFile("SUMMARY_WORK_M_TRANSO", -1);
        mSummaryWorkersM_Transw = createFile("SUMMARY_WORK_M_TRANSW", -1);
        WriteFile(mSummaryWorkersM, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Nhindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Windoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Dhindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Sindoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Outdoor, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Transo, lBuffer, lLenght, &lWritten, 0);
        WriteFile(mSummaryWorkersM_Transw, lBuffer, lLenght, &lWritten, 0);

        mSummaryNonWorkersF = createFile("SUMMARY_NW_F", -1);
        mSummaryNonWorkersF_Nhindoor = createFile("SUMMARY_NW_F_NHINDOOR", -1);
        mSummaryNonWorkersF_Dhindoor = createFile("SUMMARY_NW_F_DHINDOOR", -1);
        mSummaryNonWorkersF_Sindoor = createFile("SUMMARY_NW_F_SINDOOR", -1);
        mSummaryNonWorkersF_Outdoor = createFile("SUMMARY_NW_F_OUTDOOR", -1);
        mSummaryNonWorkersF_Transo = createFile("SUMMARY_NW_F_TRANSO", -1);
              WriteFile(mSummaryNonWorkersF, lBuffer, lLenght, &lWritten, 0);
              WriteFile(mSummaryNonWorkersF_Nhindoor, lBuffer, lLenght, &lWritten, 0);
              WriteFile(mSummaryNonWorkersF_Dhindoor, lBuffer, lLenght, &lWritten, 0);
              WriteFile(mSummaryNonWorkersF_Sindoor, lBuffer, lLenght, &lWritten, 0);
              WriteFile(mSummaryNonWorkersF_Outdoor, lBuffer, lLenght, &lWritten, 0);
              WriteFile(mSummaryNonWorkersF_Transo, lBuffer, lLenght, &lWritten, 0);

        mSummaryNonWorkersM = createFile("SUMMARY_NW_M", -1);
        mSummaryNonWorkersM_Nhindoor = createFile("SUMMARY_NW_M_NHINDOOR", -1);
        mSummaryNonWorkersM_Dhindoor = createFile("SUMMARY_NW_M_DHINDOOR", -1);
```

```
    mSummaryNonWorkersM_Sindoor = createFile("SUMMARY_NW_M_SINDOOR", -1);
    mSummaryNonWorkersM_Outdoor = createFile("SUMMARY_NW_M_OUTDOOR", -1);
    mSummaryNonWorkersM_Transo = createFile("SUMMARY_NW_M_TRANSO", -1);
          WriteFile(mSummaryNonWorkersM, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Nhindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Dhindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Sindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Outdoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Transo, lBuffer, lLenght, &lWritten, 0);

    LOG<12> () << "running scenario 5";
  }
  break;
case 5:
  {
                             strcat(lPath, "SCEN6");
          _chdir(lPath);

          mSummaryWorkersM = createFile("SUMMARY_WORK_M", -1);
    mSummaryWorkersM_Hindoor = createFile("SUMMARY_WORK_M_HINDOOR", -1);
    mSummaryWorkersM_Windoor = createFile("SUMMARY_WORK_M_WINDOOR", -1);
    mSummaryWorkersM_Sindoor = createFile("SUMMARY_WORK_M_SINDOOR", -1);
    mSummaryWorkersM_Outdoor = createFile("SUMMARY_WORK_M_OUTDOOR", -1);
    mSummaryWorkersM_Transo = createFile("SUMMARY_WORK_M_TRANSO", -1);
    mSummaryWorkersM_Transw = createFile("SUMMARY_WORK_M_TRANSW", -1);
          WriteFile(mSummaryWorkersM, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Hindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Windoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Sindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Outdoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Transo, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersM_Transw, lBuffer, lLenght, &lWritten, 0);

          mSummaryWorkersF = createFile("SUMMARY_WORK_F", -1);
    mSummaryWorkersF_Hindoor = createFile("SUMMARY_WORK_F_HINDOOR", -1);
    mSummaryWorkersF_Windoor = createFile("SUMMARY_WORK_F_WINDOOR", -1);
    mSummaryWorkersF_Sindoor = createFile("SUMMARY_WORK_F_SINDOOR", -1);
    mSummaryWorkersF_Outdoor = createFile("SUMMARY_WORK_F_OUTDOOR", -1);
    mSummaryWorkersF_Transo = createFile("SUMMARY_WORK_F_TRANSO", -1);
    mSummaryWorkersF_Transw = createFile("SUMMARY_WORK_F_TRANSW", -1);
          WriteFile(mSummaryWorkersF, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Hindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Windoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Sindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Outdoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Transo, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryWorkersF_Transw, lBuffer, lLenght, &lWritten, 0);

    mSummaryNonWorkersF = createFile("SUMMARY_NW_F", -1);
    mSummaryNonWorkersF_Hindoor = createFile("SUMMARY_NW_F_HINDOOR", -1);
    mSummaryNonWorkersF_Sindoor = createFile("SUMMARY_NW_F_SINDOOR", -1);
    mSummaryNonWorkersF_Outdoor = createFile("SUMMARY_NW_F_OUTDOOR", -1);
    mSummaryNonWorkersF_Transo = createFile("SUMMARY_NW_F_TRANSO", -1);
          WriteFile(mSummaryNonWorkersF, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Hindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Sindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Outdoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersF_Transo, lBuffer, lLenght, &lWritten, 0);

          mSummaryNonWorkersM = createFile("SUMMARY_NW_M", -1);
    mSummaryNonWorkersM_Hindoor = createFile("SUMMARY_NW_M_HINDOOR", -1);
    mSummaryNonWorkersM_Sindoor = createFile("SUMMARY_NW_M_SINDOOR", -1);
    mSummaryNonWorkersM_Outdoor = createFile("SUMMARY_NW_M_OUTDOOR", -1);
    mSummaryNonWorkersM_Transo = createFile("SUMMARY_NW_M_TRANSO", -1);
          WriteFile(mSummaryNonWorkersM, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Hindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Sindoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Outdoor, lBuffer, lLenght, &lWritten, 0);
          WriteFile(mSummaryNonWorkersM_Transo, lBuffer, lLenght, &lWritten, 0);
```

```
            LOG<12> () << "running scenario 6";
         }
         break;
   }


   mContent.mPercent1.GetLine(0, lBuffer);
   mContent.mPercent1.EnableWindow(FALSE);
   sPercent1 = atof(lBuffer);

   mContent.mPercent2.GetLine(0, lBuffer);
   mContent.mPercent2.EnableWindow(FALSE);
   sPercent2 = atof(lBuffer);

   mContent.mPercent3.GetLine(0, lBuffer);
   mContent.mPercent3.EnableWindow(FALSE);
   sPercent3 = atof(lBuffer);

   mTrack = 0;
   SetTimer(1, 10);
}

void FrmMain::stopScenario()
{
   int lIndex = mContent.mScenario.GetCurSel();

   switch (lIndex)
   {
      case 0:
         {
            CloseHandle(mSummaryWorkers);
            CloseHandle(mSummaryWorkers_Nhindoor);
            CloseHandle(mSummaryWorkers_Windoor);
            CloseHandle(mSummaryWorkers_Dhindoor);
            CloseHandle(mSummaryWorkers_Sindoor);
            CloseHandle(mSummaryWorkers_Outdoor);
            CloseHandle(mSummaryWorkers_Transo);
            CloseHandle(mSummaryWorkers_Transw);

            CloseHandle(mSummaryNonWorkersF);
            CloseHandle(mSummaryNonWorkersF_Nhindoor);
            CloseHandle(mSummaryNonWorkersF_Dhindoor);
            CloseHandle(mSummaryNonWorkersF_Sindoor);
            CloseHandle(mSummaryNonWorkersF_Outdoor);
            CloseHandle(mSummaryNonWorkersF_Transo);

            CloseHandle(mSummaryNonWorkersM);
            CloseHandle(mSummaryNonWorkersM_Nhindoor);
            CloseHandle(mSummaryNonWorkersM_Dhindoor);
            CloseHandle(mSummaryNonWorkersM_Sindoor);
            CloseHandle(mSummaryNonWorkersM_Outdoor);
            CloseHandle(mSummaryNonWorkersM_Transo);
         }
         break;
      case 1:
         {
            CloseHandle(mSummaryWorkers);
            CloseHandle(mSummaryWorkers_Hindoor);
            CloseHandle(mSummaryWorkers_Windoor);
            CloseHandle(mSummaryWorkers_Sindoor);
            CloseHandle(mSummaryWorkers_Outdoor);
            CloseHandle(mSummaryWorkers_Transo);
            CloseHandle(mSummaryWorkers_Transw);

            CloseHandle(mSummaryNonWorkersF);
            CloseHandle(mSummaryNonWorkersF_Hindoor);
            CloseHandle(mSummaryNonWorkersF_Sindoor);
            CloseHandle(mSummaryNonWorkersF_Outdoor);
            CloseHandle(mSummaryNonWorkersF_Transo);
```

```
    CloseHandle(mSummaryNonWorkersM);
    CloseHandle(mSummaryNonWorkersM_Hindoor);
    CloseHandle(mSummaryNonWorkersM_Sindoor);
    CloseHandle(mSummaryNonWorkersM_Outdoor);
    CloseHandle(mSummaryNonWorkersM_Transo);
  }
  break;
case 2:
  {
    CloseHandle(mSummaryWorkersF);
    CloseHandle(mSummaryWorkersF_Nhindoor);
    CloseHandle(mSummaryWorkersF_Windoor);
    CloseHandle(mSummaryWorkersF_Dhindoor);
    CloseHandle(mSummaryWorkersF_Sindoor);
    CloseHandle(mSummaryWorkersF_Outdoor);
    CloseHandle(mSummaryWorkersF_Transo);
    CloseHandle(mSummaryWorkersF_Transw);

    CloseHandle(mSummaryWorkersM);
    CloseHandle(mSummaryWorkersM_Nhindoor);
    CloseHandle(mSummaryWorkersM_Windoor);
    CloseHandle(mSummaryWorkersM_Dhindoor);
    CloseHandle(mSummaryWorkersM_Sindoor);
    CloseHandle(mSummaryWorkersM_Outdoor);
    CloseHandle(mSummaryWorkersM_Transo);
    CloseHandle(mSummaryWorkersM_Transw);

          CloseHandle(mSummaryNonWorkersF);
          CloseHandle(mSummaryNonWorkersF_Nhindoor);
          CloseHandle(mSummaryNonWorkersF_Dhindoor);
          CloseHandle(mSummaryNonWorkersF_Sindoor);
          CloseHandle(mSummaryNonWorkersF_Outdoor);
          CloseHandle(mSummaryNonWorkersF_Transo);

          CloseHandle(mSummaryNonWorkersM);
          CloseHandle(mSummaryNonWorkersM_Nhindoor);
          CloseHandle(mSummaryNonWorkersM_Dhindoor);
          CloseHandle(mSummaryNonWorkersM_Sindoor);
          CloseHandle(mSummaryNonWorkersM_Outdoor);
          CloseHandle(mSummaryNonWorkersM_Transo);
  }
  break;
case 3:
  {
    CloseHandle(mSummaryWorkersM);
    CloseHandle(mSummaryWorkersM_Hindoor);
    CloseHandle(mSummaryWorkersM_Windoor);
    CloseHandle(mSummaryWorkersM_Sindoor);
    CloseHandle(mSummaryWorkersM_Outdoor);
    CloseHandle(mSummaryWorkersM_Transo);
    CloseHandle(mSummaryWorkersM_Transw);

    CloseHandle(mSummaryWorkersF);
    CloseHandle(mSummaryWorkersF_Hindoor);
    CloseHandle(mSummaryWorkersF_Windoor);
    CloseHandle(mSummaryWorkersF_Sindoor);
    CloseHandle(mSummaryWorkersF_Outdoor);
    CloseHandle(mSummaryWorkersF_Transo);
    CloseHandle(mSummaryWorkersF_Transw);

    CloseHandle(mSummaryNonWorkersF);
    CloseHandle(mSummaryNonWorkersF_Hindoor);
    CloseHandle(mSummaryNonWorkersF_Sindoor);
    CloseHandle(mSummaryNonWorkersF_Outdoor);
    CloseHandle(mSummaryNonWorkersF_Transo);

    CloseHandle(mSummaryNonWorkersM);
    CloseHandle(mSummaryNonWorkersM_Hindoor);
    CloseHandle(mSummaryNonWorkersM_Sindoor);
    CloseHandle(mSummaryNonWorkersM_Outdoor);
```

```
            CloseHandle(mSummaryNonWorkersM_Transo);
        }
        break;
    case 4:
        {
            CloseHandle(mSummaryWorkersF);
            CloseHandle(mSummaryWorkersF_Nhindoor);
            CloseHandle(mSummaryWorkersF_Windoor);
            CloseHandle(mSummaryWorkersF_Dhindoor);
            CloseHandle(mSummaryWorkersF_Sindoor);
            CloseHandle(mSummaryWorkersF_Outdoor);
            CloseHandle(mSummaryWorkersF_Transo);
            CloseHandle(mSummaryWorkersF_Transw);

            CloseHandle(mSummaryWorkersM);
            CloseHandle(mSummaryWorkersM_Nhindoor);
            CloseHandle(mSummaryWorkersM_Windoor);
            CloseHandle(mSummaryWorkersM_Dhindoor);
            CloseHandle(mSummaryWorkersM_Sindoor);
            CloseHandle(mSummaryWorkersM_Outdoor);
            CloseHandle(mSummaryWorkersM_Transo);
            CloseHandle(mSummaryWorkersM_Transw);

                        CloseHandle(mSummaryNonWorkersF);
                        CloseHandle(mSummaryNonWorkersF_Nhindoor);
                        CloseHandle(mSummaryNonWorkersF_Dhindoor);
                        CloseHandle(mSummaryNonWorkersF_Sindoor);
                        CloseHandle(mSummaryNonWorkersF_Outdoor);
                        CloseHandle(mSummaryNonWorkersF_Transo);

                        CloseHandle(mSummaryNonWorkersM);
                        CloseHandle(mSummaryNonWorkersM_Nhindoor);
                        CloseHandle(mSummaryNonWorkersM_Dhindoor);
                        CloseHandle(mSummaryNonWorkersM_Sindoor);
                        CloseHandle(mSummaryNonWorkersM_Outdoor);
                        CloseHandle(mSummaryNonWorkersM_Transo);
        }
        break;
    case 5:
        {
            CloseHandle(mSummaryWorkersM);
            CloseHandle(mSummaryWorkersM_Hindoor);
            CloseHandle(mSummaryWorkersM_Windoor);
            CloseHandle(mSummaryWorkersM_Sindoor);
            CloseHandle(mSummaryWorkersM_Outdoor);
            CloseHandle(mSummaryWorkersM_Transo);
            CloseHandle(mSummaryWorkersM_Transw);

            CloseHandle(mSummaryWorkersF);
            CloseHandle(mSummaryWorkersF_Hindoor);
            CloseHandle(mSummaryWorkersF_Windoor);
            CloseHandle(mSummaryWorkersF_Sindoor);
            CloseHandle(mSummaryWorkersF_Outdoor);
            CloseHandle(mSummaryWorkersF_Transo);
            CloseHandle(mSummaryWorkersF_Transw);

            CloseHandle(mSummaryNonWorkersF);
            CloseHandle(mSummaryNonWorkersF_Hindoor);
            CloseHandle(mSummaryNonWorkersF_Sindoor);
            CloseHandle(mSummaryNonWorkersF_Outdoor);
            CloseHandle(mSummaryNonWorkersF_Transo);

            CloseHandle(mSummaryNonWorkersM);
            CloseHandle(mSummaryNonWorkersM_Hindoor);
            CloseHandle(mSummaryNonWorkersM_Sindoor);
            CloseHandle(mSummaryNonWorkersM_Outdoor);
            CloseHandle(mSummaryNonWorkersM_Transo);
        }
        break;
}
```

```
    mContent.mPercent1.EnableWindow(TRUE);
    mContent.mPercent2.EnableWindow(TRUE);
    mContent.mPercent3.EnableWindow(TRUE);

                _chdir(mRoot);
    KillTimer(1);
}

void FrmMain::loadXYZ(HANDLE iFile, float*& iBuffer, int& iSize)
{
    DWORD lSize= GetFileSize(iFile,0);
    char* lBuffer = new char[lSize];
    DWORD lRead;
    SetFilePointer(iFile, 0, 0, FILE_BEGIN);
    ReadFile(iFile, lBuffer, lSize, &lRead, NULL);

    iBuffer = new float[lSize/35];
    iSize = 0;

    char* lPtr = lBuffer;
    while (lPtr - lBuffer < lSize)
    {
        char* i=0;

        float lZh=0;
        lPtr=lPtr+31;
        while (*lPtr != '.')
        {
            lZh*=10;
            lZh+=*(lPtr++)-'0';
        }
        lPtr++;

        float lZl=0;
        float div = 10.0;
        while (*lPtr != ' ')
        {
            lZl += (*(lPtr++)-'0')/div;
            div *= 10;
        }
        lPtr++;
        lPtr++;
        lPtr++;
        iBuffer[iSize++] = lZh+lZl;   // JSTIER maybe doubles
    }

    delete [] lBuffer;
};

void FrmMain::loadCSV(HANDLE iFile, float*& iBuffer, int& iSize)
{
    DWORD lSize= GetFileSize(iFile,0);
    char* lBuffer = new char[lSize];
    DWORD lRead;
    SetFilePointer(iFile, 0, 0, FILE_BEGIN);
    ReadFile(iFile, lBuffer, lSize, &lRead, NULL);

    iBuffer = new float[lSize];
    iSize = 0;

    char* lPtr = strchr(lBuffer,'\n');
    while (lPtr - lBuffer < lSize - 2)
    {
        float lValue = 0;

        lPtr++;
        if (*lPtr == 0x0a)
        {
            lPtr++;
```

```
        }

        do
        {
            lValue*=10;
            lValue+=*(lPtr++)-'0';

            char c=*lPtr;
        }
        while (*lPtr != ',' && *lPtr != 0x0d && *lPtr != 0x0a);

        iBuffer[iSize++] = lValue;
    }

    delete [] lBuffer;
};

void FrmMain::loadOutside(HANDLE iFile, float*& iBuffer, int& iSize)
{
    DWORD lSize= GetFileSize(iFile,0);
    char* lBuffer = new char[lSize];
    DWORD lRead;
    SetFilePointer(iFile, 0, 0, FILE_BEGIN);
    ReadFile(iFile, lBuffer, lSize, &lRead, NULL);

    iBuffer = new float[lSize/68];
    iSize = 0;

    char* lPtr = lBuffer + 143;
    while (lPtr - lBuffer < lSize - 68)
    {
        float lValue = 0;

        lPtr += 68;
        sscanf(lPtr, "%f", &lValue);
        iBuffer[iSize++] = lValue;
    }

    if (lSize/68 <= iSize)
    {
        LOG<12> () << "This is a problem!";
    }

    delete [] lBuffer;
};


void FrmMain::loadTrans(HANDLE iFile, float*& iBuffer, int& iSize)
{
    DWORD lSize= GetFileSize(iFile,0);
    char* lBuffer = new char[lSize];
    DWORD lRead;
    SetFilePointer(iFile, 0, 0, FILE_BEGIN);
    ReadFile(iFile, lBuffer, lSize, &lRead, NULL);

    iBuffer = new float[lSize];

    int lIndex = 0;
    char* lPtr = lBuffer + 108;

    iSize = 0;
    while (lPtr - lBuffer < lSize - 18)
    {
        float lValue = 0;

                                lPtr[18] = '\0';
        sscanf(lPtr, "%f", &lValue);
        lPtr += 28;
        iBuffer[lIndex++] = lValue;
        iSize++;
```

```
   }

   if (lSize <= iSize)
   {
      LOG<12> () << "This is a problem!";
   }
   delete [] lBuffer;
}

void FrmMain::loadTransW(HANDLE iFile, Distribution* iTrack)
{
   DWORD lSize= GetFileSize(iFile,0);
   char* lBuffer = new char[lSize];
   DWORD lRead;
   SetFilePointer(iFile, 0, 0, FILE_BEGIN);
   ReadFile(iFile, lBuffer, lSize, &lRead, NULL);

   char* lTemp = lBuffer;
   while (lTemp - lBuffer < lSize)
   {
      int lOrg;
      int lDes;
      float lV1;
      float lV2;
      float lV3;
      float lV4;
      sscanf(lTemp, "\"ORG%dDES%d\",%f,%f,%f,%f", &lOrg, &lDes, &lV1, &lV2, &lV3, &lV4);

      iTrack[lOrg-1].TRANSWt[lDes-1] = lV4;
      iTrack[lOrg-1].TRANSWv[lDes-1] = lV3;

      lTemp = strchr(lTemp, '\n')+1;
   }

   delete [] lBuffer;
}



HTREEITEM FrmMain::addItem(HTREEITEM iParent, char* iName, int iImage, void* iParam)
{
   HTREEITEM lItem = 0;

   lItem = mTree.InsertItem(TVIF_TEXT  |
                         TVIF_PARAM |
                         TVIF_IMAGE |
                         TVIF_SELECTEDIMAGE,
                         iName,
                         iImage,
                         iImage,
                         0,
                         0,
                         (LPARAM)iParam,
                         iParent,
                         TVI_LAST);

   return lItem;
}



LRESULT FrmMain::OnViewToolBar(WORD, WORD, HWND, BOOL&)
{
            static BOOL bVisible = TRUE;
            bVisible = !bVisible;
            CReBarCtrl rebar = m_hWndToolBar;
            int nBandIndex = rebar.IdToIndex(ATL_IDW_BAND_FIRST + 1);
            rebar.ShowBand(nBandIndex, bVisible);
            UISetCheck(ID_VIEW_TOOLBAR, bVisible);
            UpdateLayout();
```

```
	return 1;
}

LRESULT FrmMain::OnViewStatusBar(WORD, WORD, HWND, BOOL&)
{
	BOOL bVisible = !::IsWindowVisible(m_hWndStatusBar);
	::ShowWindow(m_hWndStatusBar, bVisible ? SW_SHOWNOACTIVATE : SW_HIDE);
	UISetCheck(ID_VIEW_STATUS_BAR, bVisible);
	UpdateLayout();
	return 1;
}
```

Appendix B. CHAPS codes and associated SESM microenvironments

Work Indoor

ACT1	TIME SPENT AT MAIN JOB
ACT5	TIME SPENT AT SECOND JOB

Transit to Work

ACT9	TIME SPENT AT TRAVEL TO/FROM WORK

Home Indoor

WHERE100	TIME SPENT IN HOME-OTHER
WHERE101	TIME SPENT IN KITCHEN
WHERE102	TIME SPENT IN LIVING ROOM/FAMILY ROOM/DEN
WHERE103	TIME SPENT IN DINING ROOM
WHERE104	TIME SPENT IN BATHROOM
WHERE105	TIME SPENT IN BEDROOM
WHERE106	TIME SPENT IN STUDY/OFFICE
WHERE107	TIME SPENT IN GARAGE
WHERE108	TIME SPENT IN BASEMENT
WHERE110	TIME SPENT IN UTILITY ROOM, LAUNDRY ROOM
WHERE113	TIME SPENT MOVING FROM ROOM TO ROOM
WHERE120	TIME SPENT IN OTHER VERIFIED LOCATION
WHERE199	TIME SPENT IN HOME REFUSAL
WHERE200	TIME SPENT IN FRIENDS HOME-OTHER
WHERE201	TIME SPENT IN FRIENDS KITCHEN
WHERE202	TIME SPENT IN FRIENDS LIVING/FAMILY/DEN
WHERE203	TIME SPENT IN FRIENDS DINING ROOM
WHERE204	TIME SPENT IN FRIENDS BATHROOM
WHERE205	TIME SPENT IN FRIENDS BEDROOM
WHERE206	TIME SPENT IN FRIENDS STUDY/OFFICE
WHERE207	TIME SPENT IN FRIENDS GARAGE
WHERE208	TIME SPENT IN FRIENDS BASEMENT
WHERE210	TIME SPENT IN FRIENDS UTILITY/LAUNDRY ROOM
WHERE213	TIME SPENT MOVING FROM FRIENDS ROOM TO ROOM
WHERE220	TIME SPENT IN FRIENDS OTHER, VERIFIED
WHERE299	TIME SPENT IN FRIENDS HOUSE REFUSAL

Transit Other

NOTE: Includes work related transit therefore adjusted by subtracting time in ACT9

WHERE300	TIME SPENT IN OTHER TRAVEL LOCATION-SPECIFIC
WHERE301	TIME SPENT IN CAR
WHERE302	TIME SPENT IN TRUCK (PICK UP OR VAN)
WHERE303	TIME SPENT IN TRUCK (NOT PICK UP OR VAN)
WHERE304	TIME SPENT IN MOTORCYCLE/MOPED/SCOOTER
WHERE305	TIME SPENT IN BUS
WHERE310	TIME SPENT IN TRAIN/SUBWAY/RAPID TRANSIT

Other Indoor

Note: Includes time spent at work, therefore adjusted by subtracting time in ACT1 and ACT5

WHERE314	TIME SPENT WAITING FOR TRAVEL, INDOORS
WHERE400	TIME SPENT IN OTHER INDOOR – SPECIFY
WHERE401	TIME SPENT IN OFFICE BLDG/BANK/POST OFFICE
WHERE402	TIME SPENT IN INDUSTRIAL PLANT/FACTORY
WHERE403	TIME SPENT IN GROCERY/CONVENIENCE STORE
WHERE404	TIME SPENT IN MALL/NON-GROCERY STORE
WHERE405	TIME SPENT IN BAR/NIGHT CLUB/BOWLING ALLEY
WHERE406	TIME SPENT IN AUTO REPAIR SHOP/GAS STATION
WHERE407	TIME SPENT IN INDOOR GYM/SPORTS,HEALTH CLUB
WHERE408	TIME IN PUBLIC BLDG/LIBRARY/MUSEUM/THEATRE
WHERE409	TIME SPENT IN LAUNDROMAT
WHERE410	TIME IN HOSPITAL/HEALTH LOCATION/DOCTORS OFFICE
WHERE411	TIME IN BEAUTY PARLOR/BARBAR SHOP/HAIR DRESSER
WHERE412	TIME AT WORK: NO SPECIFIC LOCATION, MOVING
WHERE413	TIME SPENT IN SCHOOL
WHERE414	TIME SPENT IN RESTAURANT
WHERE415	TIME SPENT IN CHURCH
WHERE416	TIME SPENT IN HOTEL/MOTEL
WHERE417	TIME SPENT IN DRY CLEANERS
WHERE418	TIME SPENT IN OTHER REPAIR SHOP
WHERE419	TIME SPENT IN INDOOR PARKING GARAGE
WHERE420	TIME SPENT IN OTHER INDOOR – VERIFIED
WHERE499	TIME SPENT IN OTHER INDOOR REFUSAL

Outdoor

WHERE111	TIME SPENT IN POOL, SPA (OUTDOORS)
WHERE112	TIME SPENT IN YARD,PATIO, OTHER OUTDOOR
WHERE114	TIME SPENT MOVING IN AND OUT OF HOUSE
WHERE211	TIME SPENT IN FRIENDS POOL, SPA (OUTDOOR)
WHERE212	TIME SPENT IN FRIENDS YARD, PATIO, OTHER
WHERE214	TIME SPENT MOVING IN AND OUT FRIENDS HOUSE
WHERE306	TIME SPENT WALKING
WHERE307	TIME SPENT IN BIKE/SKATEBOARD/ROLLERSKATING
WHERE313	TIME SPENT WAITING AT BUS,TRAIN, RIDE STOPS
WHERE500	TIME SPENT IN OTHER OUTDOOR – SPECIFY
WHERE501	TIME SPENT IN NEIGHBORHOOD SIDEWALD/STREET
WHERE502	TIME SPENT IN PARKING LOT
WHERE503	TIME SPENT IN SERVICE/GAS STATION
WHERE504	TIME SPENT IN CONSTRUCTION SITE
WHERE505	TIME SPENT IN SCHOOL GROUNDS/PLAYGROUND
WHERE506	TIME SPENT IN SPORTS STADIUM
WHERE507	TIME SPENT IN PARK/GOLF COURSE
WHERE508	TIME SPENT IN POOL, RIVER, LAKE
WHERE510	TIME SPENT IN RESTAURANT/PICNIC
WHERE511	TIME SPENT IN FARM
WHERE520	TIME SPENT IN OTHER OUTDOOR – VERIFIED
WHERE599	TIME SPENT IN OUTDOOR REFUSAL

Appendix C. Actual use codes for residential and commercial properties and assigned indoor/outdoor ratios

Moderate I/O	Worst Case I/O	Actual Use Code	Description
-- indicates either properties with code were not present in the study area or were not assigned an I/O			
0.70	0.75	000	SINGLE FAMILY DWELLING
--	--	001	VACANT RESIDENTIAL LESS THAN 2 ACRES
--	--	002	PROPERTY SUBJECT TO SEC 19(8)
--	--	020	RESIDENTIAL OUTBUILDING ONLY
--	--	029	STRATA LOT - PARKING RESIDENTIAL
0.70	0.75	030	STRATA-LOT RESIDENCE (CONDOMINIUM)
--	--	031	STRATA-LOT SELF STORAGE-RES USE
0.70	0.75	032	SINGLE FAMILY DWELLING WITH BASEMENT SUITE
0.70	0.75	033	DUPLEX (/SUO FRONT)
0.70	0.75	034	DUPLEX - UP & DOWN (/SUO BOTTOM)
0.70	0.75	035	DUPLEX - SINGLE UNIT OWNERSHIP (SIDE)
0.70	0.75	036	DUPLEX - SINGLE UNIT OWNERSHIP, BACK
0.70	0.75	037	MANUFACTURED HOME - (WITHIN MANUFACTURED HOME PARK)
0.70	0.75	038	MANUFACTURED HOME - (NOT IN MANUFACTURED HOME PARK)
0.70	0.75	039	ROW HOUSING - SINGLE UNIT OWNERSHIP
--	--	040	SEASONAL DWELLING
0.70	0.75	041	DUPLEX - SINGLE UNIT OWNERSHIP, TOP
--	--	042	STRATA-LOT SEASONAL DWELLING (CONDOMINIUM)
--	--	043	PARKING - LOT ONLY, PAVED OR GRAVEL
0.70	0.75	047	TRIPLEX
0.70	0.75	049	FOURPLEX
0.70	0.75	050	MULTI-FAMILY - APARTMENT BLOCK
--	--	051	MULTI-FAMILY - VACANT
0.70	0.75	052	MULTI-FAMILY - GARDEN APARTMENT & ROW HOUSING
0.70	0.75	053	MULTI-FAMILY - CONVERSION
0.70	0.75	054	MULTI-FAMILY - HIGH-RISE
0.70	0.75	055	MULTI-FAMILY - MINIMAL COMMERCIAL
0.70	0.75	056	MULTI-FAMILY - RESIDENTIAL HOTEL
0.70	0.75	057	STRATIFIED RENTAL TOWNHOUSE
0.70	0.75	058	STRATIFIED RENTAL APARTMENT - FRAME CONSTRUCTION
0.70	0.75	059	STRATIFIED RENTAL APARTMENT - HI-RISE CONSTRUCTION
0.70	0.75	060	2 ACRES OR MORE - SINGLE FAMILY DWELLING, DUPLEX
--	--	061	2 ACRES OR MORE - VACANT
--	--	062	2 ACRES OR MORE - SEASONAL DWELLING
0.70	0.75	063	2 ACRES OR MORE - MANUFACTURED HOME
--	--	070	2 ACRES OR MORE - OUTBUILDING
--	--	110	GRAIN & FORAGE
--	--	111	GRAIN & FORAGE - VACANT
--	--	120	VEGETABLE & TRUCK

Moderate I/O	Worst Case I/O	Actual Use Code	Description
-- indicates either properties with code were not present in the study area or were not assigned an I/O			
--	--	121	VEGETABLE & TRUCK - VACANT
--	--	130	TREE FRUITS
--	--	131	TREE FRUITS - VACANT
--	--	140	SMALL FRUITS
--	--	141	SMALL FRUITS - VACANT
--	--	150	BEEF
--	--	151	BEEF - VACANT
--	--	160	DAIRY
--	--	161	DAIRY - VACANT
--	--	170	POULTRY
--	--	171	POULTRY - VACANT
--	--	180	MIXED
--	--	181	MIXED - VACANT
--	--	190	OTHER
--	--	191	OTHER - VACANT
0.70	0.35	200	STORE(S) AND SERVICE - COMMERCIAL
--	--	201	VACANT
0.70	0.75	202	STORE(S) AND LIVING QUARTERS
0.70	0.75	203	STORES AND/OR OFFICES WITH APARTMENTS
0.70	0.75	204	STORE(S) AND OFFICES
0.70	0.75	206	NEIGHBOURHOOD STORE
0.35	0.35	208	OFFICE BUILDING (PRIMARY USE)
0.70	0.35	209	SHOPPING CENTRE - NEIGHBOURHOOD
0.70	0.35	210	BANK
0.70	0.35	211	SHOPPING CENTRE - COMMUNITY
0.70	0.35	212	DEPARTMENT STORE
0.70	0.35	213	SHOPPING CENTRE - REGIONAL
0.70	0.35	214	SHOPPING CENTRE
0.70	0.35	215	FOOD MARKET
--	--	216	COMMERCIAL STRATA-LOT
--	--	217	AIR SPACE TITLE
--	--	218	STRATA-LOT SELF STORAGE-BUSINESS USE
--	--	219	STRATA LOT - PARKING COMMERCIAL
0.70	0.75	220	AUTOMOBILE DEALERSHIP
--	--	222	SERVICE STATION
--	--	224	SELF-SERVE SERVICE STATION
--	--	225	CONVENIENCE STORE/SERVICE STATION
--	--	226	CAR WASH
0.70	0.75	227	AUTOMOBILE SALES (LOT)
0.70	0.75	228	AUTOMOBILE PAINT SHOP, GARAGES, ETC.
0.35	0.35	230	HOTEL
0.70	0.75	232	MOTEL & AUTO COURT
0.70	0.75	233	INDIVIDUAL STRATA LOT - HOTEL/MOTEL
--	--	234	MANUFACTURED HOME PARK
--	--	236	CAMPGROUND (COMMERCIAL)

Moderate I/O	Worst Case I/O	Actual Use Code	Description
-- indicates either properties with code were not present in the study area or were not assigned an I/O			
0.70	0.75	237	BED & BREAKFAST OPERATION 4 OR MORE UNITS
0.70	0.75	238	SEASONAL RESORT
0.70	0.75	239	BED & BREAKFAST OPERATION LESS THAN 4 UNITS
--	--	240	GREENHOUSES AND NURSERIES (NOT FARM CLASS)
0.70	0.35	250	THEATRE BUILDINGS
--	--	252	DRIVE-IN THEATRES
0.70	0.35	254	NEIGHBOURHOOD PUB
0.70	0.35	256	RESTAURANT ONLY
0.70	0.75	257	FAST FOOD RESTAURANTS
--	--	258	DRIVE-IN RESTAURANT
--	--	260	PARKING - LOT ONLY, PAVED OR GRAVEL
--	--	262	PARKING GARAGE
0.70	0.35	266	BOWLING ALLEY
--	--	270	HALL (COMMUNITY LODGE, CLUB, ETC.)
--	--	272	STORAGE & WAREHOUSING - OPEN
--	--	273	STORAGE & WAREHOUSING - CLOSED
--	--	274	STORAGE & WAREHOUSING - COLD
--	--	276	LUMBER YARD OR BUILDING SUPPLIES
--	--	280	MARINE FACILITIES - MARINA
0.70	0.75	285	NURSING HOME
0.70	0.75	286	CONGREGATE CARE FACILITY
0.70	0.75	287	GROUP HOME
--	--	288	SIGN OR BILLBOARD ONLY
--	--	400	FRUIT & VEGETABLE
--	--	401	INDUSTRIAL - VACANT
0.50	0.35	402	MEAT & POULTRY
0.50	0.35	403	SEA FOOD
0.50	0.35	404	DAIRY PRODUCTS
0.50	0.35	405	BAKERY & BISCUIT MANUFACTURING
0.50	0.35	406	CONFECTIONERY MANUFACTURING & SUGAR PROCESSING
0.50	0.35	407	SOFT DRINK BOTTLING
0.50	0.35	408	BREWERY
0.50	0.35	409	WINERY
0.50	0.35	410	DISTILLERY
0.50	0.35	412	FEED MANUFACTURING
0.50	0.35	413	FLOUR MILLS & BREAKFAST CEREAL PRODUCTS
0.50	0.35	414	MISCELLANEOUS (FOOD PROCESSING)
--	--	415	SAWMILLS
--	--	416	PLANER MILLS (WHEN SEPARATE FROM SAWMILL)
--	--	417	PLYWOOD MILLS
--	--	418	SHINGLE MILLS
--	--	419	SASH & DOOR
--	--	420	LUMBER REMANUFACTURING (WHEN SEPARATE FROM SAWMILL)
--	--	421	VACANT
--	--	424	PULP & PAPER MILLS (INCLUDING FINE PAPER)

Moderate I/O	Worst Case I/O	Actual Use Code	Description
-- indicates either properties with code were not present in the study area or were not assigned an I/O			
0.50	0.35	425	PAPER BOX, PAPER BAG AND OTHER PAPER REMANUFACTURING.
--	--	426	LOGGING OPERATIONS, INCLUDING LOG STORAGE
--	--	427	LOGGING ROADS & BRIDGES
--	--	428	IMPROVED
--	--	429	MISCELLANEOUS (FOREST AND ALLIED INDUSTRY)
--	--	430	PETROLEUM AND GAS EXPLORATION (INCLUDING OIL AND GAS
--	--	431	PRODUCTION PIPELINES
--	--	432	OIL REFINING PLANTS
--	--	433	GAS SCRUBBING PLANTS
--	--	434	PETROLEUM BULK PLANTS
--	--	435	LIQUID GAS STORAGE PLANTS
--	--	436	OIL & GAS TRANSPORTATION PIPELINES
--	--	437	OIL & GAS PUMPING & COMPRESSOR STATIONS
--	--	438	MISCELLANEOUS (PETROLEUM INDUSTRY)
--	--	440	MINING - COAL
--	--	442	MINING & MILLING - METALLIC
--	--	443	MINING & MILLING - NON-METALLIC (INCLUDING ASBESTOS)
--	--	444	SMELTING & REFINING
--	--	445	SAND & GRAVEL (VACANT AND IMPROVED)
--	--	446	CEMENT PLANTS
--	--	447	ASPHALT PLANTS
--	--	448	CONCRETE MIXING PLANTS
--	--	449	MISCELLANEOUS (MINING AND ALLIED INDUSTRIES)
--	--	450	RUBBER & PLASTICS PRODUCTS
0.50	0.35	452	LEATHER INDUSTRY
0.50	0.35	454	TEXTILES & KNITTING MILLS
0.50	0.35	456	CLOTHING INDUSTRY
0.50	0.35	458	FURNITURE & FIXTURES INDUSTRY
0.50	0.35	460	PRINTING & PUBLISHING INDUSTRY
0.50	0.35	462	PRIMARY METAL INDUSTRIES (IRON & STEEL MILLS
0.50	0.35	464	METAL FABRICATING INDUSTRIES
0.50	0.35	466	MACHINERY MANUFACTURING (EXCLUDING ELECTRICAL)
0.50	0.35	468	TRANSPORTATION EQUIPMENT INDUSTRY (INCLUDING AIRCRAFT
0.50	0.35	470	ELECTRICAL & ELECTRONICS PRODUCTS INDUSTRY
0.50	0.35	472	CHEMICAL & CHEMICAL PRODUCTS INDUSTRIES
--	--	474	MISCELLANEOUS & (INDUSTRIAL OTHER)
--	--	476	GRAIN ELEVATORS
--	--	478	DOCKS & WHARVES
--	--	480	SHIPYARDS
--	--	488	STRATA-LOT SELF STORAGE-INDUSTRIAL USE
--	--	490	PARKING LOT ONLY (PAVED OR GRAVEL)
--	--	500	RAILWAY
--	--	505	MARINE & NAVIGATIONAL FACILITIES (INCLUDES FERRY)
0.70	0.75	510	BUS COMPANY, INCLUDING STREET RAILWAY
--	--	515	AIRPORTS, HELIPORTS, ETC.

Moderate I/O	Worst Case I/O	Actual Use Code	Description
-- indicates either properties with code were not present in the study area or were not assigned an I/O			
--	--	520	TELEPHONE
--	--	525	FIBEROPTIC CONDUIT
--	--	530	TELECOMMUNICATIONS (OTHER THAN TELEPHONE)
--	--	540	COMMUNITY ANTENNA TELEVISION (CABLEVISION)
--	--	550	GAS DISTRIBUTION SYSTEMS
--	--	560	WATER DISTRIBUTION SYSTEMS
--	--	570	IRRIGATION SYSTEMS
--	--	580	ELECTRICAL POWER SYSTEMS (INCLUDING NON-UTILITY)
--	--	590	MISCELLANEOUS (TRANSPORTATION & COMMUNICATION)
0.50	0.35	600	RECREATIONAL & CULTURAL BUILDINGS (INCLUDES CURLING)
0.50	0.35	601	CIVIC - INSTITUTIONAL & RECREATIONAL - VACANT
--	--	610	PARKS & PLAYING FIELDS
--	--	612	GOLF COURSES (INCLUDES PUBLIC & PRIVATE)
--	--	614	CAMPGROUNDS (INCLUDES GOVERNMENT CAMPGROUNDS)
--	--	615	GOVERNMENT RESERVES (INCLUDES GREENBELTS (NOT IN FARM))
0.50	0.35	620	GOVERNMENT BUILDINGS (INCLUDES COURTHOUSE, POST OFFICE)
--	--	622	ALRT
--	--	623	ALRT/MIXED USE
--	--	625	GARBAGE DUMPS, SANITARY FILLS, SEWER LAGOONS, ETC.
--	--	630	WORKS YARDS
--	--	632	RANGER STATION
0.50	0.35	634	GOVERNMENT RESEARCH CENTRES (INCLUDES NURSERIES)
0.50	0.35	640	HOSPITALS (NURSING HOMES REFER TO COMMERCIAL SECTION).
--	--	642	CEMETERIES (INCLUDES PUBLIC OR PRIVATE).
0.50	0.35	650	SCHOOLS & UNIVERSITIES, COLLEGE OR TECHNICAL SCHOOLS
--	--	652	CHURCHES & BIBLE SCHOOLS
--	--	654	RECREATIONAL CLUBS, SKI HILLS
--	--	660	LAND CLASSIFIED RECREATIONAL