Health outcomes projected from Transportation Modelling for the New Zealand Transport Outlook

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1. Introduction

Diseases caused by inactivity are very expensive, in terms both of direct costs (healthcare costs, absences and reduced productivity) and in human terms (lost years of life, disability, pain and suffering). Transportation policy could have a major impact on these rates by presenting opportunities for people to be physically active. Transport policy can encourage active transport modes—walking and bicycling—but also public transport, which is nearly always accompanied by walking access.

This document describes a model designed to estimate the health impacts of different transport scenarios for New Zealand.

2. Background

In 2008 MR Cagney were commissioned to look at the health impacts of active transport to determine how these impacts can be better accounted for in economic evaluations of transport projects and to inform a review of the Economic Evaluation Manual. They focused on the monetised benefits from increased physical activity from active transport that come from reductions in the burden of disease to New Zealand, specifically from reductions in all-cause mortality, cardiovascular disease, cancer (including all cancers, colon cancer, breast cancer and lung cancer), type 2 diabetes, and depression.

Since 2008 advances in accounting for the health impacts of transport have been made and significant pieces of work on the modelling of health impacts of transport have been published. Probably the most relevant piece of work to this project is the Integrated Transport and Health Impact Modelling Tool (ITHIM) produced by James Woodcock *et al* at the Centre for Diet and Activity Research at the University of Cambridge, UK. ITHIM models the health effects of transport scenarios by taking into account changes in physical activity, road traffic injury risk and exposure to air pollution (PM2.5), and reports results as changes in Disability Adjusted Life Years (DALYs) and deaths attributable to the transport intervention, and the associated healthcare costs. ITHIM was first published in 2009. It is based on the World Health Organisation's Comparative Risk Assessment of burden of disease and injury, and includes a physical activity exposure model, an air pollution exposure model and an injury model (Woodcock *et al* 2009a).

A detailed description of the methodology behind ITHIM can be found in Maizlish *et al* (2012) and the web-appendix of Woodcock *et al* (2009b). ITHIM has been used in a number of academic and government projects in many cities, regions and countries around the world, including the UK (for England and Wales and London specifically), California, Malaysia, Brazil, India, Canada, and Portland, Oregon. ITHIM is a spreadsheet model that is open-source and available on request from the Centre for Diet and Activity Research at the University of Cambridge, UK.

1. Measures of health outcomes for baseline year

The Ministry of Transport is using 2013 as the baseline year from which scenarios are projected. The Institute of Health Metrics and Evaluation has produced estimates for each country of the health burden

due to various diseases and types of injuries, known as the GBD study (Institute of Health Metrics and Evaluation, 2013). The GBD estimates for New Zealand have been used for the current project. Regional measures of disease and injury burden have been derived by applying per population rates nationally to the regional 2013 populations as estimated by Statistics NZ for the same age and sex categories as provided by the GBD study. Both the disease/injury burden estimates and factors multiplied by these burden estimates to derive the Regional estimates are provided in the spreadsheet GBDNZ2013withregionalfactors.csv.

2. Physical activity exposure model

The physical activity exposure model compares distributions of physical activity under different transport scenarios. Risk ratios (RR) for diseases associated with physical activity have been taken from peer-reviewed literature. Strict inclusion criteria were applied so only diseases with strong evidence based associations with physical activity and air pollution (backed up by systematic reviews) are included in ITHIM. For physical activity these diseases are cardiovascular diseases (ischaemic heart disease, hypertensive heart disease and cerebrovascular disease), type 2 diabetes, breast cancer, colon cancer, dementia and Alzheimer's, and depression, as well as all-cause mortality. The initial literature search was carried out in 2009. Subsequent research is being monitored to see whether the risk ratios need updating.

Walking and cycling duration and distance from the modelled transport scenarios are converted to a standard measure of physical activity (metabolic equivalent task (MET) hours/week) and combined with risk ratios to estimate changes in burden of disease for each scenario (compared to a baseline). The dose-response parameters (which capture the extent of disease reduction for each increment increase in physical activity) have been estimated for each disease by converting physical activity levels identified in the systematic reviews to marginal MET hours/week, and extracting the additional MET hours/week associated with the reported Relative Risk of disease.

The relationships between activity and disease reduction have been assumed to be log-linear, with transformations of exposure of 0.25 to 1 (Götschi *et al* 2015, Woodcock *et al* 2013). This indicates that while the greater the physical activity exposure the better, the greatest marginal benefits come when moving from very low levels of physical activity to some physical activity.

The non-linear dose response relationships means also that effects on disease rates of physical activity due to walking and cycling for transport vary according to individual levels of non-transport-related physical activity. Hence the ITHIM model also includes an assessment of the latter levels of physical activity. Effects of exposure to physical activity also vary by age and sex, so population distributions of exposure to non-transport and transport related physical activity are estimated for each age-sex group at baseline using national travel and physical activity surveys. Alternative population distributions are then estimated for each alternative future scenario. These distributions are based on log-normal distributions with a cut-off of ≤2.5 MET hours/week (activity of this value or less is considered to be sedentary).

Some additional analysis (as-yet unpublished) was carried out with data collected to assess the Model Communities Programme (MCP) in New Zealand, a quasi-experimental study of a funding package provided to two small cities to construct cycling and walking infrastructure and promote active travel, described in Chapman et al. (2014) and Keall et al. (2015). This new analysis looked at who most

"benefitted" most from the MCP according to their baseline levels of physical activity, and found that people who were already physically active were most likely to increase their uptake of active transport options when presented with better cycling and walking facilities. The ITHIM model can account for such effects (which yield lower levels of health benefits) by applying larger changes in active travel behaviours for quintiles within age/sex groups that are more physically active.

These distributions of physical activity (i.e. estimates of MET hours/week for each age-sex group for each transport scenario) and risk ratios are used to calculate attributable fractions, the proportion of a disease that is attributable to a shift in the distribution of physical activity from the baseline to a scenario:

$$AF = \frac{\int_{xmin}^{xmax} R(x)P(x)\,dx - \int_{xmin}^{xmax} R(x)Q(x)\,dx}{\int_{xmin}^{xmax} R(x)P(x)\,dx} \tag{1}$$

AF = attributable fraction, x = exposure (e.g. physical activity level), R(x) = disease specific risk ratio at exposure level x, P(x) = baseline population distribution of exposure x, Q(x) = alternative population distribution.

These attributable fractions are then used to calculate the alternative DALYs for each disease as follows:

$$DALY_{Alternative} = AF \times DALY_{baseline} \tag{2}$$

As mentioned in section 1, the baseline disease burden is taken from the Global Burden of Disease study and from Ministry of Health data, has been scaled to the regional level and projected forward using population age/sex/regional projections.

3. Injury risk model

ITHIM models changes in injury risk and absolute injuries using a risk, distance and speed limit-based model. The model used by the Ministry of Transport does not include a level of road type (a surrogate for speed limit), so in the New Zealand analysis changes in exposure to risk of injury are assumed to occur equally across all road types. We note that some road types (for example, motorways) can have increases in car use without accompanying increases in pedestrian injury rates, as pedestrians are rarely exposed to the risk of injury on these roads. This means that some transport patterns that have a differentially larger increase on higher speed limit roads will overestimate the effects on injuries to pedestrians and cyclists. The model also incorporates the finding from many studies that the risk of injuries increases less than linearly with increases in exposure (motor vehicle traffic).

Table 1 shows the number of deaths, Years of Life Lost (YLLs), Years Lived with Disability (YLDs) and DALYs estimated for NZ in the year 2013 by the GBD study, due to road crash injuries.

Table 1: 2013 GBD NZ estimates of road injury burden

cause	Deaths*	YLLs	YLDs	DALYs
Cyclist road injuries	12.42	595.92	275.63	871.55
Motor vehicle road injuries	316.37	14808.88	2562.03	17370.92
Motorcyclist road injuries	39.06	2179.62	635.04	2814.66
Other road injuries	1.87	77.17	28.26	105.42
Pedestrian road injuries	64.95	2414.83	633.18	3048.01
Road injuries	434.66	20076.41	4134.15	24210.56

*Note that these are expected rates rather than actual counts of events

The total number of deaths, YLLs, YLDs and DALYs for any given scenario relative to the respective values at baseline can be estimated using the following, where s1 and s2 are the exposure levels of the striking vehicle (here, a motor vehicle) at times 1 and 2; m, c and p are the exposure levels of motorcyclists, cyclists and pedestrians; baseline refers to the baseline measure of health measured, which corresponds to exposure level at time 1. The summations are over the age and sex groups used in the ITHIM model, for each of which the estimated burden is provided (and Table 1 shows the 2013 burden summed across all the age/sex groups). Note that the appropriate health burden estimates to use in the following formulae from the GBD data are specific to motorcyclist road injuries, cyclists and pedestrians (as noted in the cause name).

motorcycles =∑(0.5*baseline*(m2/m1)^0.8 + 0.5*baseline*(m2/m1)^0.525*(s2/s1)^0.525)

cyclists=∑ (baseline*(c2/c1)^0.5*(s2/s1)^0.7)

pedestrians=∑ (baseline*(p2/p1)^0.4*(s2/s1)^0.7)

cars=∑ (baseline*(s2/s1)^0.8)

The total burden associated with a scenario is:

motocycles+cyclists+pedestrians+cars (as defined above)

All the above are adaptations from formulae in Woodcock et al (2013). The formula for motorcycles gives equal weight to single motorcycle crashes and car vs. motorcycle crashes, hence the 0.5 occurring twice in the formula. This is because the injury burden is approximately equal for these two crash types, as indicated by the two-year injury figures shown in Table 2, obtained from Ministry of Transport statistics (not the GBD estimates for NZ).

Table 2: Motorcyclist injuries for 2013 and 2014 by severity level and whether single vehicle crash or impact from car

Crash type	Hospitalised	Minor	Fatal
Motorcycle single vehicle	353	551	37
Car vs. motorcycle	388	13	40

4. Inferring changes in health burden from transport exposures

Table 3 shows the formulae to calculate changes in health effects according to specified changes in exposures. The rationale for the dose-response relationships are provided in Woodcock et al (2013; 2009a; 2009b).

Table 3: Exposure, health effects and change in health effects estimated

Exposure	Health effect	Risk ratio or reduction
Air quality: x_1 is the baseline mean ambient concentration of $PM_{2.5}$ in $\mu g/m^3$ and x_2 is modelled level	Cardio-respiratory (age>30)	$RR = Exp(b(x_1 - x_2))$ where $b = 0.00893$ Reduction=1-RR
	Lung cancer	$RR = Exp(b(x_1 - x_2))$ where $b = 0.01267$

	(age>30)	Reduction=1-RR
	Acute respiratory infections (age<5)	RR=Exp(b(x_1-x_2)) where b=0.00332 Reduction=1-RR
Physical activity: metabolic equivalent (MET) hours per week	Cardiovascular disease	Reduction=1-RR$^{(a/b)}$ RR=0.84, a=(scenario MET hours)$^{0.5}$, b=(baseline MET hours)$^{0.5}$
	Breast cancer	Reduction=1-RR$^{(a/b)}$ RR=0.94 females, a=(scenario MET hours)$^{0.5}$, b=(baseline MET hours)$^{0.5}$
	Colon cancer	Reduction=1-RR$^{(a/b)}$ RR=0.80 males, RR=0.86 females, a=(scenario MET hours)$^{0.5}$, b=(baseline MET hours)$^{0.5}$
	Dementia	Reduction=1-RR$^{(a/b)}$ RR=0.72, a=(scenario MET hours)$^{0.5}$, b=(baseline MET hours)$^{0.5}$
	Depression	Reduction=1-RR$^{(a/b)}$ RR=0.83 age>29, RR=0.93 age>15-29, a=(scenario MET hours)$^{0.5}$, b=(baseline MET hours)$^{0.5}$
	Diabetes	Reduction=1-RR$^{(a/b)}$ RR=0.89, a=(scenario MET hours)$^{0.375}$, b=(baseline MET hours)$^{0.375}$
	All cause mortality (total activity)	Reduction=1-RR$^{(a/b)}$ RR=0.81, a=(scenario MET hours)$^{0.25}$, b=(baseline MET hours)$^{0.25}$
	All cause mortality (walking only)	Reduction=1-RR$^{(a/b)}$ RR=0.89, a=(scenario MET hours)$^{0.375}$, b=(baseline MET hours)$^{0.375}$

5. Estimation of social cost

This subsection outlines the method for deriving estimates of social cost from the output of the model specifying estimated deaths, YLLs, YLDs and DALYs associated with a transport scenario.

Suppose   D = Number of premature deaths

YLLs = Total life years lost due to D deaths

DALYs = Total disability adjusted life years lost due to premature deaths and disabilities

SCD = Total social cost of all deaths within an age-sex group.

Assume that the ratio of DALYs to YLLs remains constant within a narrow age-sex group.

The total social cost TSC of all DALYs can now be estimated as

$$TSC = \sum SCD*(DALYs/YLLs).$$

The total social cost including loss of life and permanent disability, loss of output due to temporary disability due to non-fatal injuries and cost of medical treatment is observed to be about 1.03 times the value of loss of life and permanent disability (MoT, 2016). It should be noted that the total social cost estimated from DALYs for road injury is considerably lower than that estimated by the Ministry of Transport (MOT). There could be many reasons for this. One of them is that there is lack of compatibility between loss of life quality as a percentage of VOSL as found in willingness to pay surveys in New Zealand and elsewhere. This needs further investigation. One approach to address this underestimate would be to make an adjustment using the ratio of social cost of injuries as estimated by MOT and the total social cost estimated from DALYs as defined above.

6. New Zealand adaptation of the ITHIM model: User Information

Further details of the technical aspects of the ITHIM model can be found in the web-appendix of Woodcock *et al.* (2009) and the California Department of Public Health ITHIM Technical Report (Maizlish *et al. 2011).* The ITHIM model is also described in Woodcock *et al.* (2013) and Maizlish *et al.* (2013).

Baseline data:

The ITHIM model offers two ways of running baseline data, one using travel survey data and the other using model data. The Calibration Data sheet holds all of the travel survey data as well as other baseline data required to run the model. All baseline data to be used by other sheets are found in column R, unless stated otherwise. Data to be entered on this page, and current sources are:

- Per capita mean daily travel times for each mode from the New Zealand Travel Survey
- Per capita mean daily travel distances for each mode from the New Zealand Travel Survey
- Per capita mean daily walking and cycling travel times for each age-sex group, as a ratio to that of females aged 15-29 from the New Zealand Travel Survey
- Population distribution by age and gender as a percentage of total population in the baseline year from the 2013 Census
- Per capita weekly non-travel related physical activity levels for quintiles of each age-sex group. To our knowledge, this information is not available in suitable form for the New Zealand population, so data from the Bay Area in California, USA have been used (as was done in the previous version of ITHIM).
- The standard deviation (in cell R145) and coefficient of variation (in cell T145) of mean daily active travel time. This is not available for the NZ Travel Survey so these values have been left the same as those used in the previous version of ITHIM.

- The population of the region of interest (in this case New Zealand) in the base year. The 2013 figure has been taken from the 2013 Census
- The projected population of the region of interest in the scenario year. The 2043 figure has been taken from Statistics New Zealand's medium population projection.

The baseline can also be run off modelled transport data that are entered on the Scenario Data sheet. However, all data listed above except per capita mean daily travel times and distances for each mode will still need to be entered in the Calibration Data sheet. On the Scenario Data sheet rows 2-20 contain the baseline data, with the values used in other sheets found in column U. Data to be entered on this sheet are:

- Per capita mean daily travel times for each mode
- Per capita mean daily travel distances for each mode
- Total daily km travelled for car drivers (U16) and car passengers (U17)
- Total daily hours travelled for car drivers (U18) and car passengers (U19)
- Total population. This is drawn from the Calibration Data page, so does not need to be changed here.

Scenario data:

Other than the total projected scenario population, which is entered on the Calibration Data sheet, all scenario data is entered on the Scenario Data sheet. The model is currently set up to run three complete scenarios, a baseline and a 'What If' scenario that is based on the baseline data and hypothetical changes that are entered by the user on the Visions person sheet (discussed later). Data for the three full scenarios starts from row 21 on the Scenario Data sheet. Currently, scenario 1 is set up as Business As Usual 2043, while scenarios 2 and 3 are blank. The required data to run a scenario from here are:

- Per capita mean daily travel times by mode from the transport model
- Per capita mean daily travel distances by mode from the transport model
- Total daily km travelled for car drivers and car passengers from the transport model
- Total daily hours travelled for car drivers and car passengers from the transport model
- Population forecast for the scenario year

Optional data for each scenario can also be entered on this page. This includes a projected population distribution and per capita mean daily walking and cycling travel times for each age-sex group as a ratio to that of females aged 15-29. To use this data in the model cells N39 and/or N40 on the User Page sheet should be changed to "1". If not, the baseline data will be used for each scenario.

The names of the scenarios throughout the workbook are also set on this page in column H.

The workbook reads data from the Scenario Data sheet using 'vlookup' formulae so if columns are added or removed before column U many parts of the workbook will stop working and will require manual updating of all the formulae. Column A is used as the lookup value for the vlookup formulae. This contains a formula that creates a unique value for each row based on the scenario ID, the item ID, mode, strata, age and sex columns. If values in these columns are changed for any of the existing scenarios (or Baseline 2013) the vlookup will not work. If the scenario ID is changed it will also need to be changed in User Page 2 sheet (row 5) and Visions Person sheet (row 5). Additional scenarios can be

added to the workbook by continuing the format of the existing scenarios and altering the scenario ID cells on User Page 2 and Visions Person.

Health data:

All burden of disease data is entered on the GBDNZ sheet. This data is taken from the global burden of disease and is currently set up for New Zealand. If other regions are run on the model (e.g. subnational areas) the burden of disease data needs to be adjusted accordingly.

Each disease sheet of the workbook (e.g. Breast cancer, Colon Cancer sheets etc.) reads the deaths, years of lost life (YLL), years lived with disability (YLD) and disability adjusted life years (DALY) data from the GBDNZ sheet, and adjusts the health outcomes based on levels of physical activity and air pollution from each scenario. The results from each disease sheet are summarised on the Health Summary sheet.

Air pollution data:

Baseline PM2.5 concentrations are entered on the Air Pollution sheet and levels are adjustd depending on the changes in VKT for each scenario. We do not have baseline PM2.5 levels or the adjustment factors specific to New Zealand so these are taken from the California version of ITHIM. If/when this information is available the values should be changed on this sheet. This will alter the values elsewhere in the workbook accordingly.

Operation of the model:

Operation of the model is carried out on the User Page sheet. On this sheet there are a number of options to be selected. Firstly, it is possible to change the physical activity risk function to be applied. Altering this effectively changes the modelled dose-response relationship between physical activity and disease risk. The option is selected in cell N36.

Secondly, it is possible to choose which data are used for the baseline model. This is done in N38, where "0" will use the travel survey data from the Calibration Data sheet as the baseline and "1" will use the Baseline scenario travel data from the Scenario Data sheet as the baseline.

Thirdly, the population distribution applied to the scenarios can be selected in N39. If this data has been entered into the Scenario Data sheet and option "1" is selected then the projected population distribution is used, otherwise the baseline distribution is used.

Fourthly, scenario walking and cycling time ratios can be changed in cell N40. If the data is entered into the Scenario Data sheet and option "1" is selected in cell N40, the ratios of walking and cycling times specific to the scenario are used, otherwise the baseline ratios are used.

Finally, the source of benefit/harm to be modelled can be selected in cell N41. Here you can choose whether to model PM2.5 or physical activity effects alone or together. If both physical activity and PM2.5 effects are to be modelled double-counting of effects can occur. Instructions on how to adjust for this can be found in rows 113-117 of the Health Summary sheet. Note that the effects on injury rates of scenarios need to be calculated and added separately (this is not done within the spreadsheet).

To choose which scenario to run the number of the scenario (indicated in parentheses after the name of the scenario in row 6 of the main table on the User Page sheet) needs to be entered into cell U1. Cell W1 indicates the name of the scenario currently being run by the workbook.

Once double counting adjustments have been carried out (if necessary), the basic results can be read from the User Page sheet. More detailed health results can be found on the Health Summary sheet.

Cost results can be obtained from the Costs sheet (see section on costs). Note that the effects on costs due to injury need to be calculated and added separately (this is not done within the spreadsheet).

'What if' scenario:

This scenario is less detailed than the three main scenarios and requires less data to be entered by the user. Inputs for this scenario can be found on the Visions Person sheet. Inputs can be changed in column K, rows 58-67. These then adjust the baseline travel values accordingly and come up with a hypothetical scenario based on these user inputs.

Other sheets:

The functions of the other sheets of the workbook that have not been mentioned above are briefly outlined below:

User page 2

This sheet reports the ratios of walking and cycling times to women aged 15-29, taken from 'Calibration data'.

Visions Person

As well as being the sheet where the 'What if" scenario is adjusted this tab reports the scenario information (mean speed, distance and time by mode). Walking and cycling speeds for all scenarios are set to 4.8km/h (3mph) and 19.3km/h (12mph), respectively (see below). The mean speeds for the other modes are calculated from duration and distance.

This page takes data from the Scenario Data or Calibration Data sheets depending on the option selected on the User Page. It also takes the coefficient of variation (CV) from the User Page.

Travel Summary

This page summarises the mode distances for each scenario and plots graphs of this information.

This page takes data from the User Page.

Health Summary

This page calculates the overall changes in disease and injury burden for each scenario. It takes data from the disease pages and scales these to the population of interest (with population data taken from the Calibration Data sheet). It also takes data from the GBDNZ sheet and is affected by options selected on the User page (source of benefit/harm).

Baseline

This page calculates the average METs (metabolic equivalent of task – a standardised measure of activity) for walking for each age-sex group (average cycling MET values are set to 6). This calculation is based on relative speeds and time spent walking relative to females aged 15-29. The relative walking and cycling speeds are fixed and have been taken from several studies carried out in a range of countries (see technical report for details).

This tab also calculates total active travel METs for quintiles (10%, 30%, 50%, 70% and 90%) of each age-sex group using an inverse normal distribution.

Data is taken from Calibration data, User page 2 and User page.

Scenario

This page is similar to the Baseline sheet, but the figures change with the scenario that is selected on the User page. Relative active transport time and population distribution can be changed for each scenario if the data is entered in the Scenario Data sheet and the option is selected on the User Page. Other variables that change with each scenario are population mean active transport times and CV, and the variables calculated from these.

This page calculates the average and total active transport METs for the scenario tested, for quintiles of each age-sex group.

Data is taken from Calibration data, User page 2, User page and Baseline.

Physical Activity RRs

This page contains the risk ratios (RRs) and exposure levels identified in the literature. The physical activity risk functions are applied to these RRs, as selected on User page to model the dose-response relationship, to calculate the RR of 1 MET. The choices of dose-response relationship are square-root linear (of power 0.25, 0.5 or 0.375), log, or linear functions.

Non travel METs

This page reports the non-travel physical activity (in METs) of the population. These data have been taken from The California activity survey (see technical report for further details) and have been distributed across quintiles for each age-sex group (as has been done for active travel METs). The data on this page have are copied from the Calibration Data sheet.

Total

This page is used to create the population distribution graph on User Page. It calculates a log-normal distribution of active travel for the population of interest and takes data from User page and Scenario.

Disease pages

These pages calculate the change in burden of each disease between the scenario being run and the baseline. These pages take travel exposures from 'Scenario' and 'Baseline' and combine these with Non travel METs data. The RR for 1 MET for each disease is taken from 'Physical activity RRs' and used to work out the RR compared with no exposure for each quintile, using the physical activity exposure data and the transformation selected on 'User page'. These RRs compared with no exposure are then converted into a ratio (scenario:baseline) and summed to give the new burden percentage for each age-sex group. The ratio of disease burden for each quintile to quintile 1 is also calculated.

The number of deaths, YLLs and YLDs are taken from GBDNZ, and are multiplied by the new burden percentage, and divided by the sum of the ratio of disease burdens to quintile 1, to give those deaths/YLLs/YLDs attributable to physical activity. The change in burden is then calculated by subtracting the baseline figures from the scenario figures.

The pages for diseases that are impacted by air quality have slightly different calculations that incorporate an air pollution RR instead of the physical activity RR. The air pollution RRs are calculated from the PM2.5 exposure data on the Air Pollution page.

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