# A. Research Proposal *(7 pages)*

## AIMS AND RATIONALE

### Pathways to health: advancing bicycling as an active mode of transport

Cycling as an active mode of transport has substantial health, environmental and social benefits, particularly by promoting an active lifestyle which in turn improves population health.[1] The health benefits of cycling are unparalleled; cycling is associated with a 41% lower risk of all-cause mortality compared to non-active modes of transport.[1] However, only a small fraction of trips in Australian cities (e.g. 1% of trips in Melbourne) are by bicycle[2] and injury rates are on the rise.[3, 4]

The key barrier to increased cycling participation is how safe someone feels when riding a bicycle.[5] Providing protected and connected cycling infrastructure is critical to overcoming this barrier,[6, 7] and has been demonstrated to substantially increase cycling participation.[8-10] However, the ***absence of cycling exposure data*** (defined as bicycle volume data on individual streets) ***has crippled our ability to implement infrastructure in areas of greatest need and improve safety***. In this project, we will develop a platform for city-wide modelling of cycling exposure that will be used to monitor, inform and evaluate cycling participation and infrastructure. Specifically, we will utilise this platform to identify the safest infrastructure types, identify inequities in cycling and identify areas where infrastructure is needed to increase cycling safety and participation.

This project represents a transformative leap forward in our ability to inform cycling safety and the provision of infrastructure. In partnership with leading transportation agencies, local government and bicycle advocacy organisations, we bring together an internationally eminent team of experts in public health, transport modelling, cyclist safety and ridership, and machine learning to develop the platform that is needed to progress cycling as a safe and healthy mode of transport. In establishing a platform that will be ***the benchmark and ongoing mechanism for monitoring cycling in Australia and internationally***, we will, for the first time, be able to quantify the health and safety benefits of investments now and into the future. The outcomes of this project will not only result in reduced injury for cyclists but, importantly, promote wider uptake of cycling as a mode of transport, thereby leading to substantial gains in population and environmental health.

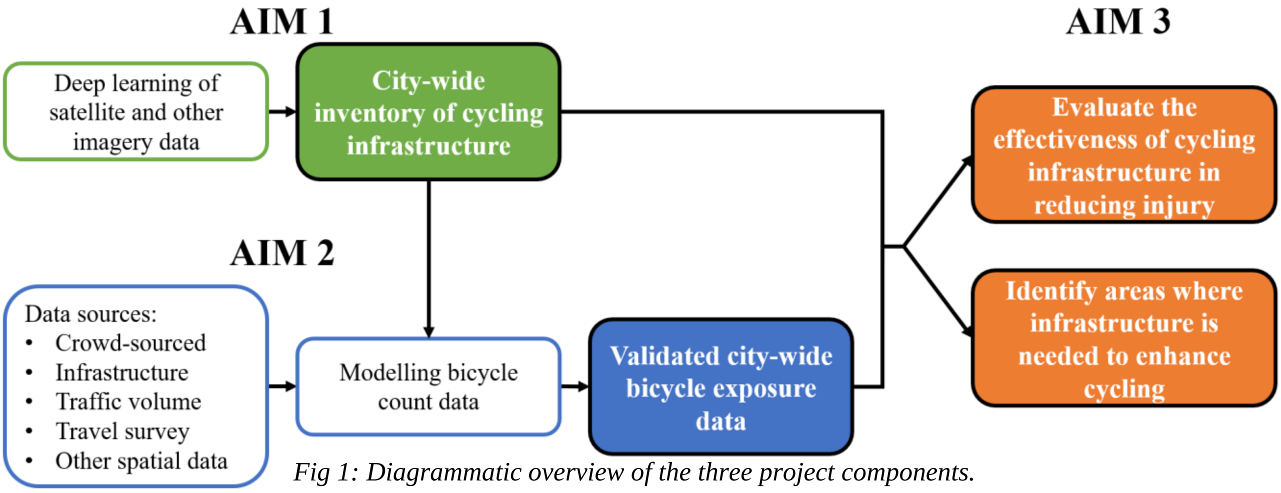


*Fig 1: Diagrammatic overview of the three project components.*

The overall aim of this project is to develop a universal platform for city-wide modelling of cycling exposure, and apply these data to advance the provision of safe and connected infrastructure to enhance cycling as a healthy and preferred mode of transport (Fig 1). We aim to:

1. Employ deep learning of imagery data to develop detailed databases of cycling infrastructure;
2. Combine crowd-sourced, travel survey and spatial data in a novel platform that will deliver validated city-wide bicycle volume data; and
3. Evaluate the effectiveness of cycling infrastructure in reducing injury, and identify areas where infrastructure is needed to increase cycling safety and participation.

## BACKGROUND

### The burden of inactivity

Globally, populations are facing significant health challenges, including increases in physical inactivity, chronic diseases, road traffic injury and obesity.[11] This is combined with continued population growth, rapid urbanisation and climate change.[12] Physical inactivity is the fourth leading risk factor for global mortality, and is estimated to be the primary cause of 21-25% of breast and colon cancers, 27% of diabetes and 30% of ischaemic heart disease burden.[13] In Australia, less than 50% of adults meet physical activity guidelines, and the annual economic costs of inactivity alone total more than $800 million.[14] With the world's population expected to reach 10 billion people by 2050, of which 75% will reside in urban areas,[12] urban and transport planning will play an even greater role in shaping the health of populations today and generations to come, particularly through the provision of opportunities for accessible and safe physical activity.

There is now widespread recognition that the global dependence on personal motor vehicles for transport has substantial and wide-reaching negative health impacts. Traffic-related exposures (including increases in air pollution, noise, local temperature rises and dwindling green spaces) are associated with all-cause mortality, cardiovascular diseases, cardiorespiratory morbidity, cerebrovascular disease, cancer, type 2 diabetes, dementia, anxiety, depression, and childhood behavioural problems.[12] This significant burden of chronic disease and increased premature mortality is in addition to the 1.3 million lives that are lost each year on roads globally. Further, the transport sector is a major contributor to climate change pathways, accounting for 25% of global carbon dioxide emissions; 75% of which arise from road transport.[12, 15] As a result of these wide-reaching population and environmental health impacts, Governments are increasingly emphasising the need for policies that encourage walking, cycling and public transport.[15]

### Transformative benefits of cycling

Cycling, as an active mode of transport, is critical to providing accessible and affordable physical activity as part of everyday life, and therefore improving population health. The health benefits of cycling for transport are astounding. Compared to non-active modes of transport, cycling is associated with a 41% lower risk of all-cause mortality, 45% lower risk of cancer, and 46% lower risk of cardiovascular disease.[1] Therefore, if cycling was invented today, it would be regarded as a modern health miracle. In addition to these health benefits, modal shift away from private car-based travel to cycling helps ease traffic congestion, improves productivity, reduces carbon emissions, improves connections within and between communities and combats social isolation.[2]

### Safe and connected infrastructure key to increasing cycling

Despite the profound health and environmental benefits of cycling, the number of people commuting by bicycle in Australia and many other countries is low. In Melbourne, only 1% of trips are made by bicycle.[2] Furthermore, injury rates are on the rise.[3, 4] CI Beck demonstrated that in Victoria, the number of seriously injured cyclists more than doubled over a 9-year period.[4]

The major barrier to increased cycling participation is perceived safety (i.e. how safe someone feels when riding a bicycle).[5] It is well known that the provision of connected and designated cycling infrastructure is critical to overcoming this barrier.[6, 7] The implementation of such infrastructure has been demonstrated to dramatically increase cycling rates.[8-10] For example, the provision of high-quality cycling infrastructure in parts of London resulted in a 24% increase in cycling participation within the first year of implementation.[10] Furthermore, high-quality infrastructure has been highlighted as the key factor that will shift non-riders to commence cycling. In a survey of potential riders (people who were not cycling, but may be interested in cycling), 83% reported that they would feel confident to ride on a protected bicycle lane, but only 22% would feel confident to ride on a marked on-road bicycle lane and only 6% would feel confident to ride on a road with no cycling infrastructure (Figure 2).[16] Therefore, in order to facilitate a transition to commencing cycling in the group of 'potential cyclists', it is evident that there is a need to provide safe and connected infrastructure.

Furthermore, as a consequence of the COVID-19 pandemic, we have observed a substantial shift to cycling as a form of physical activity that is compatible with physical distancing. As a result, regions (e.g. NSW, the City of Melbourne) have announced funding packages to support cycling and accelerated roll-out of cycling infrastructure plans. However, to ensure that we maintain and continue to stimulate this modal shift, there is an urgent need for data that can support the implementation of cycling infrastructure in areas of greatest need.

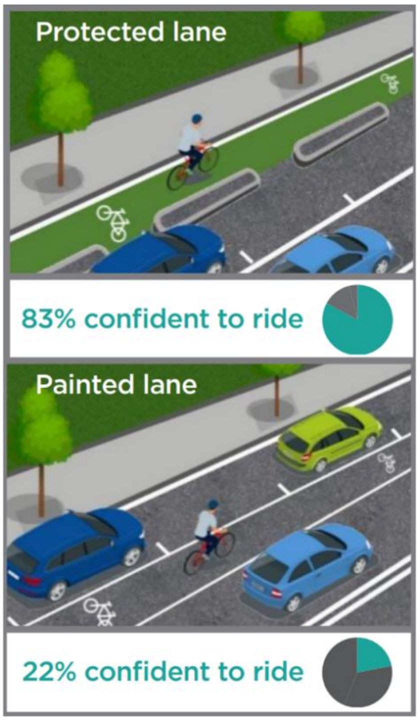


*Fig 2: 'Potential' bike riders feel far more confident using high-quality infrastructure (City of Melbourne)*

**The urgent need for cycling exposure data**

Cycling exposure data is critical for measuring health benefits and injury reductions, evaluating policies and interventions, and for future planning to advance the health of cities. However, ***the absence of cycling exposure data has severely limited our ability to progress cycling as a healthy mode of transport.*** This is in contrast to motor-vehicle volume data that critically informs network optimisation, the injury reductions resulting from road safety interventions, and planning for future growth of cities.

Traditional sources of cycling data and route information include manual and automated bicycle counts, travel surveys and questionnaires.[17] Each has their own intrinsic limitations, and often lack the spatial and temporal detail needed for monitoring cycling networks. For example, bicycle counts are often inconsistent and scarce, or counts take place on specific cycling promotion days and are thus not representative of cycling participation. There is also a clear need for accurate data on city-wide cycling infrastructure. Research conducted by CIs Beck, Saberi, Sayed and Winters demonstrates the critical role that cycling infrastructure has on safety.[18-21] However, inventories of cycling infrastructure, such as those generated by transportation agencies, are often out-dated and missing critical detail (e.g. protected lanes vs. shared lanes).

Globally, there are few city-wide spatial and temporal models of cycling volumes. Exemplary efforts include those developed by CI Sayed in Vancouver, Canada,[22] CIs Nelson and Winters in Victoria, Canada,[23] and the 'Cynemon' model developed by Transport for London. Such models have been used to evaluate the effectiveness of cycling infrastructure,[24] evaluate bike network structure,[20] and identify crash hot spots (accounting for exposure).[25] To date, these models can only predict cycling volumes on a limited set of street segments within a city,[22] or have inadequate predictive accuracy,[23] and rely on single sources to predict cycling volumes.

In this project, we will develop a universal platform that generates detailed city-wide inventories of cycling infrastructure and cycling volumes. This capability will enable us to, for the first time, identify the safest infrastructure types, identify inequities in cycling and identify areas where infrastructure is needed to increase cycling safety and participation. Overall, this will lead to improved safety, greater equity and a substantial increase in the number of people riding bikes, therefore realising the potential for huge gains in population and environmental health.

## RESEARCH PLAN

The overall objective of the project is to develop a platform that will be used to monitor, inform and evaluate cycling participation and infrastructure in perpetuity (Figure 3).

**Setting:** Similar to CI Beck's previous modelling,[26] the area of Greater Melbourne (57,285 street segments) is selected as the case study city as the majority of the data (satellite imagery, travel survey data, spatial data, crowd-sourced data) are available, the city is undergoing rapid urban growth and the proportion of trips made by bicycle is low, therefore provide an opportunity for substantial modal shift.

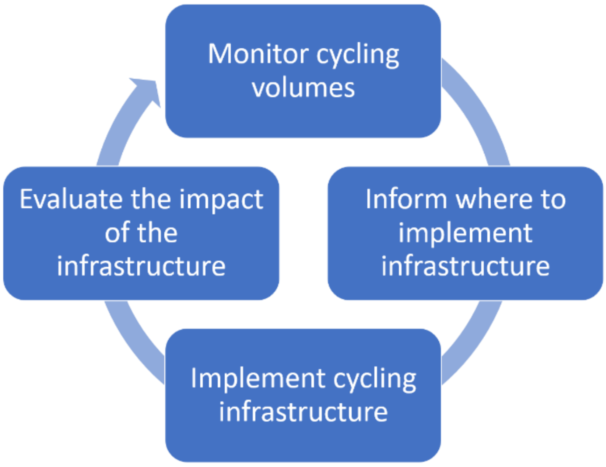


*Fig 3: How the platform will be used to monitor, inform and evaluate cycling and infrastructure in perpetuity.*

**AIM 1: Deep learning of imagery data to develop detailed databases of cycling infrastructure**

CIs Beck, Saberi, Stevenson, Sayed, Nelson, and Winters have demonstrated the importance of cycling infrastructure on cyclists' safety and where cyclists choose to ride.[6, 7, 17-19] However, current inventories of cycling infrastructure, such as that held by transportation agencies (e.g. Victorian Department of Transport; DoT) or through mapping products (e.g. OpenStreetMap) are often out-dated and/or missing critical information (such as lane type and width). For example, the Victorian DoT inventory of cycling infrastructure was last updated over three years ago. With increasing accessibility of satellite and street level imagery, it is now possible to extract this informing using computer vision techniques.

<u>Data sources:</u> The main data source will be satellite imagery from Nearmap, harnessing Monash University's Nearmap license. This provides complete coverage of Greater Melbourne at a 7.5cm resolution and is updated regularly (≥five times yearly). Using an existing framework developed by CI Nice,[27] imagery from Google Street View will be utilised as supplementary data for locations that are obscured by trees and other overhead obstructions.

<u>Methods:</u> Identification of road features from satellite imagery through computer vision techniques has previously been implemented by CI Nice,[28] and a range of these will be applied to catalogue cycling infrastructure. Line markings (to enable the quantification of bicycle/traffic lanes and line widths) and other sections of road paint (i.e. green bike lanes) will be extracted using computer vision techniques such as edge detection and colour clustering. Deep learning semantic segmentation will also be applied in combination to produce a spatial map of road features. A validation of this method will be enabled through the higher resolution imagery and 3D point cloud/canopy data from the City of Melbourne.

<u>Outcomes:</u> The outcome will be a city-wide map of bicycle infrastructure that will include the infrastructure type (e.g. protected bicycle lane, marked on-road bicycle lane, off-road path) and important characteristics of the road/bicycle lane (such as lane width).

**AIM 2: Combine crowd-sourced, travel survey and spatial data in a novel platform that will deliver validated city-wide bicycle volume data**

In Aim 2, we will develop a platform for modelling city-wide cycling exposure using a three-step approach. Here, we will firstly collect GPS route data from a cohort of cyclists. The route data will then be paired with bicycle infrastructure data (developed in Aim 1) and other spatial data. Based on these data, a route choice model will be developed (Aim 2.1). This model will then be applied to origin-destination data from population-weighted travel survey data to generate population-wide crude estimates of cyclist volumes along street segments (Aim 2.2). We will then combine these crude cyclist volumes with crowd-sourced data and other spatial data to predict known bicycle count data (Aim 2.3). The model will be validated in Phoenix, USA, to assess generalisability and scalability in cities outside of Australia, and demonstrate international application of the platform. CI Nelson (Phoenix, USA) has access to all relevant crowd-sourced, travel survey and count data.

***<u>Aim 2.1 – Understanding the routes that cyclists choose</u>***

<u>Data sources:</u> We will use GPS route data from a cohort of cyclists recruited for this project. CI Stevenson has developed an iOS and Android application that accesses GPS coordinates and maps

individual motor vehicle trips. We will leverage this platform and customise this app for cycling-specific trips. Cyclists will be recruited from our partner organisation, Bicycle Network, Australia's largest cycling membership organisation (45,000+ members), and Monash University and the University of Melbourne social media accounts. Similar approaches used by CI Beck to recruit cycling participants have been highly successful.[19] We will aim to recruit 2,500 individuals to capture their trips for a one week period. Purposive sampling will be used to ensure geographical coverage and representation across various cyclist types, with a particular focus on understanding the needs of the 'interested but concerned' cohort of cyclists (potential riders). Participant recruitment will occur over a 12-month period to ensure coverage across seasons. As implemented by CI Beck,[19] we will use probabilistic map matching to align GPS traces to the road/path network.

The road network shapefile (number of lanes, speed zone, signals, presence of on-street parking) will be sourced from the Victorian DoT. Topography, land use and green space data will be sourced from the Australian Urban Research Infrastructure Network (AURIN). Traffic volumes will be sourced from DynaMel; a dynamic model of traffic volumes developed by CI Saberi.[29]

Methods: To develop the route choice model, we will utilise a link-based recursive logit model, which is formulated as a sequence of link choices. To account for the application of this model to a large-scale network, we will adopt and further develop a recently proposed decomposition technique by Mai *et al*.[30] Key factors that our team have demonstrated are associated with the routes that cyclists select will be considered in the route choice model.[7, 27, 31, 32]

***Aim 2.2 – Generating bicycle flows from origin-destination travel survey data***

Data sources: Travel survey data will be sourced from the Victorian Integrated Survey of Travel and Activity (VISTA), which provides population-weighted estimates of trip origin and destinations (O-D) for all travel modes. O-D data for Statistical Areas Level 1 will be provided at no cost.

Methods: To generate estimated bicycle flows across the network, we will use an approach implemented by CI Saberi[33] whereby we will apply the parameter estimates for route characteristics from the route choice model to the bicycling O-D data.

Outcomes: The output will be crude bicycle volumes on each road/path segment in Melbourne.

***Aim 2.3 – Develop a platform to model city-wide bicycle volume data***

Data sources: Count data will be sourced from: automatic counters (provided by the Victorian DoT; 42 off-road and 4 on-road counters), and from a cutting-edge machine learning computer vision method (developed by CI Beck and AI Chang) applied to closed circuit television (CCTV) camera streams. We have developed this algorithm so that it can be applied to CCTV in real-time, rather than relying on the storage of video data, which is time and storage-intensive, and costly. This has been developed in partnership with the Victorian DoT, such that it can be applied to the 330 DoT CCTV cameras. We will also explore opportunities to access CCTV streams from local councils (e.g. City of Melbourne, City of Port Phillip). We will utilise crowd-sourced data from Strava; a social network for cyclists. A mobile app is used to track activities with aggregate and de-identified data provided by Strava Metro. Data provided will be volumes through intersections and street segments for each hour of each day of the week. As CI Beck is the Strava Metro 'Strategic Partner' for the region of Melbourne, these data are provided at no cost (cost saving of $87,000). Weather data (daily temperature and rainfall data) will be sourced from the Bureau of Meteorology.

Methods: We will use four groups of independent variables: infrastructure (from Aim 1), estimated counts from travel surveys (from Aim 2.2), Strava and additional spatial data. In both models, the dependent variable will be known bicycle counts. Spatial data will include land use, road/bicycle infrastructure (including measures of bicycle network connectivity)[19] and traffic volume data, supplemented with Census data (socioeconomic data; e.g. household income, level of education, age and sex distribution) and historical weather data.[34] We will compare both spatial statistical and machine learning models to identify the most robust approach for predicting bicycle volumes. Our team has substantial experience in the use of spatial statistical models and machine learning models to estimate bicycle and traffic volumes.[22, 23, 31, 35-37] We will employ both modelling approaches to identify the most accurate method. For both models, we plan to use a random selection of 80% of the bicycle volume data as the training data (300 locations) and 20% as testing data (76 locations). Volumes will be modelled by weekday/weekend, peak/off-peak, and will account for seasonality.

*Statistical model:* Drawing from the work of CIs Sayed, Nelson and Winters,[22, 34, 36] we will develop a statistical model that will create adjustment factors for both the estimated bicycle volumes and the Strava data based on the observed bicycle count data (in locations where count data are available). These adjustment factors will be applied to the estimated bicycle volumes (Phase 2) and Strava data on each road segment to using a spatiotemporal Empirical Bayes model. Model parameter estimates developed where observed count data are available will then be used as adjustment factors to be applied on road segments without observed count data.

*Machine learning model:* Deep learning models, such as artificial neural networks (ANNs), are considered to be one of the most cutting-edge artificial intelligence (AI) techniques. Such approaches have been employed by CIs Saberi[37] and Sayed[36] and AI Vu.[35] We will employ a multi-layer neural network with several interconnected layers, including input neurons (estimated count data from Phase 2, Strava data, spatial data) and output neurons (known bicycle count data).

<u>Outcomes:</u> A platform that will provide validated city-wide bicycle volumes on each street segment.

**AIM 3: Evaluate the effectiveness of existing infrastructure on cycling activity and crash risk, identify areas where infrastructure is needed to enhance cycling safety and participation**

In Aim 3, we will address substantial knowledge gaps in cycling participation, the effectiveness of specific cycling infrastructure types and the location of where to implement cycling infrastructure for greatest impact. Specifically, we will identify areas with low cycling participation and explore correlates of low participation (Aim 3.1), evaluate the effectiveness of specific types of cycling infrastructure on crash risk (Aim 3.2), and develop a novel tool to prioritise investment in cycling infrastructure to achieve the greatest gain in cycling participation and safety (Aim 3.3).

<u>Data sources:</u> Infrastructure and exposure data developed in Aims 1 and 2 will be used in Aim 3. Crash data will be sourced from the Victorian DoT's open-source CrashStats database of police-reported crashes and the Victorian State Trauma Registry (CI Beck is a Chief Investigator).

***<u>Aim 3.1: Identify areas with low cycling participation and poor access to infrastructure</u>***

Here, we will explore spatial patterns in cycling participation and identify localised opportunities for investment in bicycle infrastructure, with a focus on equitable access to infrastructure.

<u>Methods:</u> As applied by CI Winters,[38] we will explore spatial patterns in participation and access to infrastructure using infrastructure data from Aim 1 and cycling volume data from Aim 2. This will be achieved using local measures of spatial autocorrelation (Local Moran's $I_i$), which will be mapped to visualise spatial variation in participation and access to infrastructure. A particular focus of Aim 3.1 will be exploring variation by socioeconomic decile, to identify inequities in cycling.

***<u>Aim 3.2: Evaluate the safety of specific types of cycling infrastructure</u>***

The Cochrane Review of cycling infrastructure concludes that "there is a lack of high-quality evidence to be able to draw firm conclusions as to the effect of cycling infrastructure on cycling collisions."[39] To inform the infrastructure investment into the future, there is an urgent need to understand the relative effectiveness of specific infrastructure types in reducing crash/injury risk.

<u>Methods:</u> Similar to methods applied by CI Beck[26] and CI Sayed,[40] we will utilise Bayesian Poisson lognormal models to model street-level crash risk relative to exposure. A specific focus of this modelling will be investigating the effectiveness of specific infrastructure types on crash risk.

***<u>Aim 3.3: Prioritising implementation of cycling infrastructure</u>***

We will develop a novel tool to prioritise cycling infrastructure to achieve the greatest gain in cycling participation and safety. We will combine measures of bikeability (a measure of how friendly an area is for riding), safety and propensity to cycle (areas where the greatest uptake of cycling is likely to occur), to prioritise the implementation of cycling infrastructure.

Methods: Drawing from methods developed by CI Winters[41] and CI Sayed[42], we will firstly develop street-level measures of bikeability and combine these with objective measures of crash risk (using outputs from Aim 3.2) to create a composite measure of attractiveness and safety. In parallel, we will develop measures of propensity to cycle. This will be achieved using the travel survey data from Aim 2.2 to classify areas with a high proportion of short car-based trips (<7km); a marker of potential opportunity to shift individuals to cycling. Using these measures, we will be able to identify areas that have a high propensity for increased cycling participation, but inadequate cycling infrastructure. This will enable infrastructure to be strategically implemented to maximise the uptake of cycling and to enhance safety. This will be the first time that strategic and evidence-based decisions on where to implement infrastructure can be made for the greatest health gain.

## OUTCOMES AND SIGNIFICANCE

We will develop a highly novel platform for city-wide modelling of cycling exposure that will be used to ***monitor, inform and evaluate cycling participation and infrastructure in perpetuity.*** For the first time ever in Australia, we will address significant knowledge gaps in our understanding of cycling safety, the effectiveness of cycling infrastructure and the identification of areas in need of enhanced cycling infrastructure. Overall, the findings of this project ***will revolutionise our ability to advance cycling as a healthy and sustainable mode of transport*** through providing the evidence that is needed to improve safety, equity, and increase the number of people riding bikes. This will therefore result in ***substantial gains in population and environmental health***.

## IDENTIFIED RISKS

As this proposal has been developed around data sources that CIs already have access to and significant experience with (e.g. satellite imagery,[28] GPS traces,[7, 19, 27, 32] Strava,[23, 34] travel surveys[27]), there are minimal risks with respect to achieving the aims. However, given the novelty of the proposed research, there are three identified potential risks. Risk 1: challenges of participant recruitment. Mitigation: CIs Beck and Stevenson have successfully recruited large numbers of riders for similar research studies. Risk 2: challenges in access to CCTV footage. Mitigation: CI Beck has already established the relationship with and mechanisms to access Victorian DoT CCTV streams and has commenced discussions with local councils. Risk 3: inadequate prediction of bicycle counts. Mitigation: Similar to our prior work,[23] we will consider modelling categorical counts, rather than continuous counts, should we need to improve model accuracy.

## TIMELINE

| | 2021 | | | | 2022 | | | | 2023 | | | | 2024 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Aim 1: Deep learning of imagery data*** | | | | | | | | | | | | | | | | |
| Deep learning model development | ■ | ■ | | | | | | | | | | | | | | |
| Development of infrastructure database | | | ■ | ■ | | | | | | | | | | | | |
| ***Aim 2: Platform for modelling cycling volumes*** | | | | | | | | | | | | | | | | |
| Aim 2.1: Route choice model | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | |
| Aim 2.2: Flows from O-D travel survey data | | | | | | | ■ | ■ | | | | | | | | |
| Aim 2.3: Develop platform | | | | | | | | | ■ | ■ | ■ | ■ | | | | |
| ***Aim 3: Infrastructure and participation*** | | | | | | | | | | | | | | | | |
| Aim 3.1: Participation and infrastructure | | | | | | | | | | | | | ■ | ■ | ■ | ■ |
| Aim 3.2: Effectiveness of infrastructure | | | | | | | | | | | | | ■ | ■ | ■ | ■ |
| Aim 3.3: Prioritising cycling infrastructure | | | | | | | | | | | | | ■ | ■ | ■ | ■ |

## B. References *(2 pages)*

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## C. Innovation and Creativity statement *(1 page)*

This project will provide the critical data that is needed to fundamentally shift cycling as an active and sustainable mode of transport in Australia. By developing a universal platform for city-wide modelling of cycling exposure, we will, for the first time, identify the safest infrastructure types and identify areas where infrastructure is needed to increase cycling safety and participation. The absence of bicycle mobility data has crippled our ability to improve safety and prioritise investments in infrastructure; this innovative project represents a major breakthrough that will transform our ability to advance cycling as a healthy and sustainable mode of transport.

***1. Developing inventories of cycling infrastructure using deep learning of imagery data***

Firstly, we will use deep learning methods applied to imagery data to develop a novel inventory of cycling infrastructure; the first time that such a method has been applied to catalogue cycling infrastructure globally. Current inventories of cycling infrastructure are out-dated, held back by the need for manual updating, and often missing critical information. Our approach overcomes these limitations by developing novel computer vision methods applied to imagery data; an approach that can be applied in cities across the world.

***2. A platform to monitor, inform and evaluate cycling and infrastructure in perpetuity***

We will develop a globally novel platform that combines multiple unique datasets to develop detailed city-wide models of cycling volumes. The development of this platform and the methods used to combine multiple datasets requires substantial creativity. The few previous international models of cycling exposure that have been reliant on single datasets have shown inadequate predictive accuracy and have been applied only on a limited set of street segments. We will use advanced statistical and machine learning techniques to develop robust city-wide models of cycling exposure. Our approach in fusing diverse and big data and automating the development of this model ensures that this platform is scalable and generalisable to other cities, not just in Australia, but globally. The international applicability of the model will be demonstrated through testing and validation in Phoenix, USA, by CI Nelson. Further, we will establish the infrastructure and methodological approach to enable this platform to be used in perpetuity to monitor cycling volumes, and inform the provision of safe and connected cycling infrastructure. This platform will become the benchmark and ongoing mechanism for monitoring cycling in Australia.

***3. The first city-wide evaluation of the effectiveness of cycling infrastructure in reducing injury***

The proposed platform will enable us to, for the first time, prioritise cycling infrastructure to enhance safety. Specifically, we will quantify risk (crashes/injuries per kilometre travelled) across the entire network, and identify areas in need of improved safety. Critically, we will provide the first Australian data on the effectiveness of various types of infrastructure (marked on-road bicycle lanes, protected bicycle lanes, etc) in reducing injury. These highly innovative approaches to enhancing safety are a step change in our ability to inform evidence-based decision making on the implementation of safe cycling infrastructure.

***4. New tool to prioritise future investment of cycling infrastructure for the greatest health gain***

We will develop a new tool which will, for the first time, enable us to identify areas that have a high propensity for increased cycling participation, but inadequate cycling infrastructure. This will provide the first evidence-base that can inform decisions on where to implement infrastructure to maximise cycling participation and physical activity, thereby realising substantial health gains.

***5. Paradigm shift in our ability to advance cycling as a healthy and sustainable mode of transport***

Overall, these substantial breakthroughs will enable us to address significant knowledge gaps in our understanding of cycling safety and where to implement cycling infrastructure for the greatest gain. This project will provide us with the capability to develop evidence-informed policy, evaluate the health and economic benefits of cycling, enable robust evaluations of cycling infrastructure and interventions, and prioritise investments in cycling infrastructure to advance cycling as a healthy and sustainable mode of transport.

## D. Significance statement *(1 page)*

This project will revolutionise our ability to enhance population health through providing the evidence that is needed to implement safe and connected infrastructure to enhance cycling as a sustainable mode of transport and increase the number of people riding bikes.

**An urgent need for cycling mobility data:** As populations face growing health challenges, combined with continued population growth, rapid urbanisation and climate change, the need to provide opportunities for easy and safe physical activity is more important than ever. Cycling, as an active mode of transport, is the sustainable mode of transport of the future and has transformative benefits to population and environmental health. However, ***how safe someone feels when riding a bike remains as the key barrier to increased participation***. The provision of dedicated cycling infrastructure has been shown to overcome this barrier. Yet our ability to inform decision making on where to invest cycling infrastructure for the greatest population health impact has been severely limited by the absence of bicycle mobility data. The urgent need for these data is highlighted by a recent Cochrane review that reported an absence of high-quality evidence on the effectiveness of cycling infrastructure in reducing injury. Furthermore, this need is recognised by government and transportation agencies across Australia, as noted in the *Victoria's Cycling Strategy 2018-2028.*

**Transformative outcomes to propel cycling as a healthy and safe mode of transport:** This project will result in highly significant outcomes that have the power to transform cycling as a mode of transport, thereby resulting in ***unparalleled gains in population health***. For the first time ever in Australia, we will provide city-wide cycling volumes in a platform that can be scaled and applied to other regions across the world. The potential of these data and the analyses proposed in this project are transformative. We will provide the first Australian evidence of the injury reductions resulting from the provision of cycling infrastructure, and the first street-level measures of safety enabling interventions to be targeted to areas of greatest need. Further, we will provide insights into inequities in cycling participation and the provision of infrastructure. Importantly, we will identify areas that have a high propensity for increased cycling participation, but inadequate infrastructure. These outcomes will enable infrastructure to be strategically implemented to maximise the uptake of cycling, to enhance safety and to reduce transport inequities. This will be the first time that ***any of these outcomes have been possible***. The significance of this project is further enhanced by the design and implementation of this platform that will enable monitoring and evaluation of cycling now and into the future.

Overall, we anticipate that the outcomes of this project will result in improved safety for cyclists, lower injury rates, greater equity and critically, a substantial increase in the number of people riding bikes. This will therefore result in unparalleled gains in population and environmental health.

**Translation:** Implementation of study findings and changes to policy will be facilitated through CI Beck's extensive collaborative relationships with key partners. An advisory group will be setup that will comprise members of health and transportation agencies (the Victorian DoT, the Transport Accident Commission, VicHealth), local government, bicycle advocacy organisations (Bicycle Network, WeRide Australia), other researchers and policy makers. The advisory group will ensure that the project outcomes are relevant, timely and will be used to directly inform the provision of cycling infrastructure with the objective of increasing the number of people who ride bikes.

**Significant research outputs:** We anticipate that this project will become the benchmark and ongoing mechanism for monitoring cycling in Australia and internationally into the future, and will establish Australia as a centre of excellence in active transport research. The project will act as a major enabler of future research and guide the development of evidence-informed policy, evaluations of the health and economic benefits of cycling and future investments in cycling. Given the significance and impact, findings will be published in the highest-ranking journals in the transport and AI fields. Data will be disseminated through university data and analytics platforms (in which CI Pettit and Leao have significant expertise) and with the Victorian DoT. The framework for this platform will be made open access to maximise its utility and impact globally.

## E. Capability statement *(1 page)*

**World-leading research team:** One of the key strengths of this proposal is the multi-disciplinary and world-leading expertise of the CI/AI research team. Our team represents leading public health, transportation, urban planning and machine learning researchers who have unparalleled expertise in the methods proposed in this project and applying these to improve cycling safety and increase cycling participation. Collectively, our team have led the majority of ***sentinel*** papers in cycling safety and modelling cycling volumes. Furthermore, the team have a strong track record in delivering major projects on time and budget, and have the stakeholder relationships to successfully execute the project and ensure that the findings result in enhanced cycling safety and participation.

**Leadership:** CI Beck is uniquely positioned to provide very strong leadership on the proposed project and ensure that the findings have strong translational outcomes. CI Beck is an internationally-renowned cycling safety expert and has significant expertise in cycling, spatial analyses, modelling and leading large teams. He has extensive national and international collaborations with transportation agencies (Victorian DoT, Transport Accident Commission, Transport for London), cycling advocacy organisations (Bicycle Network, WeRide Australia) and Strava, all of whom have indicated will provide support for this project. Since returning to academia 5 years ago, CI Beck has published 52 papers (70% as first/senior author), secured $5.5 million of research funding (including NHMRC funding) and has demonstrated strong translational outcomes. For example, CI Beck led the largest study in the world on the distance that motor vehicle drivers provide when passing cyclists, which, in the 6 months since publication, has already been used to set cycling safety and infrastructure priorities by the UK Parliament. CI Beck holds numerous key local and international policy and academic positions, including on the Victorian DoT Expert Advisory Group for Victoria's Walking and Cycling Data Framework and Action Plan, as President of the Australasian Injury Prevention Network and as the Strava Metro Strategic Lead for Victoria.

**Multi-disciplinary expertise to deliver novel program of research:** This ambitious proposal is only possible through the combined expertise of world-leading CIs/AIs. CIs Stevenson, Nice and Sayed have significant expertise in computer vision machine learning (Aims 1 and 2); CIs Beck and Stevenson has significant experience in recruiting cyclists for data collection (Aim 2); CIs Pettit, Leao, Sayed, Winters and Nelson all have significant expertise in advanced statistical or machine learning modelling of cycling volumes (Aim 2); and CIs Beck, Stevenson, Sayed, Winters and Nelson all have significant expertise in modelling cycling safety (Aim 3). Preliminary and related work already completed by our team (e.g. deep learning of imagery data, computer vision model to count cyclists, experience in working with Strava data), approval to access existing data, and partnerships developed with the Victorian DoT, Bicycle Network and Strava, demonstrates clear capability to successfully deliver on the high-impact aims proposed in this project.

**Exceptional resources:** The project will be conducted at the world-class research environments of Monash University, the University of Melbourne and the University of New South Wales. These centres have the facilities required for the machine learning, imagery data, spatial data, statistical modelling and data visualisations, along with high-level technical and intellectual support. All centres have made significant investments in research infrastructure with world-class data and technology platforms. For Aims 2 and 3, we will leverage Monash's High Performance Computing facilities including the Multi-modal Australian ScienceS Imaging and Visualisation Environment (MASSIVE). We will also leverage Monash University's Nearmap license to access satellite imagery data and utilise UNSW City Futures Research Centre's CityViz urban data visualisation and analytics platform for dissemination.

**Developing talent:** Our team represents a mix of Professors and early and mid-career researchers, providing excellent opportunities for developing international talent in Australia. This project will also develop the next generation of sustainable mobility researchers (Monash University research fellow and PhD candidate, UNSW research fellow) through world-leading research training.