Feasibility of modelling impacts of working from home on travel and land use pre- and post-COVID-19

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Mark Gregory, WSP, Christchurch
Rachael Gordon, WSP, Petone
Vivienne Ivory, WSP, Petone
Francene Thomas, WSP, Petone

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NZ Transport Agency Waka Kotahi
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
NZTAresearch@nzta.govt.nz
www.nzta.govt.nz

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Abbreviations and acronyms

4SM	four-stage modelling
ABM	activity-based modelling
CBD	central business district
VKT	vehicle kilometres travelled
WFH	work/working from home

Contents

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Executive summary

The context

The legacy of the COVID-19 pandemic includes the demonstration that some parts of the economy can achieve business as usual without relying on staff attending a centralised workplace. The possibility that many roles can be undertaken from home is now established. Although there has been a steady reduction in working from home (WFH) since the end of lockdowns around the world, data from the US is suggesting a longer-term trend of 28% of workdays WFH.

Although there is not yet equivalent data in New Zealand, the prevalence of WFH is evident through empty seats in the office and observed fluctuations in road and public transport demands. There are also indications of changing living habits, including establishing home offices and the possibility of living further away from the office on the basis of needing to travel less.

Given the impact WFH can have on transport such as reducing vehicle kilometres travelled (VKT), changing public transport patronage or reducing peak hour traffic demands, there is an imperative to include it in transportation forecasts and models. The intention of this work is to set out the feasibility of including WFH as an alternative transport mode within forecasting and appraisal tools.

What we did

Literature review of WFH demand variables

The literature review highlighted multiple themes of drivers behind choosing to WFH. These included:

- work and employment factors – the type of role, whether it can be WFH, corporate policy on WFH, the size of company and physical home working environment
- transport and accessibility – length of trip, modes available, quality of access and quality of digital connectivity
- social and demographic – the role of gender, household interactions, psycho-social determinants and the role of perceived social obligation in weighing up whether or not to WFH
- environment and land use – location of workplace, size of city and agglomeration effects
- other drivers such as days of the week.

Some 50 quality sources were used with contributions from the entire research team. The information obtained included varying degrees of quantitative analysis, including some with a statistical significance context (for example, Mayer & Boston, 2022).

Identifying optimal approaches to modelling and uncertainty management

Strategic models are tools used to assist decision making by testing alternative interventions such as road schemes, pricing mechanisms or land-use outcomes in terms of how much and by what means people would travel. The outputs of these tools are used to inform design and as part of economic evaluation and evidence for investment quality assurance. The inclusion of WFH as a separate model of travel in a strategic model would provide a scientific basis to test impacts on network capacities, emissions and potentially settlement patterns.

Incorporating WFH into a choice framework is challenging. Characteristics of WFH are totally different from other modes of transport. Disruptive influences are transforming the ways people travel and also how they plan their lives and make decisions. COVID-19 and subsequent societal changes, including WFH, have highlighted an increasing need for modelling and appraisal frameworks to adapt in order to reflect these changes and provide better information to decision makers.

Traditional methods were considered alongside newer methods of practice emerging in New Zealand that are better suited to handling more complex travel choice behaviours. Specialised uncertainty management methods were also assessed for their usefulness.

Rationalisation phase

From the literature review, it was possible to determine the more significant variables behind decision making and insights into the volition itself.

Using a team-based cognitive mapping exercise, it was possible to express relationships between the variables. Building on this, an appraisal of the likely statistical behaviours of the variables was considered, directly leading to understanding how each variable would fit into a model framework. For one example, some significant variables were found to be collinear, meaning that they would be ineffective at explaining choice and therefore not an effective independent variable in a model. This processing of variables enabled a shortlist of what choice attributes would represent WFH in a model.

Other key findings included the illusive or qualitative nature of some variables and therefore needing to deploy synthetic valuation methods such as contingency valuation in order to capture into a quantitative framework. Some key variables were considered beyond the capabilities of conventional statistical methods of estimation requiring more bespoke methods, including scenario planning.

Drawing on enquiries into optimal approaches and uncertainty management methods, it was possible to begin developing possible model structures for the shortlisted variables. A hypothetical survey framework was considered that could yield a basis (main effects plan) for estimating the weightings of the variables in a model.

Assessment of methods

Three different model frameworks were developed and overlayed against a high-level assessment framework. Each framework consisted of an initial high-level checking stage, a main model (based on variations of logit) and attached scenario planning tool to manage variables beyond statistical estimation.

Each option was split into two options – one representing use in a conventional model framework and the other representing use in an emerging activity-based modelling (ABM) framework.

The themes of the assessment sought to capture resource requirements (both model build and data), ongoing costs, ease of implementation and use by the industry, consultation with the industry, quality of outcome (effectiveness) and ability to be used in conjunction with other tools and methods.

Further, the method used would need to fit inside a regional model and preferably be compatible with ABM. An architecture was developed to highlight how the preferred method would fit into a larger tool.

Presentation of hypothetical model and discussion

The recommended option is centred around a nested logit, a method capable of managing heterogeneity between variables. It is also a method compatible with both traditional regional model frameworks and emerging ABM. The nested logit method can be used in combination with the use of the initial and scenario planning stages that complements the main tool but can be input discretely, limiting the amount of work required in updates, maintenance and so on.

Our recommendation and conclusions

Our findings have shown that it is feasible to incorporate WFH as a mode into transport models by using a combination of methods. A key finding of the work is that many of the variables are beyond the capabilities of traditional methods to meaningfully capture, and the complementary use of scenario planning or similar is essential. Some of the variables would be more effectively represented in the emerging ABM, and the

recommended framework would also be compatible with that method. It was considered that more technically effective methods would be more resource intensive and less available to the industry to put into practice.

Our overall recommendation is to progress the recommended option towards development as an effective tool for capturing the effects of WFH. As a method that can enhance traditional regional modelling tools, this would therefore enable improved opportunities to measure and monetise the impacts of WFH on the transport system and provide a step change in terms of supporting informed decision making.

Abstract

Working from home (WFH) has become widespread following COVID-19, made possible due to significant investment in digital connectivity in the preceding decade. Transport and land-use planners have many questions around the full implications and opportunities that can arise from realising the potential of WFH such as improving transport outcomes and a role in the broader avoidance of continuing negative outcomes of mass, low-energy efficient mobility.

Addressing these questions requires significant analysis and the ability to forecast or otherwise account for futures in order to successfully plan ahead. New Zealand has a number of sophisticated regional models that are used for this purpose. The question this report serves to answer is how to account for WFH as an alternative to mobility that the regional models are already set up to measure and predict. The challenge is that WFH is very different to mobility. It has no journey time or ticket cost associated with it. The variables that influence user decision making are numerous, complex and likely to be highly variable between one household and another.

This research uses a targeted and wide-ranging literature review to identify variables for decision making that could be considered significant and a parallel review into methods capable of capturing and modelling these variables. Methods include uncertainty analysis and specific methods to manage what might be considered unpredictable by conventional means.

A few different frameworks for estimating and forecasting WFH outcomes are presented and contrasted in a high-level scoring mechanism. The recommended option is that which balances technique with availability of skills and resources to deliver.

The next steps following this work will be to formally test the outcomes and develop the framework identified.

1 Introduction

The purpose of this work is to identify a method that could include working from home (WFH) outcomes as a discrete choice of access that is comparable with conventional travel alternatives to inform the enhancement of decision-making tools such as transportation models. Ultimately, transportation modelling has been developed to support evidence-based decision making. Much transportation modelling practice in New Zealand uses tools with origins in a time where access was facilitated almost exclusively via physical mobility and the growth of physical mobility was inextricably connected to the growth in energy consumption. Since these times, New Zealand and the world have witnessed the rise of both digital mobility and increasing activities of governments and societies to address climate change. Policy responses to COVID-19 – being restrictions in movement to prevent the mass loss of life – have demanded the realisation of a more digital age, manifest through a rise in WFH.

Many of the tools used to perform modelling pre-date these disruptions. Although many have been retrofitted to include an additional mode (such as cycling) or a longer time period, many modelling tools are not keeping pace with changes in where, when and how people move and therefore increasing levels of uncertainty.

Uncertainty is an inevitable element of forecasting, and there are guidelines in place for its communication and management, particularly in an investment decision context. The leading approach is sensitivity testing – effectively stress testing an economic evaluation against a particular parameter to which the forecast outcome is sensitive. Since COVID-19, the variable of WFH has been named as one such parameter. However, there is limited ability to define and execute a suitable test through manipulating latent variables given that WFH itself is not included as a discrete variable.

The demands being placed on models are also increasing in response to global challenges. In New Zealand, there is an increased demand for the ability to:

- model emissions under the emissions reduction plan
- model vehicle kilometres travelled (VKT), noting a policy to reduce by 20% by 2030
- model road user charges to a standard addressing investment assurance criteria
- model rail/light rail schemes to a standard addressing investment assurance criteria.

Models are developed to provide some insights into likely cost and benefit ranges associated with different transport outcomes, and this guides the allocation of public resources. Understanding the implications of alternative options is required under multiple pieces of legislation, including section 32 of the Resource Management Act 1991 and section 77 of the Local Government Act 2002 and is part of delivering the objectives under section 2 of the Land Transport Management Act 2003.

Aside from evaluation, models also support decisions in regard to the allocation of land for development. Models can be used to determine the outcomes of alternative planning strategies such as comparing enhanced brownfield medium-density outcomes with lower-risk peripheral developments and return outcomes including the higher outcomes of VKT associated with the later. Including WFH in a strategic model could, in a more basic format, provide more robust land-use travel generation estimates or, if in a more advanced manner, provide some insights into potential changes to settlement patterns (including under free market conditions), therefore providing increased insight into strategic planning decisions.

Although there are several factors that could impact on these, the role of digital access is arguably the greatest, which is not explicitly represented in models. As explained below, a high or low preference for digital connectivity, most notably manifest through WFH, could significantly change the forecast performance outcome of these interventions. Therefore, inclusion of WFH in model frameworks to a robust standard will serve the purpose of more informed decision making and better outcomes.

The task of accommodating WFH variables into a model is complex given the diverse typology of variables and the ability to scale them relative to one another and accounting for variances in behaviours. Determining a suitable method requires examination of specialised methods of managing bias and uncertainty. An in-depth understanding of the methods available is imperative both to knowing limitations and to recognising opportunities for integrating new variables and practices. For example, differentiating between forecasting and simulating capabilities can support the task of improving previously unaccounted for variables while avoiding exceeding method capabilities.

There are several choice model specification types that might be considered, most notably including discrete choice methods that are currently universally employed across transport models, old and new, in New Zealand.

However, models are incomplete simply because there is more information behind human decision than is possible to include. For example, while a model represents a defined period in time, decision making includes exogenous variables tending to be influenced by events outside of this time period. Nevertheless, when developed in accordance with good-practice guidelines, models can provide something akin to a controlled environment for the testing of alternatives and provide robust investment quality assurance.

Some of the basic principles of modelling will be challenged as method development progresses. Traditionally, 'the probability of individuals choosing a given option is a function of their socio economic characteristics and the relative attractiveness of the options' (Ortúzar & Willumsen, 2011, p. 227). This principle appears to hold true approaching WFH. Although the ability to WFH would be 'free' and does not incur the same costs as transport, there is a relationship established between socio-economic characteristics (such as the type of job, also a product of income) and the ability to access opportunities to WFH.

The traditional modelling methods are built on estimation of utility for a given alternative – this is the sum of what users value and how this multiplies with attributes of their decision making. The challenge for developing options will be in converting those variables believed to describe the outcome of WFH as choice variables inside a utility expression. The issues of heterogeneity will also need to be addressed at this stage and the capacity for a single utility function to accommodate variables that do not relate to one another. It is highly unlikely that a single method will be able to represent WFH in models and that a staged or combined approach will be required.

Ortúzar and Willumsen (2011) state that the search for a suitable model specification involves selecting the structure of the model and the best explanatory variables and their form and the identification of suitable alternatives and that, following a comprehensive understanding of the drivers of decision making, the objectives of a subsequent model specification will need to reflect realism, efficiency and added value and be appropriate to the intended decision context.

1.1 Objectives

The ultimate outcome of this study is to improve the understanding of travel behaviour for transport planners and policy makers with regard to WFH so they can make more informed decisions on appropriate transport interventions and improve investment decision making to meet future accessibility requirements. The objectives of the research are to:

- get a better understanding of the substitution effects of information and communication technology and travel and its transport and land-use implications pre- and post-COVID-19
- assess the possibility of deriving utility values using different contingency valuation methods that can be used in transport models to assess traffic/transport and land-use impacts
- consider the modelling system that can be used to assess the impacts of teleworking/WFH on traffic/travel patterns and land-use impacts.

The end use of this research will be to guide the next stage of model development to represent WFH within broader modelling frameworks currently developed or under active development in New Zealand.

The following report describes the steps taken followed by recommendations, next steps and a discussion. More detailed supplementary information on specific approaches and modelling methods is available in the appendices.

2 Methodology

To include WFH as an alternative mode in modelling home to work trips is a complex matter. Foreseeable challenges include managing a potentially large mix of explanatory variables of differing typologies underpinned by different types of data, varying degrees of measurability and potentially non-stationary data (in other words, a moving target). Assessing the feasibility of modelling WFH as an alternative mode requires:

- a wide-ranging and rich literature review targeted at understanding why people chose to WFH and also approaching direct/indirect effects and the values of certain interactions between variables
- exploration of modelling methods suitable to accommodate the variables and their aforementioned complex circumstances and consideration of emerging methods designed to approach such challenges
- understanding how methods could be applied, particularly as a component inside a larger model
- identifying gaps in data availability and in the feasibility of observing important variables
- examination of uncertainty management methods with foresight of their importance.

The research requires an interdisciplinary approach. The abovementioned nature of the choice variables themselves is a project risk that is identified early. Another key to realising robust research outcomes is found in recognising the potential for practitioner bias and to mitigate it adequately. The specification of variables for inclusion and how and the order in which they are represented is undertaken at the practitioner's discretion and is also prone to influencing the outcome. The action of making decisions as to what is more or less important is informed by one's experiences, at least in part. The influences of beliefs and perspectives act at a subconscious level. A good way to manage the biases derived from a narrow perspective is to employ a broader perspective. This outcome is consistent with the direction of good practice actively discussed by the transport modelling community and its leadership. To address this potential for bias, the research team included a range of disciplines and demographic characteristics and were dispersed between Christchurch, Wellington and Hawke's Bay. Human factors specialists working with modellers helped avoid the possibility of unconscious bias against variables based on, say, their degree of complexity.

The methodology has been presented as series of steps that may be presumed chronological, but there will be interactions and overlapping of steps. For example, the stages of identifying variables and data typology will likely inform the method selection although the range of available methods will also shape how the shortlist of variables are grouped and treated.

Stage 1: Literature review of variables

The literature review identified the possible variables and methods used to measure and understand who was WFH during the COVID-19 pandemic and why. It covered literature and research undertaken in New Zealand and some pivotal relevant works from overseas.

Stage 2: Identifying optimal approaches to modelling and uncertainty management

In order to internalise WFH into a strategic transportation model context, a scan of transport modelling and analysis methods was undertaken to identify suitable approaches to treating variables in a modelling context and to identify the key technical parameters that will define the outcomes of this research.

An additional research area will be the management of model uncertainty. The majority of modelling in New Zealand uses cost, distance and time (often aggregated as a single 'generalised cost' trip valuation) as the prevailing metric for predicting mode choice. The under-representation of different variables thought to be important has been known for some time such as perceptions of personal safety or the ability to string multiple destinations into a single trip tour. One cannot approach the forecasting of WFH by generalised cost alone. The nature of some of the variables will be changeable or impossible to predict. For example, how

permissive will employers be of WFH in the future? Therefore, the methodology will include a parallel consideration of a complementary uncertainty management framework to add value to the task of strategic planning and policy making.

Stage 3: Rationalisation phase

A stage of initial sifting of variables will follow. In the first instance, data sources supporting the variables would be identified, or in the absence of data, an alternative method of quantifying or surveying would be suggested. The sifting phase will also consider the grouping of variables and the development of model methods.

Stage 4: Assessment of methods

The penultimate stage of the work will be to assess the different methods capable of accommodating the shortlisted variables. The literature review will have revealed a range of methods and approaches that can be used to inspire a list of method options. Criteria will be used based on a range of factors, including a mix of technical feasibility, resource implications, compatibility with host models and granularity of interpretation. Different method options might include varying emphasis on forecasting or simulation techniques, varying stages (including incremental options) and incorporating different strategies to testing relationships between variables.

Stage 5: Presentation of hypothetical model and discussion

The final stage will present a hypothetical model for subsequent development and testing. The scope of this report will finish at specifying shortlisted variables considered to predict WFH decision making and assembled in an appropriate configuration. The report will also reveal the options of how the model would be developed, but testing of the null hypothesis is outside of the scope.

In this stage, the limitations of the proposed model will be clearly identified, including specific strengths and weaknesses and identifying those variables that would be less well represented. This stage will also bring together the aspects of uncertainty management and seek to ensure that an appropriate method is recommended. The extent of uncertainty management will depend on the confidence of the model represented. However, allowance in the method is made for the need for a significant representation of uncertainty management.

The following report is supported by appendices with additional material relevant to the methodology for interested readers wanting more detail.

3 Literature review

3.1 Method and approach

This literature review identifies the factors or variables related to choice making around WFH versus commuting. The purpose of the literature review was to arrive at a structured list of explanatory variables, understand the relative importance of these variables in terms of theory and/or statistical significance and provide insight into relationships between the variables.

The review covered some 50 papers sourced from academic databases and globally renowned sources already known to the research team and steering group. The team used a targeted approach to the review, particularly making use of a range of research and surveying undertaken during the pandemic itself. The review snowballed from more established papers, including Mayer and Boston (2022), which derived significance confidence intervals for a range of hypothetical causes, and the Australian Productivity Commission (2021), which comprehensively analysed the WFH outcomes with data from individuals and industries and provided a rich narrative towards outcomes and reasons behind WFH trends in Australia during the pandemic.

Literature identification and review was undertaken by the interdisciplinary research team, including human factors specialists. The subject was approached under the hypothesis that determinants of WFH decision making are likely to be multifaceted and that gaining an understanding in specific behaviours was a core pillar of the approach to research. The understanding of underlying behaviours provided a basis to identify limitations in the models and methods applied later and the extent to which they can express and explain the real-world context.

As additional approaches to managing risk and research quality, several papers recommended from the wider research project steering group are included plus a gateway peer review (from our three reviewers covering different angles) that includes the literature review. Multiple sources were sought where possible to provide alternative opinions and a basis for challenging outcomes. Appendix A:shows coverage of the key research areas that were identified across our multidisciplinary team.

An initial scan of the literature indicated that the variables and research methods of valuing and measuring were both numerous and heterogeneous in nature. Therefore, a succinct high-level method was used to assess the significance rather than more complex significance testing. This process undertaken resulted in a shortlist that was used to create more rigorous analysis while a parallel review of econometric and mathematical methods capable of accommodating these variables was undertaken.

The variables were grouped under the headings of:

- work and employment factors
- transport and accessibility
- social and demographic
- environment and land use.

After the review, the relationships between the variables and their likely significance were assessed. The intention of the review was to identify variables where there was a plausible evidence base and further provide a basis for understanding their significance and/or characteristics with forecasting methods in mind. Papers were included in the review if their findings were statistically significant and/or there was a plausible theory or mechanism supported by a wider body of evidence. Consideration was given into the practical aspects of working with the variables in a predictive context, with modelling theory predominantly informed by Ortúzar and Willumsen (2011), the leading source on the subject of transport modelling in New Zealand.

3.2 Work and employment factors

3.2.1 Industry and employment type

Industry and employment types have been found to significantly impact WFH. In New Zealand, Mayer and Boston (2022) completed a full analysis of industry and employment types and considered the significance of several choice attributes, including transportation, employment characteristics and home working environment quality, towards WFH outcomes. This paper is significant, effectively bringing together several key variables into a single study with conclusions generally found to accord with the wider literature suite, and therefore is referenced throughout the review.

For analysis purposes, Mayer and Boston (2022) split their respondents into three groups based on their WFH preference:

- **Group 1:** WFH full-time (n=157).
- **Group 2:** WFH part-time (n=499).
- **Group 3:** No WFH, return full-time to the commercial workplace (n=138).

Mayer and Boston (2022) found that industry type was highly statistically significant ($p = 0.004$) on preference to WFH. The most common industry for those who wanted to WFH full-time was information technology and media. This industry is very teleworkable as few physical tasks and social interactions are required and many roles in this field require high computer use (Sostero et al., 2020). In a comparable study, Fu et al. (2012) in regression analysis also found 'industrial sector' (interpreted to be 'industry type') to be significant at a 99% confidence interval.

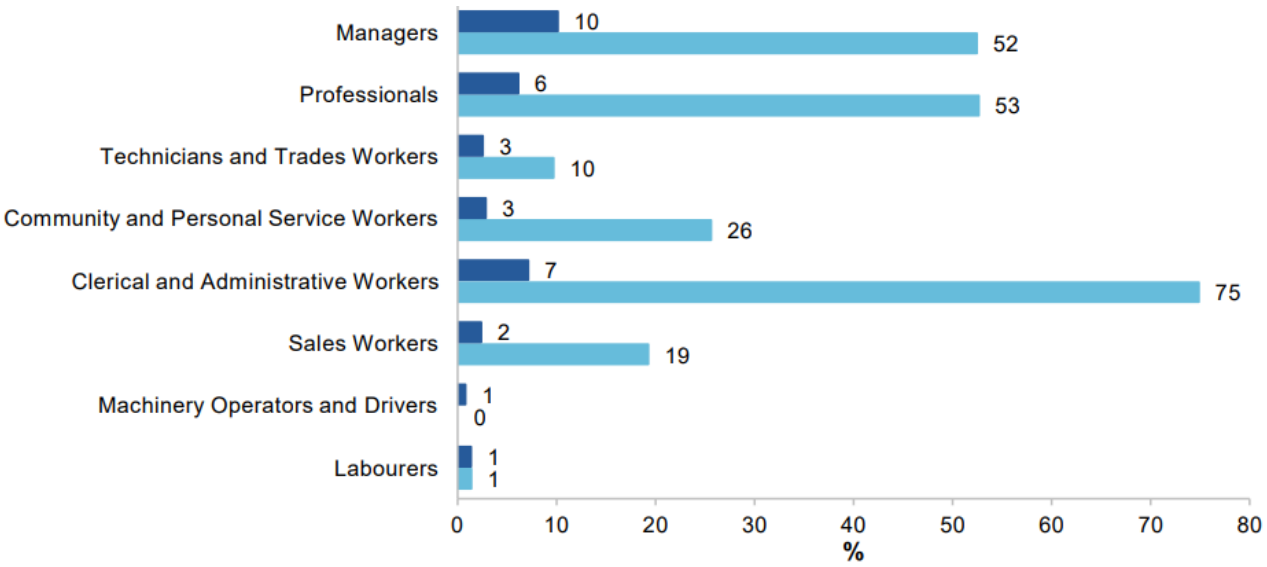
The most common industry for respondents who would prefer not to WFH full-time (WFH part-time/no WFH) was education and training, with 19.2% and 34.1% of respondents respectively employed in these fields (Mayer & Boston, 2022). Beck and Hensher (2021a) consider the 'nature of work to be a key determinant', citing the specific example of 'face to face role in a service economy' as facing 'unique difficulties' in the context of WFH during lockdown in Australia. Another key determinant to WFH is the ability to communicate effectively. Even for industries that could continue without in-person interactions, notably the professional services sectors, digital communication channels were often found to not be an adequate substitute, even resulting in outcomes such as 'cultural decay' in workplaces (Mattey et al., 2020).

All of the above papers are based on studies conducted within respective COVID-19 lockdowns – a period of time characterised by a lack of resource availability, including the ability to resource the home WFH environment. Compared with a gradual transition, the sudden, even haphazard nature of the move to WFH would have been faster than time taken to normalise such a change within a society. Beck and Hensher (2021b) consider WFH as a 'new normal' from within the pandemic, but questions remain as to the extent to which WFH might continue to be a social norm post-pandemic and into the future.

Kyriakopoulou and Picard (2022) found that 37% of jobs can be performed entirely from home and consider the prospect of WFH in the context of equilibrium between land values and salaries within which productivity changes would be simply traded off.

The Australian Productivity Commission (2021) estimates that 35% of jobs can be undertaken from home. Its report analysed census data to understand WFH outcomes by employment sectors (Figure 3.1). The sample includes data from 2016 (pre-COVID-19), thus revealing the more likely industries to encourage WFH in the future. The high make-up of managers, professionals and clerical workers appeared consistent with the outcome of technology firms in the US moving to increased WFH practices (Kyriakopoulou & Picard, 2022). Further, these findings approximately aligned with Mayer and Boston (2022) and Fu et al. (2012).

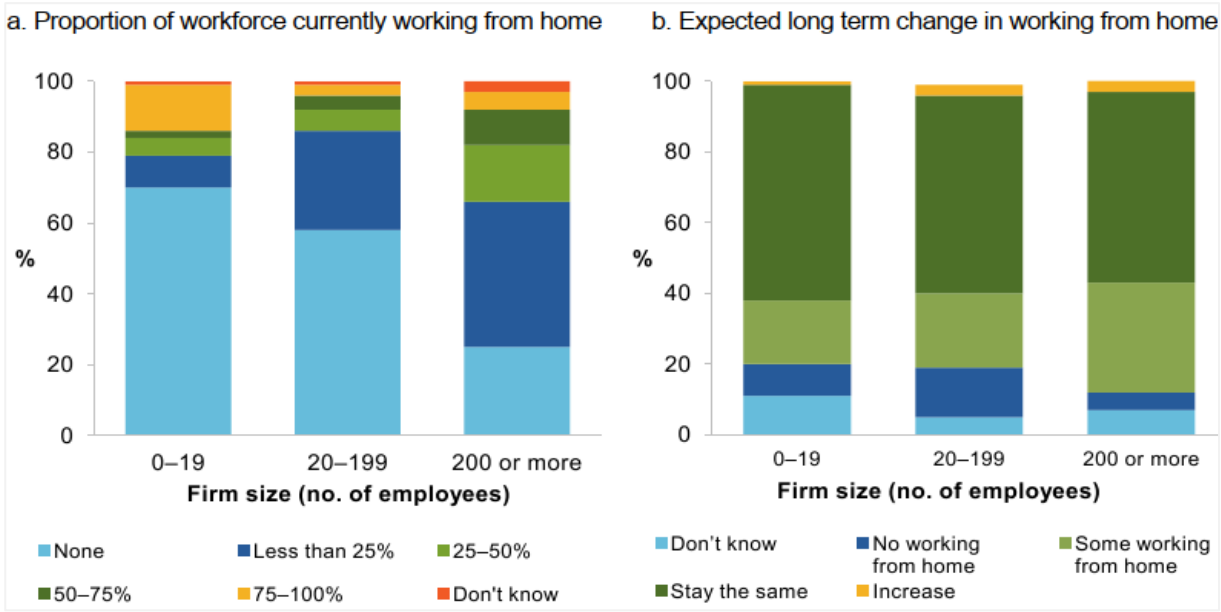
Figure 3.1 WFH outcomes in Australia by industry pre-COVID-19 (reprinted from Productivity Commission, 2021, p. 13)



There was consensus across multiple sources that industry type is a significant variable simply due to the different natures and demands of job types. Transport models already consider industry types, informed by census and/or Household Travel Survey data, and could therefore reflect the more significant industries.

Asgari (2015) noted that people who hold more than one part-time role were more likely to WFH to save on travel time. Opportunities to WFH have also created possibilities of holding more than one role. However, caution should be applied in the treatment of employment types in forecasting, which can go out to 40 years in New Zealand. One possible future scenario would include that, in 40 years, service sector roles would be mechanised, freeing up human beings to engage in more creative and thought-based industries that can be done from home. The likely pace of automation of the workforce would likely form a parameter in the scenario planning (see section 7.2.3). A significant finding of the Australian Productivity Commission report (2021) suggests both a tendency for WFH to continue and a stronger expectation for WFH to continue within smaller companies (Figure 3.2).

Figure 3.2 Employers expect WFH to continue (reprinted from Productivity Commission, 2021, p. 24)



Smaller companies may be able to be more flexible and adaptive to changes, and being more close knit, they foster a community of greater trust and therefore permitted flexibility. Therefore, the number of employees is also a likely explanatory variable of WFH outcomes.

3.2.2 Employer policy

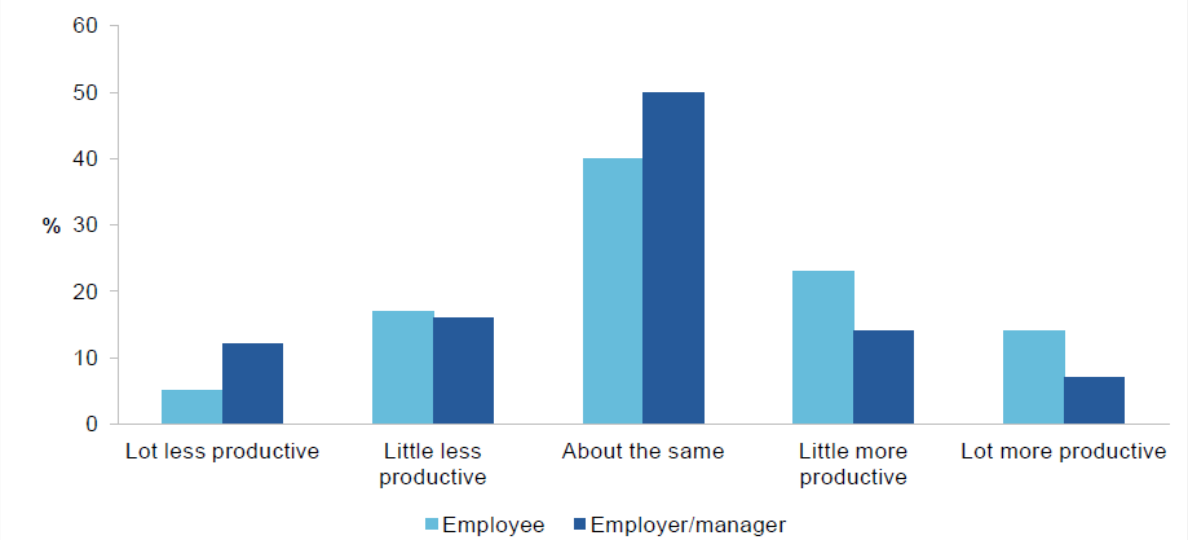
The significance of formal and informal employer policy or perceived employer attitudes (see section 3.4.1) cannot be overstated. If employers chose not to allow WFH, the need for a WFH model would be moot. Green et al. (2020) found that 90% of workers in WFH-capable organisations wanted to continue WFH to some extent, with the main barrier being management resistance:

> *The greatest barrier to successful WFH can be the mindset of management, with the traditional view of needing to see the worker and measure productivity as 'time in the seat'.* (Green et al., 2020, p. 9)

This 'time in the seat' approach is incompatible with the findings of Jain et al. (2022), concluding that both those who do and do not WFH perceive their productivity to increase.

Effectively, whether or not there is a formal employer policy on WFH, perceived views of managers are a clear driver of decision making. These views can be grounded in varying degrees of formal policy. Beck and Hensher (as cited in Productivity Commission, 2021) surveyed the attitudes of productivity between managers and employees (Figure 3.3). The relationship conveyed between employer and employee perceived level of productivity tended not to correlate – the employees perceive themselves to be more productive than do their managers.

Figure 3.3 Employee and employer views on productivity when WFH (reprinted from Productivity Commission, 2021, p. 25)



a. The survey was conducted between 23 May and 15 June 2020 and consisted of a representative sample of 1457 people across all states and territories.

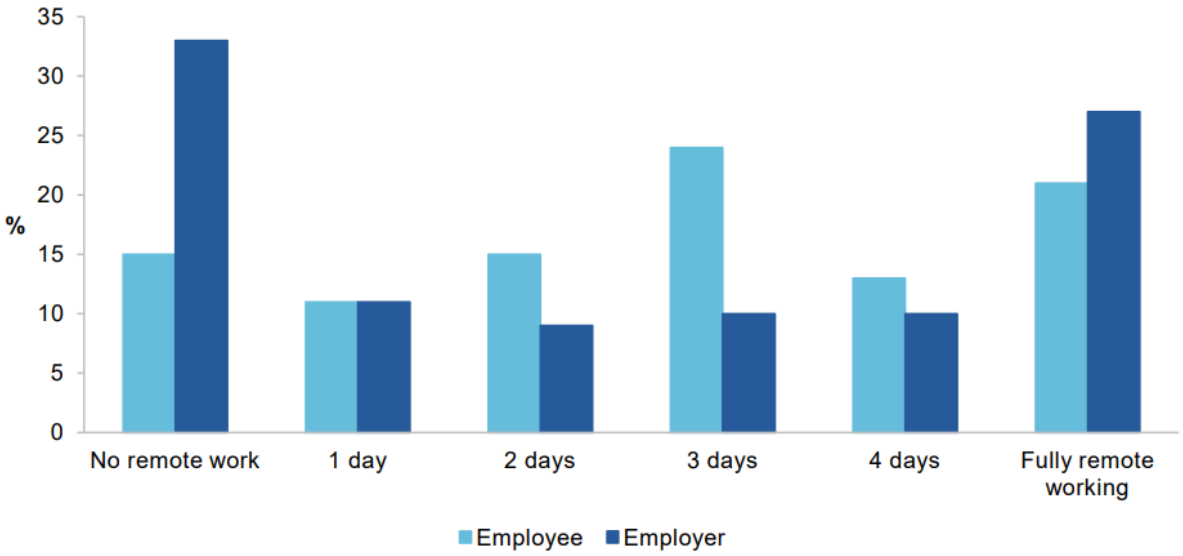
It should be noted that productivity in the Australian Productivity Commission report (2021) is measured in terms of time and revenue, which is a short-run view. Longer-run definitions of productivity might include more complex metrics of productivity such as the quality of work being undertaken. The report considers the quality of social interaction to be important but does not explicitly include it as a parameter in its WFH model.

On the working environment, Green et al. (2020) noted that employers in the US have health and safety obligations to workers regardless of their work location. Example obligations to ensure the wellbeing of staff include ergonomics reviews and providing stand-up desks to accommodate medical requirements.

The condition of the home office is often not as suitable as the office workplace. From an employer's perspective, there is no certainty of available private or dedicated workspace for employees at home that would be traditionally considered conducive to productivity. However, the ability to shift costs of a WFH set-up to the worker (internet, heating, equipment) could offset some of the employer costs associated with operating a second workstation.

Given the relationship shown in Figure 3.3, it is not surprising that the number of days WFH sought between employer and employee varies as well (Figure 3.4). Of interest is the representation of the employer in each extreme, seemingly preferring either no remote work or full remote work.

Figure 3.4 Number of days per week employers and employees would like to work remotely (reprinted from Productivity Commission, 2021, p. 30)



The preference (for either employer or employee) for full remote working may have been limited to certain sectors. The Australian Productivity Commission report (2021) highlighted both the effect of WFH in terms of increasing access to labour and therefore labour supply as well as the ability for certain industry sectors (such as so-called tech firms) to capitalise on this opportunity. For some companies where WFH is especially viable, there also comes the benefit of reduced overhead costs.

The perception of productivity is likely to change driven by improvements to technology and quality of social interactions, the quality of home working environments and societal expectations over time.

There may be defining moments in the relationships. For example, in July 2023, the Commonwealth Bank of Australia (CBA) was defending a policy at the Fair Work Commission requiring staff to work from the office for half their time (Thompson, 2023). The union pursuing the action regarded themselves as defining flexible working practices, whereas the CBA claimed that working remotely all the time was not tenable for any bank employees. There is evidence that expectations of staff towards enjoying flexible working practices have been raised. The ruling on CBA may prove to be a landmark in managing expectations of both employers and employees.

Clearly, the role of employer policy is both significant and difficult to predict. However, the aftermath of the initial COVID-19 lockdown in New Zealand witnessed a surge in skills shortages and recruiting challenges.

The offering of flexible work arrangements would increase the attractiveness of a firm. The continued impact on the offering of flexible packages will need to be considered further (for example, through examination of the Ministry of Business, Innovation and Employment survey of New Zealand employers).

Management perceived WFH options as a benefit in times of crisis but not as business as usual due to perceptions of the loss of connectiveness, collaboration and in-person communication (Donnelly & Proctor-Thomson, 2015). It should be noted this conclusion was drawn pre-COVID-19, a period characterised by significant investment in WFH capabilities. Presumably, if businesses wanted to maintain options of WFH during exceptional events (noting that Auckland weather induced demand for WFH at least twice in 2023), retaining WFH capabilities would be required. This would incur the additional benefit of avoiding significant future set-up costs (measured as both sunk and lost productivity) as incurred during the COVID-19 Alert Level 4 lockdown policy.

Kyriakopoulou and Picard (2022) reported that several of the larger US technology firms have announced plans to offer increased flexibility. Apple announced in June 2021 that it will require most employees to attend its office on Mondays, Tuesdays and Thursdays (Miller, 2021).This same outcome was noted by Beck and Hensher (2021b). It should be noted that Apple preferred to adopt a mix of practice, a matter closely related to the perceived role of face-to-face collaboration in productivity and wellbeing.

Despite these more recent changes, Global Workplace Analytics forecast in 2020 that WFH will remain a ‘permanent feature of the working environment’ (as cited in de Palma et al., 2022). Clearly, the role of employer policy is both significant and difficult to predict. Ongoing research and analysis will be undertaken to understand employer attitudes to productivity and WFH, including from the Ministry of Business, Innovation and Employment employer survey. This could potentially provide further understanding around the measuring and understanding of employer policies and potential identification within a modelling context.

Employers compete in a market for scarce talent (particularly in those industries already shown to include a strong desire to WFH). Furthermore, shocks such as COVID-19 or Cyclone Gabrielle can require employees to WFH to achieve business continuity. It is reasonable to expect that WFH options will continue into the future. However, some of the variables that determine employer policies are beyond the reasonable expectations of a transport model to capture. Therefore, this particular variable would either be treated in conjunction with the interpretation of other economics-focused models or developed within a scenario planning framework.

3.2.3 Productivity

Productivity has been examined in the literature in various ways. Jain et al. (2022) looked at perceived productivity, developing structural equation modelling based on a multinomial logit regression of three discrete aspects of planned behaviour theory to describe the decision making of groups who did and did not WFH. The outcomes reflected both improvements and detractions from productivity. While some people were able to WFH without interruptions, others found WFH had more distractions. Some identified that there was also a greater potential to overwork when WFH. Jain et al. concluded that perceived productivity was a psycho-social factor of decision making (see section 3.4.1).

Zheng et al. (2023) found that those who were satisfied with WFH tended to have positive feelings about work productivity. Therefore, it seems likely that perceptions of productivity drive WFH decision making, with perceptions of not being able to perform in a WFH environment associated with choosing not to WFH.

Barrero et al. (2023) analysed data from the US Census Bureau Household Pulse Survey 2022–23, and survey data by the authors (collected 2020–23) found that, during the pandemic, many workers were ‘favourably surprised by their ability to work remotely’ (Barrero et al., 2023, p. 25).

Recent estimates suggest that approximately one-third of jobs could be WFH. As noted above, the Australian Productivity Commission report (2021) estimated that 35% of jobs could be undertaken from home, and Kyriakopoulou and Picard (2022) proposed that 37% of jobs can be performed remotely. WFH was found to rebalance commuting patterns and commercial rents as well as organisational productivity.

However, Kyriakopoulou and Picard (2022) considered the role of externalities of agglomeration, which they posed as the driving force behind firms' location decisions with massive perceived macro-economic benefits and the impacts of increasing WFH on the sustainability of such agglomerations. WFH was seen as preventing face-to-face communication between workers within organisations as well as between organisations, which was thought to hinder innovation and productivity. On the other hand, they found that, due to advances in digital technology, there was an increase in productivity of remote workers as well as an increase in welfare benefits.

Beck and Hensher (2021a) found that not everyone can WFH as well as others. Part of this might be explained through other variables (see section 3.6), including personality types, access to suitable digital connectivity (specifically broadband), type of industry and views of management.

Effective communication between workers has been identified as important for information flows and coordinating work activities (Charalampous et al., 2019). Green et al. (2020) consider that communication and collaboration, while enhancing and enabling WFH, can also be perceived an insufficient substitute and a reason given for organisations not to adopt WFH. The success of WFH is often dependent on management and communication styles that require adjustment. Digital communication is different – much of the body language and other subtle communication cues are difficult to detect. Therefore, communication styles must adapt with more explicit communication in a WFH context needed than in comparable in-person interactions (Makarius & Larson, 2017), including more explicitly set goals, which can influence working relationships and wellbeing.

Some employees feel 'out of sight, out of mind' and may experience feelings of isolation in situations where managers are unable to adapt communication styles. Beck and Hensher (2021a) consider the role of human connectedness and friendship as a determinant of productivity.

The matter of productivity is closely related to employer policy and wellbeing. There may be challenges incorporating productivity into a model without a dummy variable – it is more likely the perception (Jain et al., 2022) that drives decision making, with researched differences in perceptions between employers and employees (Beck & Hensher, 2021a). Both of these circumstances suggest that the variable of productivity could either be difficult to measure or not to a high degree of confidence.

3.2.4 Employer and employee costs

Cost is the most common variable in transport models, historically defined as the total cost of a journey and often rolling up elements of time, value of time and journey-related expenses as generalised cost. The methods of modelling generalised cost come from an era when there were limited substitutions to physical trip making in order to be connected and participate in the economy. The outcome of utility maximisation was much more connected to minimising trip time and cost without access to portable cellular technology. Also, generalised cost is a convenient parameter that can be used in the most basic forms of mode choice modelling.

Cost of transportation is of ongoing relevance, affecting location decisions and choice of mode made by employees. It also has ramifications for the broader economy – time spent commuting is lost to other pursuits such as for leisure and recreation (Productivity Commission, 2021). It is partly on this basis that infrastructure investment can be justified through internalising monetised journey time savings into economic evaluation.

Costs are separated into actual monetisable costs and those that are perceived – a practice well established in transport modelling. Cost modelling is undertaken to predict choices within a framework of alternatives. The classical perception of costs could be categorised in three ways:

- Sunk costs such as WFH set-up, investment in a home office and ownership of a car.
- Marginal costs such as travel time differences and commute time savings.
- Perceived costs – classically, the perceived cost of congestion or overcrowding and including some lesser quantifiable costs.

The Australian Productivity Commission report (2021) provides a useful summary of the potential costs and benefits of WFH for employers and workers (Table 3.1 and Table 3.2). In both tables, there is clearly a mix of cost types and a broad scale of ease to measure and/or quantify.

Table 3.1 WFH potential costs and benefits for employers (reprinted from Productivity Commission, 2021, p. 32)

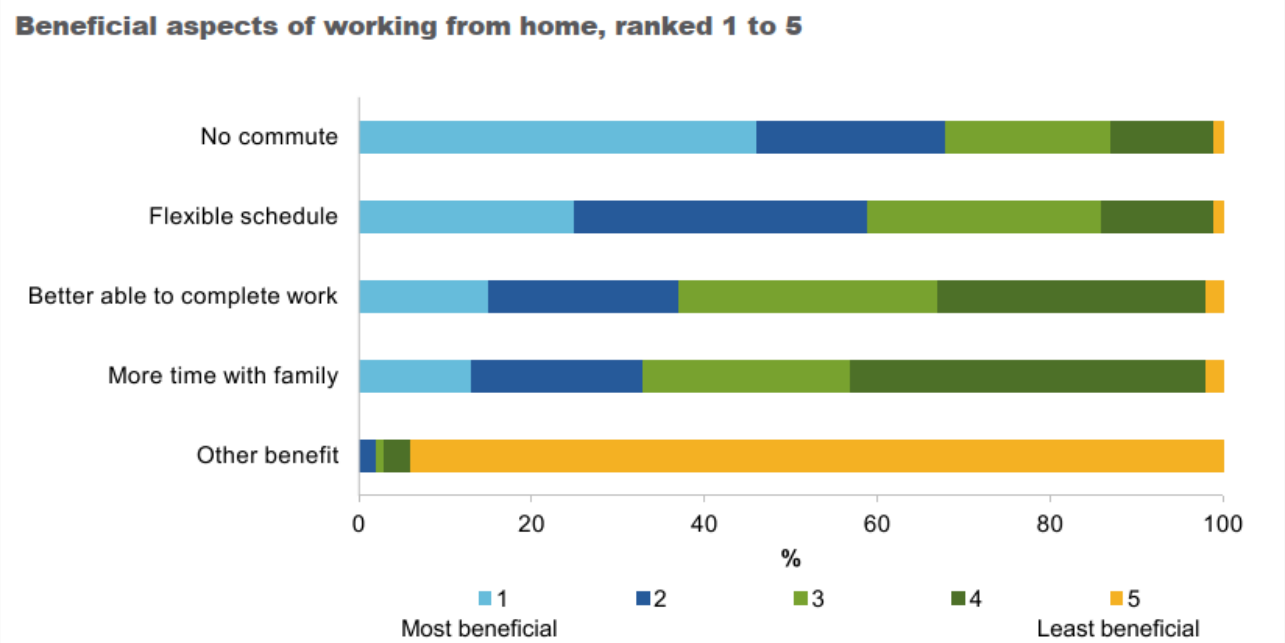
Potential costs	Potential benefits
• Lower productivity if employees cannot co-ordinate, collaborate and share knowledge effectively. • Workplace culture decays due to fewer or lower-quality interactions among workers. • Potential for remote workers to shirk; additional costs to monitor employees or change workplace processes. • Capital expenditure on equipment and telecommunication systems to enable working from home.	• Higher productivity if employees have better ability to manage their time and concentrate, and/or are better rested because of the lack of commute. • Greater output if workers work longer hours (and productivity does not decrease). • Rental savings on office space. • Ability to recruit from a greater geographic pool. • Retention of staff who prefer working from home.

Table 3.2 WFH potential costs and benefits for workers (reprinted from Productivity Commission, 2021, p. 32)

Potential costs	Potential benefits
• Decrease in job effectiveness due to distractions at home or lack of suitable working space. • Fewer networking opportunities. • Less socialising with colleagues; increased isolation. • Blurring of lines between home and work, leading to extra hours of work and inability to 'switch off'. • Higher energy costs (to heat or cool home during the day). • Costs associated with setting up a home office or purchasing a larger property to accommodate a home office. • Fewer training, development and promotion opportunities due to decreased visibility to managers.	• Commute savings (time and transport costs), resulting in more free time for other activities such as more work, exercise, housework and family time. • Flexibility to combine work and non-work activities. • Higher productivity due to greater autonomy to manage workflow and ability to concentrate on tasks (less interruption by colleagues).

In terms of being reflected in a model, there would be different considerations. Although not placed in order of importance, the theory of planned behaviour shows how the perceived costs and benefits associated with social interactions tend to be the primary driver of decision making (see section 3.4.1). However, the Australian Productivity Commission (2021, p. 28) reports that 'many workers consider it to be the most beneficial aspect of working from home'. Beck and Hensher (2020) found almost half of survey respondents ranked 'no commute' as their most beneficial reason for WFH (Figure 3.5).

Figure 3.5 Avoiding the commute is the biggest benefit for many (reprinted from Productivity Commission, 2021, p. 30, citing Beck & Hensher, 2021b)



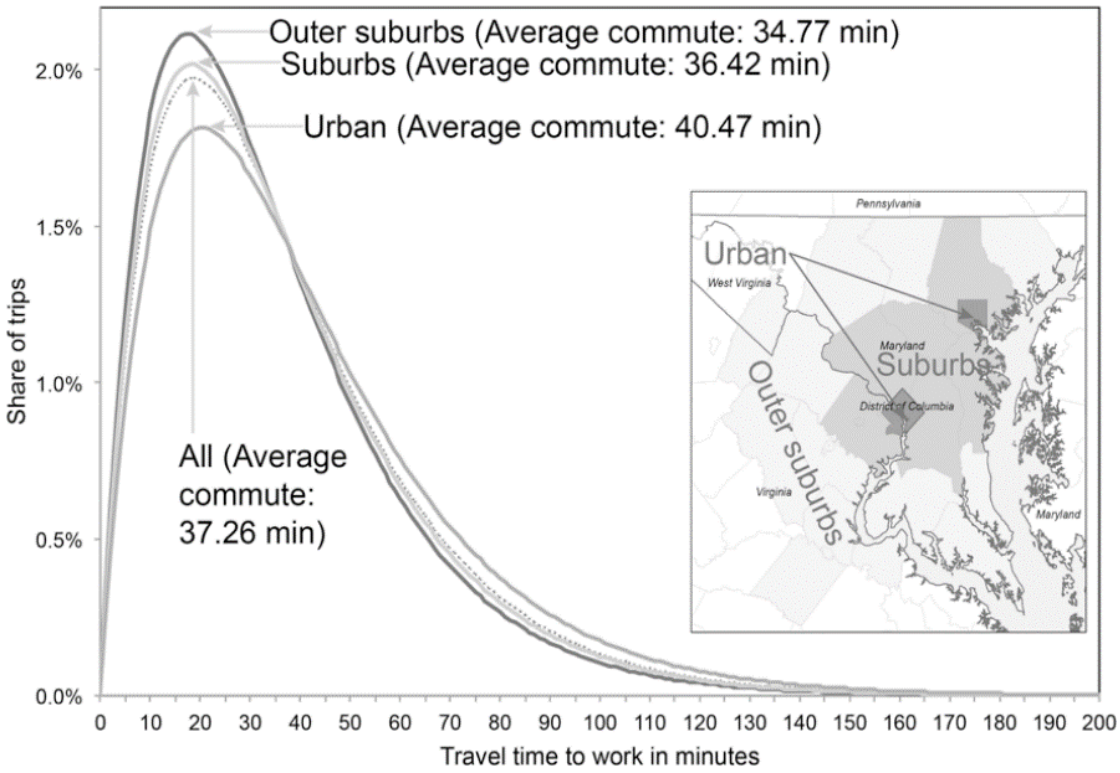
a. The survey was conducted between 23 May and 15 June 2020 and consisted of a representative sample of 1457 people across all states and territories.

It should be noted that, although Jain et al. (2022) suggested some primacy in decision making to social constraints, social constraints (associated with work) were not represented in the categories in Figure 3.5. Even if they were, it is possible that individuals would be unaware of their own subconscious decision-making biases, being more mindful of more tangible aspects such as the length of their commute. It is worth highlighting the challenges in surveying individuals. When asked to explain their behaviour under a controlled setting and often in the context of a hypothetical situation, respondents typically do not represent their true behaviour well simply because it is more complex than what they can often comprehend (Willumsen, 2014). Given the broad range of choice attributes being considered, it is quite possible that respondents would not be able to reflect their true own causes of decision making and survey design would need to be cognisant of this reality.

Planning a model, therefore, requires contemplating a wide range of costs, many of which would not fit within the traditional generalised cost aggregation. Assuming limitations of surveying to reveal among other things that willingness to pay can be overcome, the later stages of this report will consider how these attributes can be represented. This could be either as explicit operating model attributes (through which the relative increase or decrease in the importance of perceived opinions of one's colleagues could be used to partly explain WFH outcomes) or as more passive components of a model.

There are elements more conducive to being modelled as explanatory factors such as those akin to generalised cost considerations. The attraction of an employment site can increase through flexible working policies. This includes having a wider geographic area for recruitment and therefore potentially extending the geographic area considered in trip attraction. This supports the emerging theory in modelling that WFH would operate with a different gravity model to non-WFH trips, which means longer trips (Figure 3.5). However, there are warnings around false precision such as estimating average journey length to two decimal places.

Figure 3.5 Demonstration of varying trip length distribution, Maryland, US (reprinted from Moeckel, 2017, p. 212)



In theory, a single model including the possibility of WFH would calibrate a single distribution parameter. However, this could result in extending the geographic area of the model unless using so-called external zones, which offer very little value except loading demands into a simulation network. A larger model may tend to lose accuracy in validation and lead to sparser matrices. There would also be differences in perceived trip costs between those who WFH regularly and those who do not. A single gravity model would not be able to reflect these differences and would arrive at a distribution that does not accurately reflect shorter or longer trips. However, at this stage, there is limited evidence that settlement patterns have changed in response to WFH options. It is possible that WFH options (and reduced travel costs) could be a driver for increasing outer suburban or rural living.

The matter of time management is clearly important and may have ramifications on model architecture. While a classic model would consider a single given day, a WFH model may need to consider a time series perspective. WFH can affect one's willingness to pay/sensitivities to cost on the fewer days travelled and can also require longer-term planning around family and other social considerations. If one has a weekly monetary travel budget, everyday WFH will increase the residual budget, potentially allowing the traveller to indulge in a more expensive trip such as parking in the expensive parking building right next to the office.

Therefore, the process of weighing up potentially includes the perceiving of costs differently from one day to another, including factoring antecedent decisions. A conventional transport model mostly considers choice and attitudes to cost (and its derivatives) within a single day for the purposes of forecasting cost-based cross-elasticities. A WFH model would therefore require a time series basis to describe decision making, which would have ramifications for strategic model architecture. A possibility would be to include two days, with the second 'warmed up' with the outcome of the first day and slightly reworked with different cost perception coefficients in the mode choice synthesis. Development of detailed methodology will form part of subsequent research stages.

The extent of one's sunk costs into WFH options (such as acquiring a home office) could be potentially greater than that associated with transport (such as owning a car). Vehicle ownership is a traditional driver of mode choice in modelling. While the majority of those who do WFH would still own a car (Mayer & Boston, 2022), the extent of sunk set-up costs into WFH capability would likely be part of an individual's longer-term work location plan.

There are other less-obvious costs. Green et al. (2020) cite employer experiences following a WFH trend in Christchurch in the aftermath of the Canterbury seismic sequences (2011–13), and Donnelly and Proctor-Thomson (2015) cite findings of work intensification of managers to accommodate. Additional costs may be perceived by employers as reduced productivity (see Figure 3.3), noting the difference in views between the employer and employee in impacts on productivity. Perception of cost by employers is also likely to be subject to individual management styles measuring productivity as time spent at the desk (Green et al., 2020). Beck and Hensher (2021b) report on the importance of technology and the barrier this can present if it were either not available or it required additional training.

The costs that would be modelled are highly variable in typology and how they are measured (heterogeneous). They are also reflected on hierarchically rather than contemplated simultaneously. Further, the examples given above represent a mix of short-run and long-run elasticities. These two states would be mutually exclusive for a given agent and should therefore be carefully treated as such in developing forecasting tools.

All of these circumstances lend themselves to a more incremental mode selection framework, considering the estimation of choice in stages, grouped in accordance with a theme (for example, environmental conditions of a WFH set-up). This approach is known as hierarchical modelling and can overcome some issues relating to heterogeneity.

3.2.5 Job satisfaction and career prospects

Some research findings suggest that WFH has the potential to affect career prospects. Relative job effectiveness (actual or perceived), reduced opportunities for collaboration and networking and reduced face-to-face interaction with managers have been identified as potentially career-limiting consequences of WFH.

While concerns have been raised about limited career advancement, an earlier study by McCloskey and Igbaria (2003) found that teleworking did not lead to 'out of sight, out of mind' or fewer opportunities for career advancement. While it should be noted that this research pre-dates COVID-19, other research during COVID-19 found similar impacts on job satisfaction, particularly with regard to the role of social networks on promotability (Beck & Hensher, 2021a). It is still too soon since the pandemic to know the extent to which social opinion has changed on the subject of WFH, but it is reasonable to conclude from all evidence that perceptions of WFH have been changed to at least partial acceptance.

While the impact of WFH on career prospects can be mitigated by workplace policies and practices – for example, managers may actively seek to ensure all employees have networking opportunities regardless of location of work – not all employees may play by the new rules, leaving high-quality workers who prefer

remote work behind (Tadros, 2021), and regardless of whether risks to career prospects are real, perceptions of such risks can deter workers from WFH.

Jain et al. (2022) demonstrated the awareness of powerful social influences in decision making. The perceived opinions of one's managers, colleagues and family are central in choosing whether or not to WFH. The outcome of psychological wellbeing will be determined by being able to appease perceived social pulls while limiting the costs and consequences of doing so.

Along with employer preferences, policies and perceived views (Beck & Hensher, 2021a; Greaves et al., 2022; Green et al., 2020), the development of trust and perception of autonomy has also been associated with performance and satisfaction in remote workers (Gajendran & Harrison, 2007; Kröll et al., 2017). A model of the connections between level of telework practice, social networks and performance (including promotability) is offered by Arling (2004) (Figure 3.7), a matter also connected to wellbeing (Beck & Hensher, 2021a; Jain et al., 2022).

Figure 3.7 The relationship between WFH, social networks and performance (reprinted from Arling, 2004, p. 4)

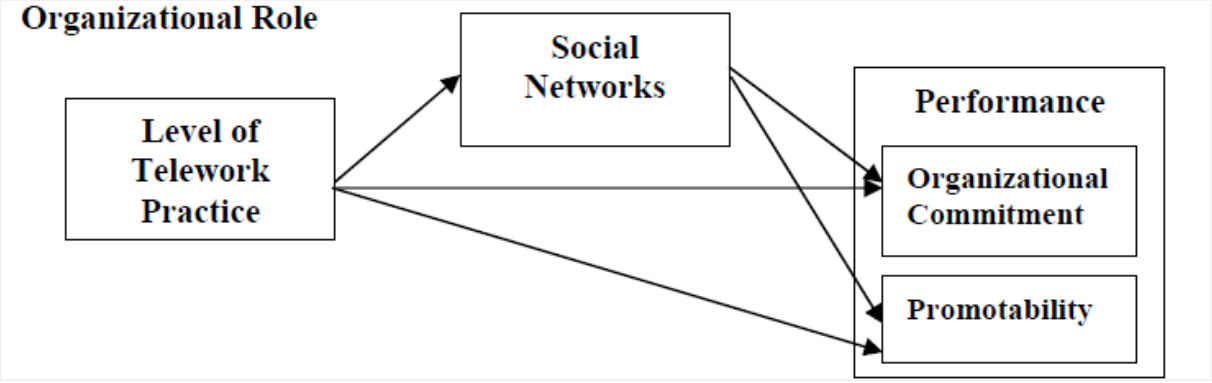


Figure 3.7 highlights performance as defined by organisational commitment (commitment to one's peers and cohort) and promotability (ability to add to the common cause of the cohort). Arling (2004) uses this as the basis for a model to understand the roles of WFH and social networks for career prospects. Arling found that those who WFH are more likely to be out of the loop, less likely to span structural holes in an organisation and therefore less promotable. Knowledge is power, and Arling's study considered that regular WFH depleted certain elements of knowledge and connectivity with colleagues. However, this model was developed in 2004, and while some of the conclusions may still hold, social norms are likely to have changed within this time. It is possible that some of the stigma attached to WFH has lessened over time, particularly since the pandemic when WFH became more normalised for several industries.

Beck and Hensher (2021a) describe some of the outcomes of WFH that contribute to wellbeing. These principally include ability to manage working time such as to realise the benefits of saved travel time and take advantage of latent investments and employer investment in WFH set-ups. Job satisfaction was a significant variable although likely correlated with social and productivity outcomes. A long-run outcome of lack of job satisfaction would be expected to be changing role, although this may be beyond reasonable scope. Therefore, a model would consider short-term behaviour trends. Further, the implications of changing jobs would suggest that job satisfaction can be derived from the market and therefore tends to be self-correcting.

3.2.6 WFH physical environment

The physical home environment was comprehensively studied by Mayer and Boston (2022) and found to be of significance alongside transportation and employment characteristics. The paper focused on determining preference and outcomes associated with WFH through analysis of survey data on preference and ability to

WFH. The physical environment characteristics investigated included the availability, size and comfort of a home office during the pandemic 'lockdown' policy.

The respondents were grouped three ways:

- **Group 1:** Preference to WFH full-time (n=157).
- **Group 2:** Preference to WFH part-time (n=499).
- **Group 3:** Preference to return full-time to the commercial workplace (n=138).

Of the respondents in Group 1 who wanted to WFH full-time, 38.2% had access to an existing office compared to 26.9% in Group 2 who preferred to WFH part-time and 12.3% in Group 3 who did not want to WFH.

Other spaces in houses (such as bedrooms, lounges and dining areas) were used by 76% of respondents in Group 3 compared to 48.4% in Group 1 and 53.4% in Group 2. However, these alternative locations were not necessarily suitable for working, with limitations noted by respondents such as a lack of ergonomic furniture, privacy and poorly integrated multifunctional areas. The importance of dedicated fit-for-purpose workspaces was important with 64.5% of respondents from Group 3 saying it made WFH more positive or desirable. Those who preferred WFH compared to those who preferred working in an office tended to:

- have a quieter work environment at home
- have an office space prior to COVID-19
- have a space that was well maintained and neat and clean.

Those who preferred not to WFH full-time tended to:

- work in a bedroom or dining area during lockdown
- work in extremely hot or cold temperatures
- not have enough space to complete work comfortably
- have a more dirty, messy, disorganised and noisy environment.

Mayer and Boston (2022) reported the WFH environment as highly statistically significant ($p = 0.000$), supporting the inclusion of the WFH environment as an explanatory variable and prioritising it for subsequent inclusion in the model framework. However, this was based on environmental outcomes around comfort. Attempts to explain the comfort in terms of building design (double glazing, air conditioning, air flows and so on) did not return a significant outcome ($p = 0.581$). This is likely due to the complexities of capturing the design causes of comfort outcomes – for example, not all homes with single glazing would be cold. While not as comprehensively examined, Baruch and Yuen (2000) also identified lack of space at home as a pitfall of WFH.

Most of the design characteristics of the home office such as space, warmth and cleanliness could be boiled down to a variable representing comfort. Given the demonstrated significance of the home environment, it may be tempting to consider modelling them in detail. However, to attempt to include all home environmental characteristics would likely not succeed and would likely generate a poor return on the costs for gathering this data. There are too many different variables that would interact in too many ways to be realistically included. However, the concept of comfort appears to be the underlying factor in considering the quality of the WFH space. Measuring comfort for purposes of modelling is not straightforward given that it is subjective. However, a method of synthetic valuation (known as contingency valuation) could be deployed against a range of relatable, hypothetical home office set-ups. This matter would need to be managed for simulating future years where increasing redevelopment of housing stock would likely include better WFH conditions, and it would need to reflect evolving comfort levels.

Of interest, the Royal Institute of British Architects (RIBA) published an article considering how home design requirements have changed since the pandemic and the increase in WFH practices that have followed (Smit, 2022). RIBA has been long advocating for the so-called live-work model of design but reports difficulties in its implementation. Smit cites a survey suggesting that 50% of respondents considered their home as practical for WFH purposes, with 70% desiring a suitable WFH space. Another key finding is that 'one size does not fit all', suggesting a subjectivity in perceiving quality of home environment, which may suggest that WFH environment as a variable interacts with industry type.

3.2.7 Communication, collaboration and colleague influence

A common theme or outcome of research is the impact of WFH on communication and collaboration.

Workplace culture refers to accepted norms and practices communicated between colleagues through informal interactions. It can be associated with productivity and development – for example, providing 'soft learning' opportunities for junior staff.

Cultural decay is suggested to increase through introduction of remote working and an associated decrease in social interaction and affiliation. This is an outcome closely related to wellbeing and performance. Consequently, businesses may limit WFH practices or specify compulsory office days such as Apple's recently announced changes (Miller, 2021).

Beck and Hensher (2021a) considered the role of social capital in the workplace and the role of connectedness with perceived performance outcomes and prospects. They suggest that a mix of WFH and in-office working styles or use of innovative solutions to foster connectedness are an important consideration for businesses in order to foster those friendships and community associated with productivity and wellbeing.

Jain et al.'s (2022) study comparing those who did and did not WFH considered from a behavioural perspective that the ease of WFH was the driving determinant of those already WFH doing so more. Another leading factor explaining the practice of WFH was the decision making of colleagues. Clearly, the role of work culture was prevalent in the outcomes of Jain et al. – a circumstance that would be difficult to model as a discrete entity.

3.3 Transport and accessibility

3.3.1 Trip characteristics

Mayer & Boston (2022) considered the statistical significance of several choice attributes, including transportation, employment characteristics and home working environment quality towards WFH outcomes. Travel to work journey time, distance and the type of transportation were all found to be of significance.

The variables of transportation are considered significant to a high confidence interval as:

- mode of transport ($p = 0.000$)
- travel distance ($p = 0.001$)
- travel time ($p = 0.015$).

All are well within the criteria 95% confidence interval, suggesting a relationship between the independent variable (mode) and the dependent variable (WFH outcome). The role of travel distances and times in influencing travel decision making is well established in planning and modelling, and WFH decision making has added a new dimension.

During interviews, Mayer and Boston (2022) received specific feedback that the effect of the lockdown revealed how 'unnecessary a lot of travel is' (p. 6) and that WFH was a perceived solution to negative

aspects of commuting. The paper considered to an extent that, for much of society, physical commuting to work is unpleasant.

Figure 3.5 offers a demonstration of how travel distances could increase for those who WFH, albeit incurring a less-frequent commute:

> *Commute distances and internet access significantly increase the probability of home working, suggesting that long commute distances stimulate an individual to work from home and ICT connectivity delivers the technical platform for the realisation of teleworking.* (Fu et al., 2012, p. 6)

Historical treatment of travel variables has focused on the loss of productive time. However, there is increased awareness in the field relating to the role of reliability. Users may be willing to tolerate delays if they are planned. Lyons (2008) analysed the use of time by passengers on a train, incorporating a range of activities such as working, reading and even taking time to reflect/transition between life roles. A key outcome of this paper was that, for many, journey time was not wasted. Since 2008, with the widespread roll-out of 4G, travel time can be spent socialising via digital channels and completing other tasks.

In Victoria, the rates of 18–30-year-olds learning to drive declined sharply between 2002 and 2012 (Charting Transport, 2015) with a sharper decrease in the younger groups. Potential factors associated with this were increased take-up of public transport, with a strong relationship ($r^2 = 0.936$) between mass transit mode share and proportion of 18–29-year-olds with a driver licence. Considering this research in conjunction with Lyons (2008), the interaction of public transport use and digital connectivity seems likely.

How we invest in the transport system could directly impact WFH rates. New Zealand is the most car-dependent nation in the OECD (DIA, 2023). However, with the possibility of mass rapid transit in Christchurch and Wellington and enhanced mass rapid transit networks in Auckland, the increased availability of mode choice would be expected to influence the transport market and justify increased policy intervention in the market (see section 7.2.3). These projects are included in the National Land Transport Plan and regional plans, which are translated into current transport model future years.

The supply of major infrastructure has historically impacted on demand characteristics, including mode choice – 'build it and they will come' (better known as latent demand). An increase in WFH could result in a reduction in physical travel, particularly public transport (Waka Kotahi NZ Transport Agency, 2022a). Understanding the complex relationship between how WFH could impact on transport demand elasticities requires integration of a sophisticated choice framework inside a strategic transport modelling suite that contains all stages of modelling beyond just choice.

3.3.2 Car usage and ownership

Mayer and Boston (2022) attempted to make sense of the significance of the transportation type and WFH ($p < 0.001$). They drew parallels between respondents' statements and broader datasets. Group 1 (those preferring full-time WFH) were the group least likely to drive and would prefer WFH over the use of alternative transport modes. The researchers attributed this to the lack of availability of non-car transport for a variety of reasons sought from literature. There was also a plausible correlation between travel habits, WFH and a conscientious decision to monitor carbon footprint. However, the strength of this relationship was not quantified in their report.

Habib and Anik (2021) used scenarios to study the long-term impacts of COVID-19 on transport and land-use systems using an agent-based microsimulation model developed for Nova Scotia, Canada. The scenarios considered households' long-term choices around residential location, mobility tool ownership (such as vehicles or bikes) and mode type and choices. The two scenarios used agent-based modelling to

simulate these choices with and without the COVID-19 pandemic up to 2030 within an integrated transport, land-use and energy (iTLE) model.

Were COVID-19 conditions to have prevailed, the modelled results forecast:

- continued restraints on car ownership for those without a car
- increased rates for car sales amongst higher-income households
- an increase in the use of SUVs by 25% by 2025 and 27% by 2030 compared to the year 2020
- the level of change in vehicle ownership could vary substantially between areas depending on whether they are downtown, more or less wealthy suburban areas or rural areas
- that households may choose to live further away from downtown with the increased ability to WFH and educate from home.

Habib and Anik's (2021) study provides useful insights to transport and land-use planners on how behaviours and long-term decision making by households may be changing and evolving in response to the COVID-19 crisis.

The relationship between the probability of car travel and residential location is one that strategic models could potentially predict but also influence as a tool used to support land-use planning decisions. Car use is a likely derivative of car ownership – the significant sunk cost in owning a car is a known leading cause of car use. However, a leading global academic on the subject of parking points out that, for 95% of the time, cars are parked (Shoup, 1997). Mobility as a service or car share schemes appear to be more efficient. With an increasing global shift towards more expensive electric vehicles encouraged by subsidies (including in New Zealand) and legislation (such as banning the sale of petrol cars by 2040 in New Zealand) and market indicators that EVs may remain expensive by merit of the scarcity of materials, the continued high ownership of cars may not persist.

Therefore, access to car travel in the future is likely to include alternatives to ownership. A model should consider differentiating between car ownership and access to cars via other means. These would likely need to be specified as different mode alternatives. Put simply, more alternatives would be harder and more costly to forecast. Alternatives to forecasting would include simulation or scenario planning.

In selecting a model framework to represent WFH, trade-offs will likely need to be made between the extent and number of variables included and the extent of choice probability forecasting included.

Research into the effects of COVID-19 on the transport system included an analysis into changing behaviour by mode of transport and by day travelled (Waka Kotahi NZ Transport Agency, 2022a). The results for those travelling by car and public transport were different. While the weekday WFH choice outcomes for those who normally drove fluctuated by around 2%, the fluctuation involving public transport was much greater at around 17%. These findings are statistically significant and support Mayer and Boston's (2022) conclusion that mode is significant.

The implications suggest that public transport users are more likely to WFH than car drivers, a finding with particular significance placed in the context of policy objectives (the extent to which WFH could impact upon VKT by car outcomes). An outcome of the tool informed by this research would be to inform such outcomes.

One interpretation of this is linked to the Australian Productivity Commission (2021) suggestion that physical commuting is unpleasant. On this basis, users would seek to make choices to minimise their pain. Historically, public transport has been associated with offering lower utility (based on cost and time considerations). Public transport trips are often costlier compared to driving in terms of waiting time, access time and transfer penalties (a cost associated with having to interchange such as changing buses).

An alternative perspective is the relationship between physical location of roles more suited to WFH likely to be clustered in central business districts (CBDs) and residential location choices of employees towards ease

of access to CBDs (close to radial routes) that would also be served by public transport. This circumstance may also change with time if increasing WFH practices decrease the overall need for physical proximity.

Another aspect of public transport use is the ability to potentially combine physical commuting and working – for example, managing emails on a smartphone. The interaction of public transport use and ability to work might also be explored, although this may be challenging. Lyons' (2008) work did suggest a multitude of types of onboard travel behaviour, including many forms of productivity not associated with paid work.

Considering the variation associated with day of the week would raise challenges as most models generally simulate a discrete time period within a given day. Activity-based modelling (ABM) considers a whole day, but there are no identified methods in New Zealand that consider multiple days. Modelling a single day would provide limited insight into the alternative mode that has been deselected in order to WFH.

An alternative approach to considering the substitution effect that WFH would have on transport by a given mode would be to examine the second most probable in situations where WFH would be predicted the most probable. Mode choice models often consider and apply only the most probable mode calculated from logistic modelling. However, the probabilities of the alternatives (modes not selected) could also be interpreted. This means that, for trips that are predicted to select WFH, the model could be further interrogated to find out if public transport was found to be the next most likely option.

3.3.3 Reliability of digital access

Beck and Hensher (2021a) noted the role of COVID-19 in investing in WFH practices, including the rise of digital platforms such as Microsoft Teams. Asgari (2015) considered the important role of technology on successful WFH outcomes before Microsoft Teams and similar products were widespread in New Zealand. During lockdowns, these platforms provided exclusive social connectivity with varying degrees of impact on wellbeing. They conclude that reliability and speed of internet connection is pivotal to the success of WFH.

Aspects of access to digital connectivity (such as access to broadband, speed, reliability and market competition) could prove to be significant variables in a model aimed at explaining WFH decision making, and this could also enable a broader outcome of considering digital and physical mobility together in a single modelling framework.

Digital access is a complex market with differing levels of coverage and cost (Lyons, 2014). Reddick et al. (2020) undertook a study in Bexar County, Texas (which includes the city of San Antonio), developing five hypotheses of predictors of access to broadband. In summary, these were themed around the potential roles of:

- income disparities within the city
- level of competition
- profit-based discrimination of (market-led) supply
- costs of deployment
- socio-economic disparities within marginalised groups.

The study drew useful conclusions – the role of price/affordability was not found to be conclusive potentially due to the providers targeting areas where affordability is not an issue. The study also found gender disparity as more men used the internet to improve their income. This outcome might not translate into post-COVID-19 Australasia since the Australian Productivity Commission report (2021) found that women were more likely to WFH than men (see section 3.4.2.1). Reddick et al. (2020) did conclude a significant relationship between broadband access and income disparity within marginalised groups, which may be attributed to profit-led discrimination of coverage. In New Zealand, the Telecommunications Development Levy exists to subsidise providing broadband access to areas associated with higher deployment costs.

Reddick et al. (2020) reference Lyons (2014) in indicating the main drivers of the supply and demand for broadband. For demand, it was price, reliability and quality of service, whereas for supply, it was population density, degree of competition and current deployment within the market. The role of market competition was also a consideration but not supported as a determinant of demand, although this was due to an effective duopoly despite there being at least four known providers. New Zealand has 17 providers, although it is not clear as to how widespread they operate.

Figure 3.8 shows the broadband coverage of Auckland and its surrounding regions. The core urban areas are covered by broadband, but many regional towns are covered only by ADSL or other less-reliable mediums. The New Zealand Commerce Commission (2022) offers a package comparison summary, effectively showing that ADSL, VDSL and fixed wireless tend to be slower, less reliable/prone to dropout and potentially more expensive than fibre. Figure 3.8 does tend to demonstrate the relationship between population density and broadband (referred to here as fibre). It should be noted that New Zealand enjoys more reliable digital connectivity than Australia and the US (nations from where many of the research papers are sourced).

Figure 3.8 Network coverage by medium, Waikato, Auckland and Northland

Source: https://broadbandmap.nz/availability/

The implications of these findings clearly place limitations on house market responsiveness to WFH, with better connectivity currently available within the urban areas. This would place a limit on the extent of near-term WFH possibilities in rural areas and smaller towns, although this will likely change over time as investment in digital technology becomes more geographically widespread and the performance and capabilities of technologies enable a higher standard of service across a wider area.

Variables representing both digital connectivity and access would need to represent varying degrees of reliability and speed. Perception among users would be varied, allowing the possibility of surveying speed and connectivity performance, using a scaled approach potentially suitable for modelling. However, there are three cautionary aspects to doing this:

- Employer policies on WFH would be expected to cover the ability to access satisfactory digital connectivity – it would unlikely be a free market decision left to employees.
- This raises a risk of collinearity – the nature of digital connectivity being simultaneously correlated with employment policy and WFH outcomes – a confounded, collinear outcome.
- Ortúzar and Willumsen (2011) warn of the tendency of some econometric methods to an 'all or nothing' (more extreme) outcome. Given that digital connectivity tends towards the speed of light while physical commuting does not, the extreme difference in access speed would skew the model significantly, especially if the variable representing digital connectivity was modelled to have a more significant relationship with the outcome of WFH. In this sense, the model could exaggerate the probability of selecting WFH as mode choice.

Assuming it were found to be a significant variable, there may be interpretation challenges:

- There may be perceived issues based on varying expectations in the population, possibly influenced by demographic circumstances.
- The variance of WFH outcomes would possibly increase with internet performance, simply reflecting an increase in available choice. Less choice would be associated with lower speeds due to constraints based on productivity and employer policy. The outcome of escalating variance is heteroskedastic and requires specific model methods to overcome.

However, one of the potential future outcomes for the field of planning transportation infrastructure would be the accounting of digital accessibility as a leading option to resolving challenges associated with mass physical transit in its current form, including escalating emissions and public health and safety impacts (Lyons & Davidson, 2016). Digital accessibility relies on digital connectivity. Lyons and Davidson offer the analogy of accessibility as a vehicle and connectivity as a highway. The notion of converging the analysis and planning for physical access, land use and digital connectivity is called triple access planning and is offered as an alternative paradigm to transport planning, which focuses mostly on physical access. The quality of digital connectivity (predominantly perceived as speed) would clearly have a role to play in this converged planning mechanism. It has been considered by Lyons and Davidson in terms of a concept uncertainty management framework, with social preference to digital or physical connectivity framed as a deterministic factor in conjunction with the price of energy and generating four scenarios (see section 7.2.3).

Therefore, the role of digital accessibility is essential to WFH, with higher speed options likely generating more possibility for choice. However, there are some foreseeable challenges to including this in a forecast. For this reason and also for other variables presenting similar challenges, a wider range of modelling and analysis methods will need to be considered.

3.3.4 Quality of access to the transport system

Commuting can impose substantial costs on workers, valued in Australia as the equivalent of $49 lost per day if travelling by car or $57 lost per day if travelling via public transport (Productivity Commission, 2021).

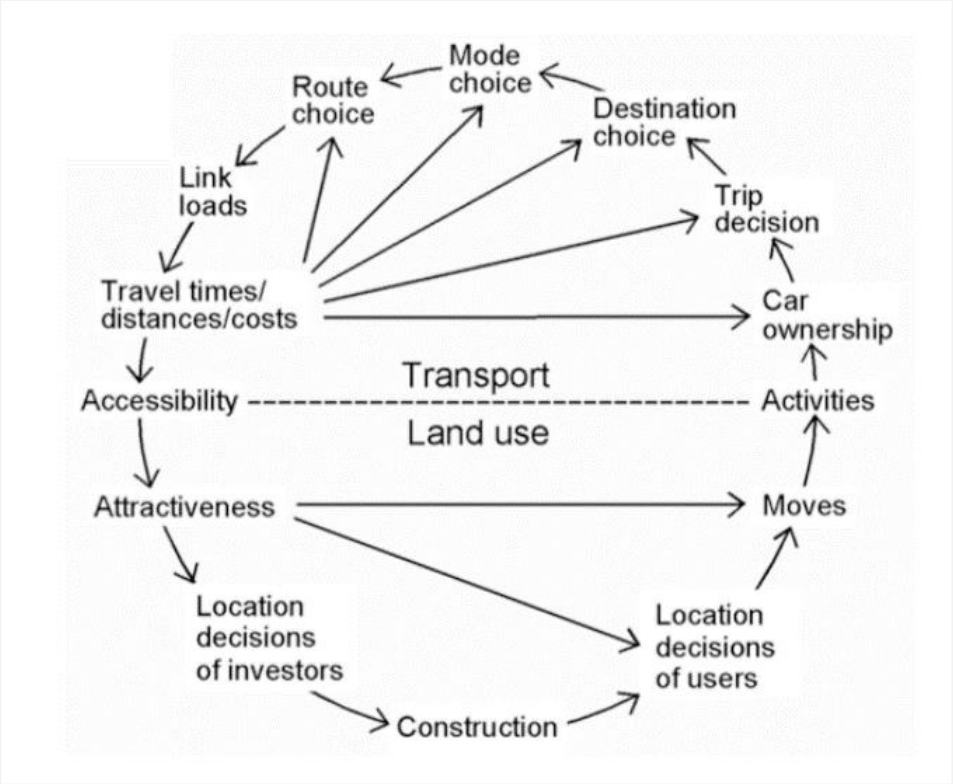
This aspect is already included in models as a determinant of choice between transport alternatives calibrated through such measures as transfer penalties. The perception of delay is also built into the aggregated generalised cost – a form of rationalising travel behaviours into a single value (measured as time), which is used extensively to predict demand elasticities between mode alternatives.

However, the generalised cost function could probably not incorporate many of the variables included in this paper, which are highly varied in terms of where, when and how they impact upon user decision making. Many generalised cost elements are considered at the point of use, whereas decision making generally is more complex than this. These complexities apply to both WFH and commuted trip types. However, where generalised cost exists as a proxy to simplify trip making (developed before the existence of digital alternatives), there is no obvious proxy for WFH. If decision making were purely down to cost, no one would choose to commute. Therefore, a model method simply cannot define choice by cost alone if it is to reflect WFH decision making. This will require a more complex approach that can process the different types of variables together and in an appropriate sequence that reflects processes around how decisions are taken. This will likely involve developing a hierarchical method.

Solutions to resolving access are often not transport based. The direction of high-density developments next to transit stations is an effective method where the necessary planning powers to achieve this outcome exist. New Zealand would have comparably limited experience in this field, although there are examples of enabling development through the management of travel behaviour such as the Wynyard Quarter in Auckland. The existing National Policy Statement on Urban Development directs Tier 1–3 planning authorities to permit increasing densities, which could have an eventual outcome of containing urban sprawl and increasing the market size available to public transport providers.

The relationship between land use and transport is shown in Figure 3.6, which offers some insights into market characteristics and responsiveness in changes between one and the other.

Figure 3.6 Land use/transport feedback cycle (reprinted from Moeckel, 2017, p. 209)



Active travel and perceived safety are also potentially significant. Standard practice in transportation planning considers the benefits of resolving barriers to active travel such as perceived safety and actual safety. This outcome is reflected by Greaves et al. (2022), who predicted an outcome whereby active mode demand could increase following an increase of WFH. However, the likelihood of this would be very location specific.

Several matters governing future access to the transport system are achievable through policy intervention and may therefore be considered uncertain. Transportation variables were the most statistically significant variables in Mayer and Boston (2022) – this variable would lend itself to either traditional forecasting methods or scenario-based planning to achieve varying degrees of confidence.

3.4 Social and demographic

3.4.1 Psycho-social determinants

Jain et al. (2022) examined the long-term impacts of COVID-19 on WFH and the psycho-social factors that impacted workers' intention to increase WFH post-COVID-19. This research is another significant piece capturing the role of perception and derived thought processes, which adds another dimension to understanding where some of the variables fit into the process of decision making and insight into relationships between those variables.

The research engages a quasi-longitudinal (repeated collection of time series data) study (n=1,364) sampling self-reported WFH participants in Melbourne. Structural equation modelling was applied to the theory of planned behaviour (the assumption that the participants are rational decision makers) to understand motivators for and barriers to increasing WFH post-COVID-19. Structural equation modelling is a method of rating the significance of multiple variables, including a mix of observed variables (such as personal income) and latent variables (such as outcomes-based or time saved variables).

The theory of planned behaviour was developed from the hypothesis that 'socio-demographic factors alone cannot predict the intention of working from home and that the inclusion of attitudinal variables have improved the explanatory power of such models' (Jain et al., 2022, p. 54).

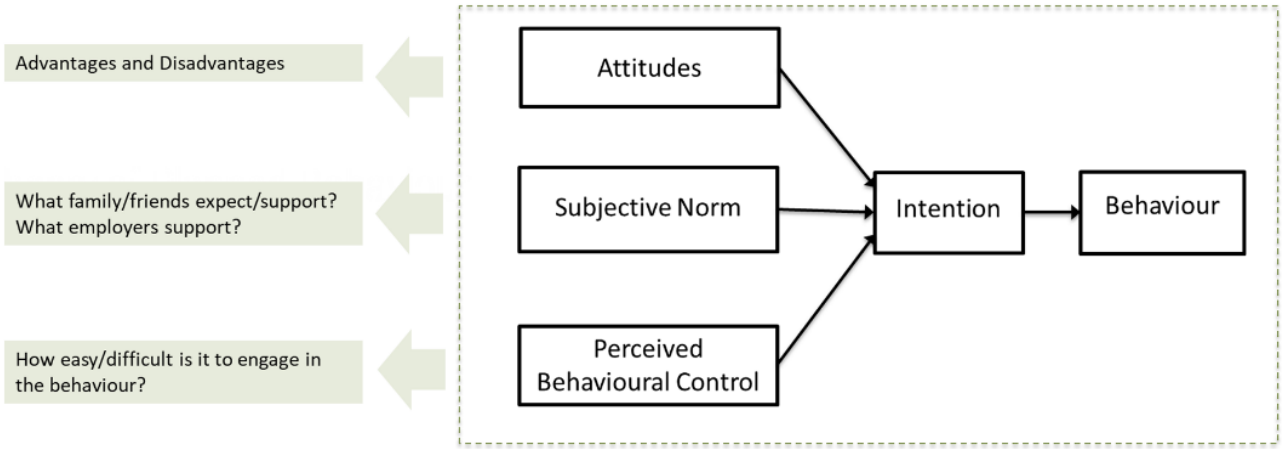
The Oxford English Dictionary describes attitudes as the way in which a person views and evaluates something or someone. Attitudes determine whether people like or dislike things and therefore how they behave towards them. Attitudes are built on experiences. Common attitudes to transport might be intolerance to lateness (such as delayed public transport). Attitudes to WFH are varied, for example, its ability to substitute for time 'in the seat' (see section 3.2.2). These different attitudes will need careful consideration in both the specification of the method and the inputs. Options of compensating for different attitudes will have trade-offs, which will be explored in the process of selecting a methodology.

A transport model really only engages with the perceived behavioural control – the forecasting of travel elasticities as a derivative of changes to generalised cost, all of which play out in the transport system. In the case of WFH, the access system, borrowing Lyons and Davidson's (2016) triple access framework, is rooted within the home, potentially at the breakfast table.

Method development might also consider the thought processes behind how decisions are made. In the context of planned behaviour theory, these can be ordered and hierarchical – traits that some methods adopt in overcoming critical differences between the nature of certain independent variables where all are required to define a dependent variable. It would also be possible for the model to emulate staged decision making through the processing of variables in tiers known as a hierarchical approach.

Planned behaviour considers three thought stages – attitudes, subjective norms and perceived behavioural control, as shown in Figure 3.7.

Figure 3.7 Theory of planned behaviour (reprinted from Jain et al., 2022, p. 55)



Examples of latent variables that might relate to Figure 3.7 from a transport modelling/WFH perspective might include those specified in Table 3.3. Different aspects of navigation in the transport system would fall into the different categories, with variance depending on variables such as age or gender. Perceived threats to personal safety would impact some groups more than others as perceived behavioural control. Of interest is the view that perceived behavioural control, as a predictor, is 'perhaps even more than the other predictors [attitudes and subjective norms] also strongly related to the use of public transport' (Hauslbauer et al., 2022, p. 2).

Table 3.3 Examples of variables from planned behaviour theory

Latent variables	Observed variables
Attitudes	Journey time outcomes (including delays)
	Cost of trip (ticket, parking)
Subjective norms	Expectations of family
	Expectations of colleagues
Perceived behavioural control	Quality of home working environment
	Access to public transport or ease of parking
Intention	Informed by prior latent variables

Jain et al. (2022) developed a method to explore the relative intentions to WFH post-COVID-19 between two groups – one with pre-COVID-19 experience of WFH and one without. The relationship shown between variables (Figure 3.7) formed the basis of a null hypothesis.

Jain et al. developed a method in structural equation modelling, offering the ability to statistically test the strength of relationships between observed variables and latent variables but also simultaneously between the latent variables themselves. This took the form of structural equation modelling, the structure and relationship illustrated in Figure 3.8, which shows the strength of relationships between observed variables and latent variables and the relationships between latent variables. Information about the observed variables themselves was derived from seven-point Likert scale surveys, which were then assembled in terms of rank order of responses. It was the relationship between the rank orders that was analysed, modelled using least squares. The values shown in Figure 3.8 relate to the predicted 'goodness of fit' between the variables.

Figure 3.8 Structural equation model describing relationships between variables for those who mostly WFH (reprinted from Jain et al., 2022, p. 62)

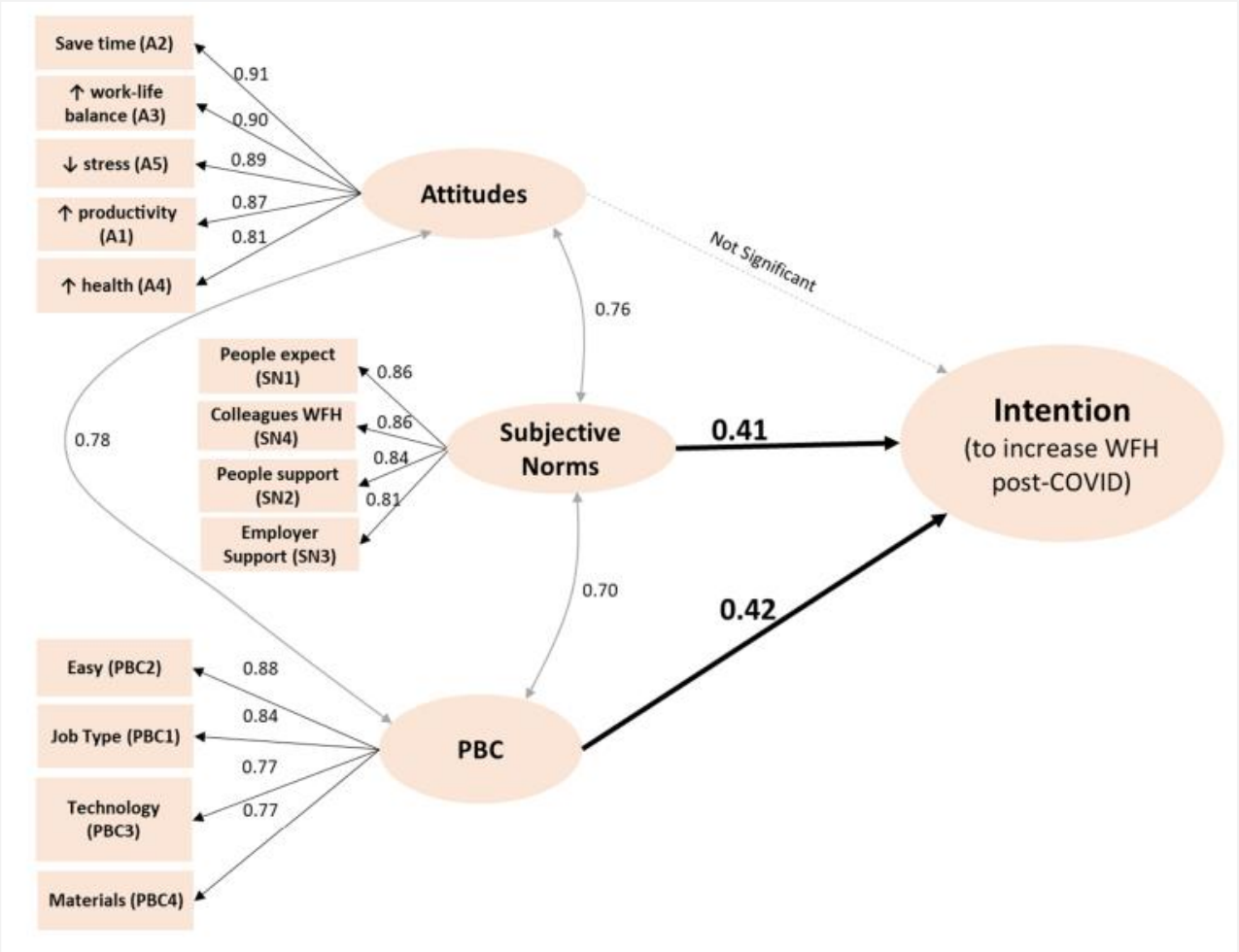


Figure 3.8 shows the strength of the rank order of the variables, therefore capturing outliers and managing the challenge of applying such a broad array of variables. Challenges would include, for example, the inability to fit some of the variables in terms of statistical distribution, which choice modelling normally uses through a method known as maximum likelihood to guide the development of model parameters. The use of rank correlation does overcome this, setting out all variables onto a common scale. The use of least squares also provides an effective means of interpretation. It is immediately obvious from Figure 3.8 that the scores approaching values of 1.0 are indicative of strong relationships.

This method assists the understanding of behaviours that can be carried forward into creating a model to predict WFH outcomes and presents some ideas as to how to manage different (heterogeneous) variables.

Jain et al. (2022) developed models comparing the two groups (one with pre-COVID-19 experience of WFH and one without) in terms of understanding potential behavioural responses of each to the latent outcome of choosing to increase WFH post-COVID-19.

For the group with previous WFH experience, the role of attitudes (which included saving time) was not found to hold a significant relationship with the final outcome of income. However, it was found to describe intention where it interacted with subjective norms and perceived behavioural control, thus having indirect positive influence. The observed variables describing attitudes displayed the strongest relationships of all the observed variables (for example, ‘save time’ was the highest at 0.91). The strength of relationships describing intent was similar between perceived behavioural control and subjective norms.

> *[G]iven attitude's strong positive covariance with subjective norms and PBC, it did have a positive indirect effect on intention. Perhaps, this indicates that for people with no pre-COVID experience of WFH, an attitude which sees WFH as advantageous cannot alone influence intention to increase WFH, unless WFH is perceived as a viable option (e.g. job type), easy, and supported by one's family and workplace.* (Jain et al., 2022, pp. 61–63)

For the other groups without prior WFH experience, the role of attitudes towards intention was actually slightly negative (-0.09), and the role of perceived behavioural control was much stronger. This observed relative strength of perceived behavioural control for both groups was synonymous with Hauslbauer et al. (2022), who suggested perceived behavioural control as having potentially the strongest influence, particularly with regard to decisions involving public transport.

The role of planned behaviour theory is important. It could potentially inform a staged approach to modelling that makes use of a similar methodology to accept or reject variables, then including them in a later stage model where these variables can be weighted in order to predict specific travel outcomes.

The models used to develop planned behaviour theory reveal much that is useful to this research:

- The role of structural equation modelling to simultaneously manage interaction between latent and observed variables and latent variables with each other.
- The prevalence and importance of indirect effects.
- A basis for grouping variables in a choice sequence and some indications as to which variables might be included.

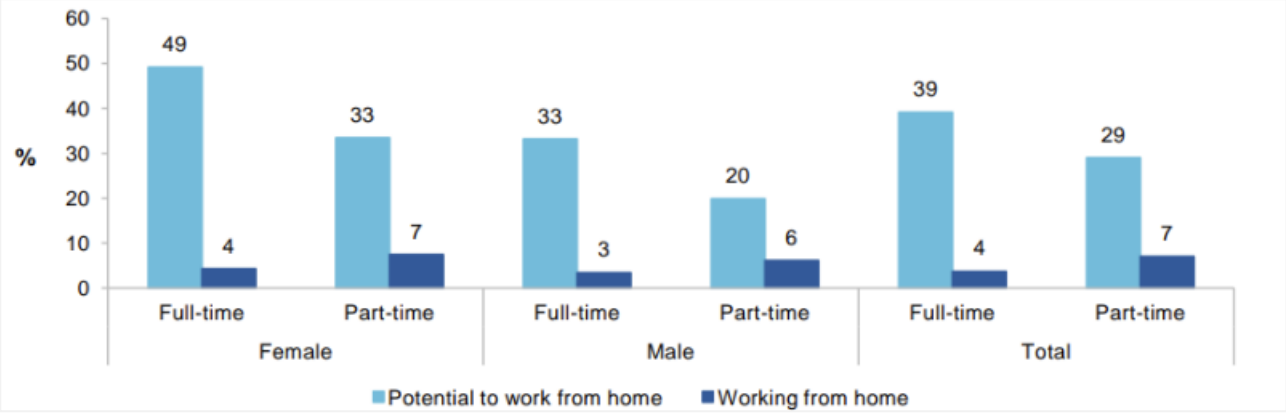
3.4.2 Demographics

3.4.2.1 Gender

There are mixed results in terms of the role of age and gender and how these variables influence the prevalence of WFH. Mayer and Boston (2022) in their working with three groups (preferring to WFH full-time, part-time and not at all) considered the role of gender, location and age between the groups, all of which were not significant for WFH. A notable sample bias is the gender composition of approximately two-thirds female. A pre-COVID-19 study by Shabanpour et al. (2018) concluded that 13% of males telecommute a few times a year compared to 10% of women. Similarly, Fu et al. (2012) found a split in favour of men (57%) who telecommute – again, a pre-COVID-19 finding.

The Australian Productivity Commission (2021) estimated that females are more likely to WFH (Figure 3.9).

Figure 3.9 WFH outcomes (Australian census) based on gender and hours worked (reprinted from Productivity Commission, 2021, p. 36)



Gender is a complex area, and gender bias was reported by the Australian Productivity Commission (2021). Women, typically mothers, were more likely to experience discrimination associated with home-based working (Chung, 2020). This prospect of discrimination would be a powerful influence in decision making considering the research by Jain et al. (2022), which demonstrates the influence of perceived views of society in decision making (see section 3.4.1).

Gender by itself is a broad concept. Subgroups (such as primary caregivers or specific ethnic backgrounds) could be considered in more detail to improve the extent to which a model could approach the subject of equity. In spite of ongoing efforts to close the gender gap, there are still different life roles, especially in the interaction of family and children, although these are complex and not always negative. A study by Bernhardt et al. (2023) considered an overall effect of combining parenting and WFH as a net 'resource gain', although mostly experienced by mothers and suggested that the prevalence of gender role stereotypes continues to be 'salient, even among young people' (p. 941).

Possible explanatory factors of why men WFH less than women could include employment type. The majority of workers in so-called manual occupations are men – roles that cannot be WFH. The COVID-19 pandemic may have changed the social landscape in ways that the two World Wars did, for example. The aftermath of World War II included some significant societal changes, including establishment of a five-day, 40-hour working week in Australia and establishment of the welfare state in the UK.

The COVID-19 pandemic has been discussed publicly in this specific context in a *Sydney Morning Herald* piece and video examining possible changes to modern working conditions, including the prospect of a four-day working week (Thompson, 2023). The matter of gender equality continues to be relevant, as described by the Ministry for Women (2023), and equal opportunities – including the ability to access flexible working arrangements – are likely to continue to improve. An increase of women in leadership may also result in a change to leadership style, which could impact upon corporate policies on flexible working practices with cross-societal impacts.

The present day suggests a shift towards more women WFH compared to previous times. However, some groups of women such as primary caregivers and certain ethnic groups may find it less easy to do so. In terms of considering the future, there have been latent advances in social progress. Gender equality is rapidly changing – for example, in 2000, data provided by the US International Telework Association and Council indicated that 57% of teleworkers were male (Nilles, 2000) compared to present day where women who WFH outnumber men (Sasso & Bloomberg, 2023), with similar findings to the Australian Productivity Commission (2021) report (see Figure 3.9).

If latent trends, including social progress, are extrapolated, a future prediction might find that:

- disadvantages currently affecting some groups would be improved upon to some extent
- women would be more likely to WFH
- senior leadership will be more gender balanced with possible implications for decisions (such as corporate working policies).

3.4.2.2 Age

The evidence for age being a significant factor for WFH was inconsistent. Mayer and Boston (2022) reported that age was not a determinant of aspirations to WFH ($p = 0.767$). A key consideration is that the survey asks respondents to state their preferences, while the ability to execute preference is more closely correlated with accommodating employer policies (see section 3.2.2).

Shabanpour et al. (2018) considered telecommuting practices by age and found that 35–55-year-olds were more likely to telecommute. However, there was limited explanation or accounting for this in their paper. It might be speculated that with age comes greater experience and value to employers, which generates ability

to negotiate working conditions and be considered more trustworthy than a younger counterpart. Fu et al. (2012) found that increasing age was associated with a greater likelihood of WFH – a finding that was consistent with the international literature. They observed that people at the age of 42 were most likely to WFH. Jain et al. (2022) considered age and gender in the psycho-social focus on WFH decision making (see section 3.4.1). An interesting conclusion was rejection of a potential hypothesis relating age to ability to use technology, finding a weak negative association between age and intention. The Australian Productivity Commission (2021) suggested that those more likely to WFH would be part-time, generally older than those who do not WFH and more likely to be caring for dependants.

In conclusion, most studies are indicating that those middle aged or older are more likely to WFH. Most models already include the variable of age in synthesising population data. Under such a model, WFH may be a useful means of increasing access to and retention of an older workforce.

3.4.2.3 Income

In a US-based study, Shabanpour et al. (2018) found that workers with higher incomes and those in communications and service industries WFH more often than others. They compared WFH outcomes by income by comparing higher earners (NZ$82,000–164,000 per year) with lower earners (less than NZ$82,000 per year). They concluded that, of the former group, 11% would telecommute at least a few times per year compared to 3% in the latter.

Mayer and Boston (2022) found similar results post-COVID-19 where respondents who wanted to WFH part-time tended to have higher incomes, with 58% earning more than NZ$70,001 per year. The role of income in describing WFH decision making was found to be significant at the 95th percentile confidence interval ($p = 0.035$). Furthermore, Mayer and Boston (2022) found that 55% of respondents who wanted to WFH full-time and 49.6% of respondents who would prefer not to WFH were earning above this threshold. This may have been because a higher income meant respondents could afford larger or better-quality houses or were able to afford better equipment to support WFH.

Although there appears to be a strong relationship between income and WFH outcomes, a variable may only be used in (most types of) models if it is independent. This means that it has a relationship with the dependent variable but not with other independent variables. Income is a variable that could be collinear with, say, employment type or education level. If these variables are all significant and collinear, decisions would need to be made in framing as to which variables would be omitted or how they might be grouped in discrete stages.

3.4.2.4 Family and social influence

Many workers face work-life balance concerns that are tied in with non-paid labour in the home and constraints on available space suitable for ongoing WFH (Beck & Hensher, 2021a). The Australian Productivity Commission (2021) suggests that workers who are part-time, older or caring for dependants were more likely to WFH.

There are differences in literature outcomes with regards to the role of family – particularly children. Chung (2020) reports on stigma attached to women as caregivers in the workplace. The role of family on the career prospects of women has long been understood. Asgari (2015) considers the range of ages of children and found a comparatively weak relationship between presence of children and WFH outcomes. Asgari points out that having children under the age of five years present at home is not conducive to a productive WFH environment.

Jain et al. (2022) demonstrate a key influence of actual and perceived social obligations on decision making. There is currently active debate as to the influence of WFH on the lives of children also present – for

example, as presented by the BBC, where experts remind parents of the importance of attention, a parent's 'primary asset', while also acknowledging some potential developmental benefits for children under some circumstances (Turits, 2022).

Bernhardt et al. (2023) consider the impact of family roles on WFH outcomes from quality German data. They suggest that gender models of breadwinner-caregiver, which have existed for decades, are still highly salient, even among young people, although evidence on the gendered impact of WFH on parenting is still sparse. They tested a hypothesis that mothers' parenting is more affected by WFH than fathers' parenting. Results suggested that working practices among men were largely unchanged whereas mothers experienced net resource gains. Effectively, this means that they were able to balance roles and overall experience a gain, not a drain. The paper considers that mothers may WFH and still be emotionally available to their children, although a key aspect of realising this benefit is found in schedule control, which requires formal arrangements to be in place. Although parents may perceive combining WFH and parenting as positive, the opinions of employers may differ.

It may be notable to point out that, given the likelihood that income is a determinant of WFH (based on analysis in section 3.4.2.3), those more likely to WFH would be expected to be able to afford access to preschool places. However, access to preschool education is becoming more equitable. The New Zealand Government currently subsidises 20 hours per week for children over three years old (Ministry of Education, 2023). The age threshold is also planned to be lowered to two years of age.

The outcome of Bernhardt et al.'s (2023) study and increasing ease of access to preschool placements does suggest that WFH can occur concurrently with family obligations and that the ability to avoid commuting (and achieving other benefits associated with WFH) can result in an overall net benefit improvement. In particular, mothers do reduce their work hours to accommodate the needs of children and still fulfil an unequal share of parenting duties – and are therefore more time sensitive. This would suggest that the role of family could be an indicator of WFH outcomes when interacted with gender.

3.4.2.5 Education level

There was reasonable consensus in the literature of a relationship between education level and WFH outcomes.

Shabanpour et al. (2018) found that, pre-COVID-19, education level positively affected the propensity to WFH. They found that only 6% of individuals who have an education level lower than bachelor's degree WFH at least a few times a year compared to 14% and 18% of individuals with bachelor's and graduate degrees. Fu et al. (2012) also found that those with higher education were more likely to WFH than those without higher education. Zheng et al. (2023) found that the higher-educated population were less likely to walk than use other modes.

Mayer and Boston (2022) found that, during COVID-19, the statistical association between education levels and WFH satisfaction was just outside the 5% significance level but within the 10% confidence interval ($p = 0.063$). There were found to be a higher proportion of those holding bachelor's degrees and higher in Group 3 (full-time on site) compared to Group 1 (full-time WFH). The Group 1 category would include professional services such as medicine. However, the null hypothesis would have reasonably aligned with Shabanpour et al. (2018) and may revert back post-COVID-19. The period of COVID-19 was likely a 'needs must' period, with a priority to business continuity wherever possible.

Although significant, education level is also likely to be correlated with income and employment type. These variables are collinear, meaning that they cannot all be independent explanatory factors of WFH and therefore either the most significant would be selected or, if more than one, included within discrete model stages.

3.4.3 Household interactions and conflicts

WFH has the potential to influence how members of the household interact. Higher job satisfaction and performance is related to fewer household conflicts and WFH outcomes (Green et al., 2020; Gajendran & Harrison, 2007). Fu et al.'s (2012) study on teleworking in Ireland found that certain demographic factors had positive impacts on home working such as the number of residents in a household, being a lone parent with young children or being married. The authors proposed that this could be because the more flexible arrangements of teleworking enabled opportunities to better balance work and family duties, in keeping with Bernhardt et al. (2023) (see section 3.4.2.4). Household interactions would be difficult to predict or even simulate, although there may be collinearity with influences of family.

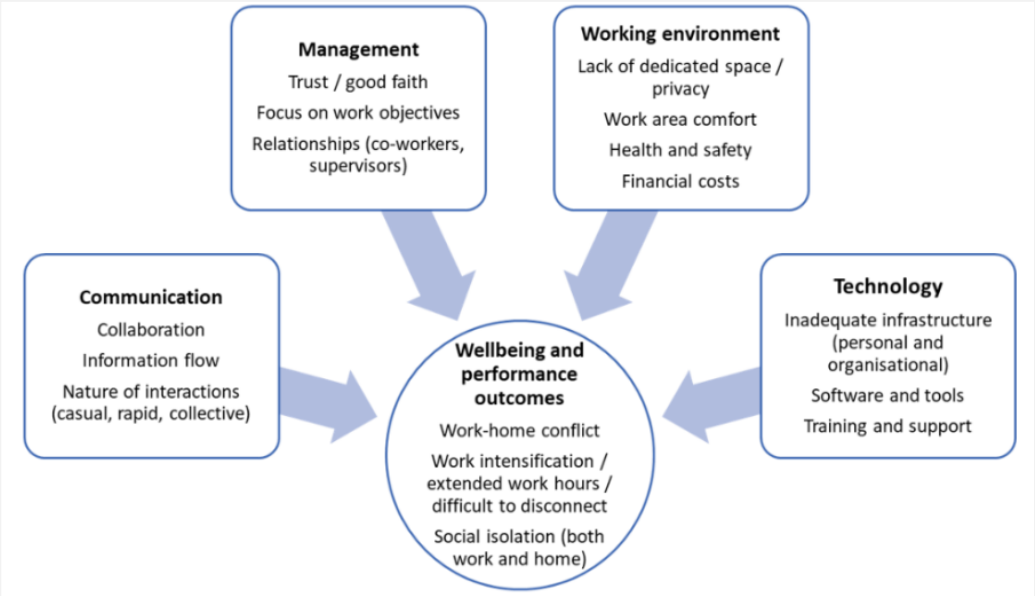
3.4.4 Social connectedness and wellbeing

Greaves et al. (2022) considered the mental health of people living in Sydney in a survey during 2020 COVID-19 restrictions. The survey of 1,750 participants included self-reported travel and work behaviour, local neighbourhood perceptions and attitudes, physical activity and subjective wellbeing. The areas of interest included demographics, travel measures, days worked and whether they were WFH/non-WFH, perceptions of the local environment close to home and travel choices, physical activity, subjective wellbeing and perceptions of change associated with the pandemic. The results of the survey identified three clusters:

- **Less change less worries:** The second-largest cluster were predominantly male and reported lower average changes to stress, limited impact to work and physical activity, lowest amount of sitting and highest quality of life.
- **Active but anxious:** The smallest cluster were younger and reported higher household incomes, largest increase in WFH, sitting for longer, highest level of physical activity, higher quality of life and increased anxiousness and stress.
- **Stressed and sedentary:** Most concerning, the largest proportion of participants had the highest levels of stress, lowest levels of physical activity and lowest quality of life.

The level of organisational support provided by employers has been shown to be critical to wellbeing and decision making (Jain et al., 2022). This relationship is summarised well in Figure 3.10.

Figure 3.10 Key challenges of WFH on wellbeing and performance outcomes (reprinted from Green et al., 2020, p. 8)



Beck and Hensher (2021a) found social isolation can be moderated by organisational social support with technology playing a significant role through the use of rich communication technologies such as video conferencing. They also considered the role of social capital in the workplace, in particular connectedness in perceived performance outcomes and prospects. They suggested that a mix of WFH and in-office working styles or use of innovative solutions to foster connectedness would be an important consideration for businesses to foster those friendships and community associated with productivity and wellbeing.

WFH can encourage remote workers to overwork as work is always right there, and this can create work–family conflict (Eddleston & Mulki, 2015), negatively impacting on wellbeing and mental health. During the COVID-19 pandemic, parents juggled WFH while simultaneously caring for and home-schooling dependants. However, remote workers who are able to separate work and family (such as by having dedicated workspaces) have been reported to have the lowest work-family conflict, at least in a business as usual situation. Eddleston and Mulki also found that WFH alleviates work–family conflict, where they can borrow time from one domain, work or family, to accommodate the other. In addition to worker behaviour, organisations need to create a culture along with policies that enable workers to disconnect from work. This is being addressed with 'the right to be disconnected' policy.

Flexible working arrangements are also potentially more equitable for those who cannot easily access the transport system for one of several reasons such as disability or form of access poverty. Research conducted by the Centre for Economics and Business Research (2019) considered the value to the US economy of adopting flexible working practices estimated at US$2.36 trillion (NZ$3.98 trillion), of which 90% of the benefit would be associated with increasing participation in the economy of those unemployed or otherwise economically inactive.

Wellbeing appears to be a more significant variable and interacts with other significant variables. However, much of the data to support it is derived from surveys during the COVID-19 pandemic when respondents would likely have perceived their wellbeing differently. Wellbeing is probably collinear with several other variables and would interact with matters associated with productivity and influences of family and so on.

3.5 Environment and land use

3.5.1 Urban characteristics – city size and density

The size of settlements and their density appear to be related to the likelihood of WFH. Shabanpour et al. (2018) looked to predict WFH outcomes based on the urban characteristics of population and employee density. The results show that those who worked in high employee density areas (more than 20,000 employees in the census tract) were more willing to participate in WFH. This could be because of the large corporations and companies located in CBD areas associated with WFH practices. In adopting flexible working practices, these businesses stood to save capital on the most expensive floor areas and reduce energy consumption. The results also suggested that individuals were less likely to telecommute almost every day (and therefore more likely not to telecommute) if they worked in areas with a low number of employees (fewer than 3,000 employees in the census tract).

Smargiassi et al. (2020) considered urban core densification on the impact of car use and found that car share would be more affected by measures targeting car use than by urban core densification. Major changes in urban planning practices in addition to the supply of transportation services are needed as early as possible to reduce environmental and health impacts of land use and transportation.

3.5.2 Real estate and rental demands, market constraints and values

Changes in the proportion of employees WFH could affect the real estate market and business location decisions, ultimately affecting land use. Kyriakopoulou and Picard (2022) reported on the real effect of WFH on commercial yields across New York and San Francisco, the latter being particularly impacted by some major incumbents of Silicon Valley announcing plans to facilitate ongoing WFH arrangements. House prices in outer suburbs increased during the same period and fell in CBD/inner-city areas, indicating a model where WFH could be associated with decentralised settlement patterns and consequential enhancement of the monocentric urban model.

The Australian Productivity Commission (2021) showed the impact of COVID-19 on Australian city commercial real estate vacancy rates (Figure 3.11). Melbourne and Sydney – by far the two largest centres – saw significant increases between 2020 and 2021. Perth may have been affected by the end of the mining boom that saw some contraction in investments in the mineral sector. If this was weighted by gross floor area, the reported upturn in vacancies would likely appear significant.

Figure 3.11 Australian commercial property vacancies (time series) by centre (reprinted from Productivity Commission, 2021, p. 64)

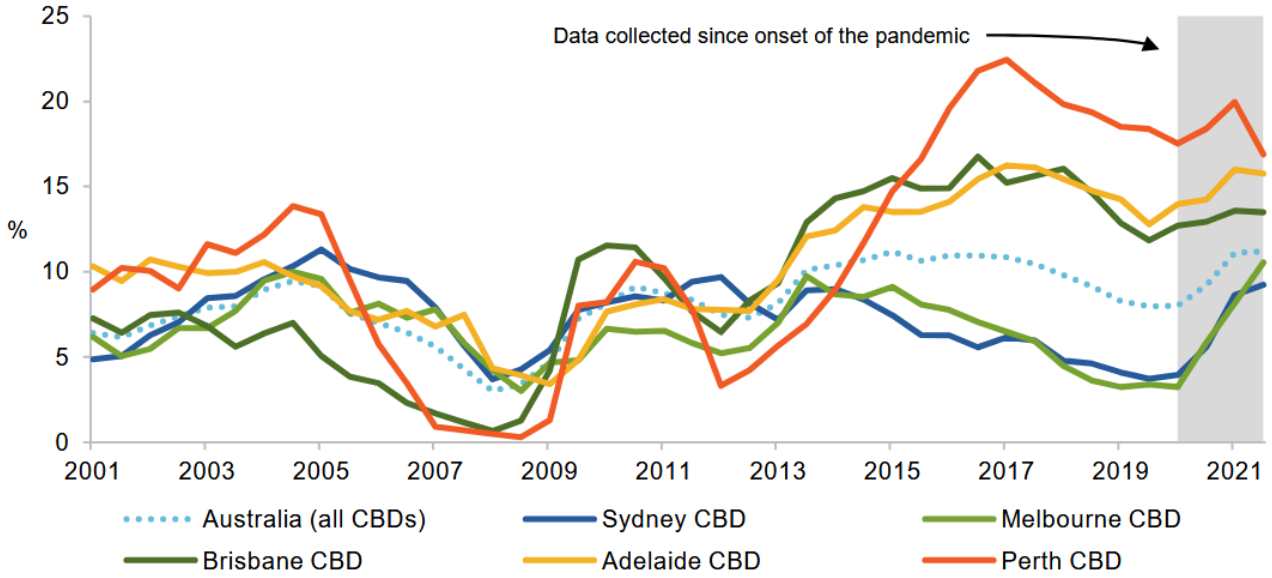


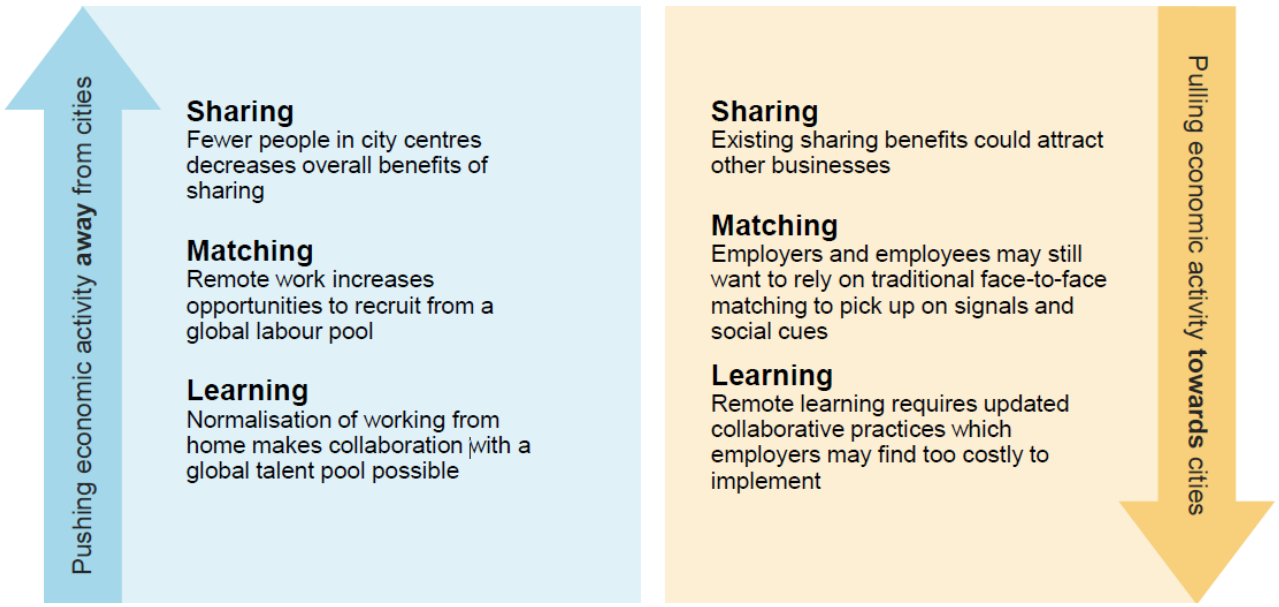
Figure 3.11 represents short-term reactive changes. However, section 3.2.2 indicates a move among major US firms towards a hybrid working model in the longer term. The effect and benefits of agglomeration would also suggest there would be limits to the weakening of commercial floor area values in CBDs.

3.5.3 Location and proximity to CBDs

The Australian Productivity Commission (2021) found that an increase in the amount of work done from home has the potential to shift some economic activity away from the centre of cities. Some businesses that require high foot-traffic to be viable such as cafés and hairdressers may choose to locate in suburbs rather than in city centres. This issue would be related to cultural and social attractions given that the CBD is also usually the regional cultural focal point. The movement of people and businesses away from the centre of cities may reduce agglomeration benefits experienced by businesses in cities – a matter discussed further below.

The impacts of WFH on CBD locations identified by the Australian Productivity Commission are summarised in Figure 3.12.

Figure 3.12 Relationship between WFH outcomes and agglomeration (reprinted from Productivity Commission, 2021, p. 68)



The increase in suburban activity clearly has consequence for modelling. The CBD is characterised by accessibility with dense and close availability of amenities and resources. The increased suburbanisation of activity could therefore generate significant levels of car travel – certainly in the short term for suburbs not well served by public transport or active travel infrastructure. It could also result in more active travel outcomes for shorter trips.

Zheng et al. (2023) noted the impact that distance to the CBD has on transportation usage. People who live closer to the city centre tended to use public transport more frequently as well as walk more often (due to the city centre having better transportation infrastructure and pedestrian amenities). When distance to the CBD increased by 10 kilometres, the usage frequencies of public transport and walking reduced and car usage increased. These were outcomes that existing transport models can predict.

Jain et al. (2022) developed the structural equation model to predict the differences in planned behaviour theory outcomes on workers based in the CBD and those based elsewhere. Planned behaviour theory considers the latent variables of attitudes, subjective norms and perceived behavioural control, and Jain et al. developed a framework to test the extent to which they were related to the outcome of WFH. In expanding the study to include a CBD/non-CBD context, they found the main difference was the extent to which the perceived behavioural control (perceived ease) was a stronger predictor of intent among CBD workers. This suggests CBD workers perceived more difficulty in attending the worksite as a behavioural control.

The role of the CBD in a model would be closely related to cultural and social attractions. However, the capturing of cultural benefits in the CBD in the context of measuring home-based work trips would represent a tour, potentially captured in ABM.

3.5.4 Agglomeration effects

Kyriakopoulou and Picard (2022) developed a model of a monocentric urban construct (relevant to New Zealand) to investigate the impacts of firms' location decisions. The hypothesis was centred around the role of agglomeration – firms clustering to both create and take advantage of markets associated with ease of doing business – and the role of agglomeration externalities as the most important force that promotes the clustering of economic activities. The impact of WFH on agglomeration could be dampening on outcomes of innovation and aggregate productivity across firms.

Agglomeration benefits can be described as the lower costs of moving inputs (sharing), moving people (matching) and moving knowledge (learning) when businesses and employees are located closely together (Ellison et al., 2010; Marshall, 1890). Agglomeration effects include macro-economic benefits, an example being the major financial centres. The functionality of an agglomeration is based on relationships, and digital relationships are not currently perceived as able to fully replace physical ones. This element is reflected in productivity.

WFH changes the geospatial relevance to agglomeration, including a perceived benefit of ability to recruit from across a wider area. Moreover, Lyons (2014) suggests an increase in agglomerations in digital platforms, further changing land use in CBDs to include a greater mix of activities, including residential and cultural.

The benefits of agglomeration may still attract businesses to cities in the short run. There are economic benefits of people clustering together in space that are expected to remain for now as a 'strong incentive' (Productivity Commission, 2021, p. 62). This view is formed on the basis that people can benefit from proximity.

The future role of digital agglomeration seems like a plausible scenario depending on the changing attitudes of businesses. Agglomeration effects will impact outcomes of the transport system in the long run and be determined by corporate decision making. For now, at least, there is strong evidence of some business practices preferring employees to not WFH and still a significant preference for the status quo.

3.5.5 Cultural and social attractions

A hypothesis for discouraging WFH could be the cultural pull of a CBD – the so-called coffee culture. However, specific research into this aspect has not been found. It is more likely in any case that the variable of connectedness could describe this same outcome.

3.5.6 Property tenure

There was little evidence for a significant relationship between household property tenure and WFH. Mayer and Boston's (2022) analysis included various forms of renting and ownership but found no statistical associations with WFH preferences ($p = 0.757$). Fu et al.'s (2012) earlier study from Ireland reported a statistically significant negative relationship between house ownership and WFH but which they argued could be explained by type of employment and associated income levels. The difference in findings may be due to the different points of time in the housing market and the COVID-19 experience.

3.6 Other variables

Clearly, the attributes of WFH are multifaceted with longer-run impacts of COVID-19 still to be seen. The following section discusses other factors that are yet to be researched with regard to WFH but have been suggested as important based on the team's technical insights and experience.

3.6.1 Day of the week

Day of the week has not been explicitly considered at this stage, although this data could be derived from multiple government survey sources (such as the Ministry of Transport's Household Travel Survey). Section 3.3.2 discusses research into pre-COVID-19 and COVID-19-induced travel behaviour by day of week and mode of transport (Waka Kotahi NZ Transport Agency, 2022a). Car travel was largely unchanged from Monday to Friday, whereas public transport trips were significantly avoided on Fridays. The reasons for this are unclear and unlikely to have a single cause. However, while WFH may not change the properties of a

public transport trip from one day to another, it could render what is currently relatively expensive car parking as more affordable if demanded less often.

The outcome of day of the week may be difficult to forecast given the reasons would be complex. While efforts will be made to better understand and potentially develop an explanatory framework, day of the week is a variable that lends itself well to scenario planning. It is also noted that policy interventions to influence the transport market (such as road user charges) may well induce mode shift towards public transport and WFH.

3.6.2 Willingness to pay

Although a potential outcome of the model, willingness to pay could change from one day to the next based on preceding behaviour. Because of the number of moving parts in behavioural-based explanations of WFH, it is likely that WFH decision making will be planned in advance. This suggests a recursive approach of the decision maker between preceding events and costs that cannot be captured within the simulation of a single day.

3.6.3 Habit or impulse

Models generally simulate a single day representing a habitual approach to travel. However, travel behaviour may be less habitual under a flexible working arrangement. The notion of flexibility empowers the user to balance the needs of aspects of competing life roles.

There are solutions to capturing habit or inertia of decision making potentially through modelling behaviour in a time series using a form of mixed logit that integrates previous models, thus capturing the effects of previous decisions.

3.6.4 Weather

The weather is a dynamic independent variable with potential to disrupt short-term plans and for which WFH provides an immediate relief. It has not been uncovered in the literature review yet it remains potentially too important to be disregarded. It may also prove to be a difficult variable to manage given inevitable taste variances (in this case, tolerance to the elements) and the extent of likely interactions with other variables. It could either be developed as an independent variable in its own right or captured through scenario-based planning.

Climate change could present a tangible outcome on WFH. Auckland's 2022/23 summer was among the wettest on record,[2] with travel being severely disrupted. Cyclone Gabrielle demonstrated the capacity for a single weather event to isolate entire regions. Climate forecasts for New Zealand indicate more extreme weather events, which could increase WFH outcomes. Based on the planned behaviour model (Jain et al., 2022), this could potentially rebalance the derivatives of decision-making thought processes, reducing the role of social constraints and therefore potentially increasing the normality of WFH as it was during the COVID-19 lockdown periods.

Scenario planning methods encourage the representation of several options in order to identify for those that perform under the greatest number of scenarios, including so-called 'black swan' events. This is a potentially useful approach for New Zealand, a society characterised by unpredictable natural events.

[2] With the La Niña climatic effect drawing more northeast-quarter winds and associated tropical depressions.

3.6.5 Touring

Touring is an important variable. If one can visit multiple destinations within a direct journey path, the attraction of physical travel (and sequential accomplishments) could exceed the WFH alternative. An example of observed touring is found in research into the trip generation characteristics of a new supermarket (Douglass & Abley, 2011), where one-third of trips were new primary trips and two-thirds were found to be diverted or pass-by. These latter categories represent touring.

The inclusion of touring is more associated with ABM. Despite its prevalence, it has been difficult to replicate in strategic models. Modelled time periods can relate network demands on the basis of a single destination. To increase destinations would require disaggregation of time slices, but there would be no universal basis for disaggregation – tours are unique in staging and duration and with varying tolerance to deviation from the prevailing direction. Therefore, to simulate the role of touring as an explanatory for not WFH would require simulation of tours themselves, for which there is currently no straightforward answer.

3.6.6 Work from anywhere

The Centre for Economics and Business Research (2019) considered the benefits of flexible working location policies. It suggested that the value of flexible working practices to the US economy could be US$2.36 trillion (NZ$3.98 trillion) in gross value added (GVA).[3] This would be the equivalent of 10% of US GDP (as of 2019). Much of this value would come from reducing 5.8 billion hours per year in commuted time and rediverting it towards leisure activities.

Time spent commuting by public transport could be used productively. Lyons (2008) has surveyed the behaviours of rail passengers considering a particularly broad range of behaviours. The sample were asked to rate their use of time (‘I made very worthwhile use of my time’, ‘I made some use of my time’ or ‘My time was wasted time’). Respondents were also asked to reveal how they spent their time by activity category and whether they spent some or most of their time on this specific activity.

The significant outcomes related to this project include that no activity category returned a majority of ‘wasted time’. For example, 80% of respondents who reported that they ate and drank rated this time as of some use. Also of interest is that, of the significant number of respondents who reported studying or engaging in work (82% of respondents claimed to have spent at least some time on this activity), a slight majority rated the time as being as ‘some use’ more so than ‘very worthwhile’.

The returning of mostly ‘some use’ of time responses in these pursuits indicates that a rail carriage is not a substitute for an office – an observation that could have implications on its own in terms of directing investment towards the design of rolling stock to fulfil a functioning purpose. Had a control sample been surveyed (surveying the value of time in a non-transport environment), it would be reasonably expected that time spent working or studying would be considered ‘very worthwhile’.

However, it is also noteworthy that Lyons’ paper was written in 2008. It would be fascinating to repeat the study in a post-5G world (and with increasing investment in coverage on the UK rail network) to examine whether mobile broadband limitations may have been a constraining factor in perceived values of time.

Other less-obvious uses of time are identified by the author as including transition time – time spent adjusting between different life roles such as from an employee to a parent. Lyons also distinguishes the likelihood of experienced time being different to clock time – a relatable outcome. These outcomes might enhance the

[3] GVA is an alternative measure of the economy to GDP and considered a more encompassing measure of monetisable value in an economy.

probability of choosing to commute for those who would prefer to separate out working and family life – a potential disadvantage for some to WFH.

In summary, more than half of respondents spent at least 'some time' engaged in work or study on the train, with around one-third of respondents spending 'most time' in this pursuit. This scenario would be relevant in Auckland and Wellington where commuting by rail is a possibility (in situations where overcrowding is not an issue).

Capturing this outcome in a choice model would be to assign a utility to the alternative of rail to represent the ability to work on board. In theory, this would increase the utility of the alternative, relative to WFH. Understanding the extent of this behaviour could include travel diaries, and attention to detail such as overcrowding (including seasonal variances) would be necessary. Observation should also inform hypotheses around interacting variables such as job type or journey time.

The Lyons (2008) study related to rail, whereas buses and other forms of public transport may be conducive to performing some form of phone or tablet-based tasks. Historically, values of time for bus passengers have been lower than other modes of transport. However, new buses generally include USB charge ports that could support favourable attitudes towards being able to achieve some tasks on the bus.

To be able to work anywhere – such as a café or a friend's house – would exceed the capabilities of models. Total working flexibility would allow better work-life balance and would require a model to speculate on the fullness of a person's life and how they perceive balance. ABM provides a possibility of doing this through the incremental allocation of a schedule, with each stage seeking to contribute to a sum outcome that optimises utility. Perhaps some of the travel associated with these tasks could be coincided with work, enabling the model to reflect the utility maximisation that working from anywhere can represent.

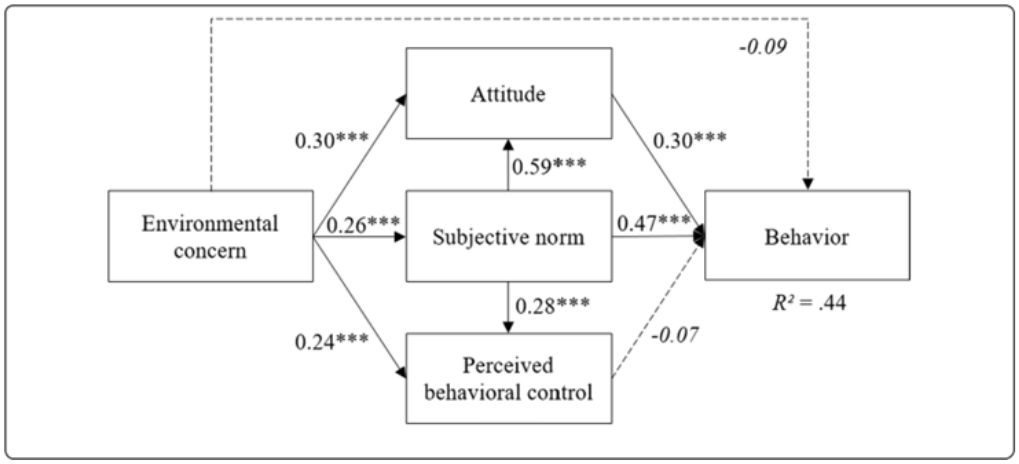
3.6.7 Travel demand management

Travel demand management is a broad field aimed at influencing behaviour to reduce or redistribute travel demand, particularly by car. A key pillar of this approach is providing information about alternative travel options to transport users, which can potentially change attitudes to travel and alternatives. A classic example is providing public transport network information within a workplace to demonstrate ease of access to the location. Travel demand management generally takes the form of one or more nudges.

Hauslbauer et al. (2022) considered the theory of planned behaviour, exploring a theory of predicting choice outcomes in planned behaviour theory and adopting a similar model structure to Jain et al. (2022) but also including the impact of nudges. Adapted from the field of behavioural economics, nudges are 'interventions that support or direct the choices that people make (e.g., healthy, sustainable, etc.) without restricting freedom of choice' (Hauslbauer et al., 2022, p. 2). Nudging is an umbrella term that can present challenges to including it in a modelling framework.

Although the Hauslbauer et al. (2022) paper does not relate specifically to WFH, it does take a step in developing planned behaviour theory through the inclusion of nudges – variables that can intercept a decision maker and potentially change their mind. The purpose of the study was to show the role of nudges as proven vehicles to change behaviour. The role of travel demand management in transportation planning (which tends to use nudges as a tactic to elicit behaviour change) is growing but not presently well reflected in transport models, particularly strategic models that could forecast or simulate the aggregate effects of travel demand management across a region. Hauslbauer et al. offered an alternative hypothesis, including the role of environmental concern and simultaneous relationships as shown in Figure 3.13 (note that values preceded with three asterisks denotes statistical significance). The researchers developed two nudge categories – a default (control-like parameter) and a social nudge. The hypotheses were that the social nudge would influence behaviour. However, the outcome shows only an indirect influence.

Figure 3.13 Structural extended planned behaviour theory model (reprinted from Hauslbauer et al., 2022, p. 7)



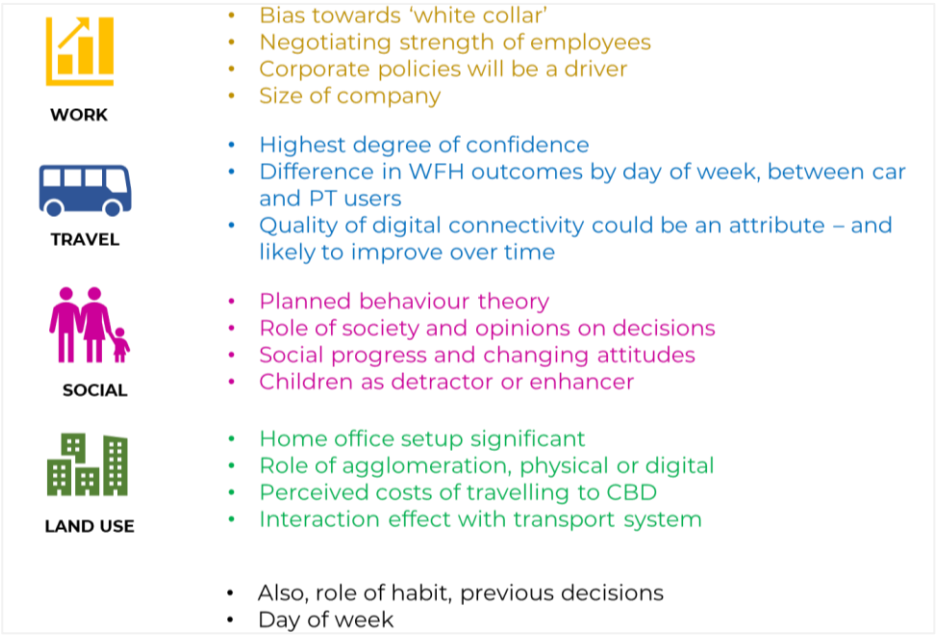
3.6.8 Fear of crime

The post-COVID-19 era in New Zealand has included a rise in both actual and perceived crime rates and some high-profile incidents, including a gunman in Auckland CBD. The *New Zealand Herald* reported 67% of the public feeling 'less safe' across a five-year period and the rise of anti-social behaviour (Venuto, 2023). This likely generates determent from accessing certain public spaces, although there is no evidence to quantify this. In Christchurch, the central bus interchange has been the scene of some high-profile incidents, including death and serious injuries resulting from anti-social behaviour. These events and coverage of ongoing issues would reasonably affect the outcomes of willingness to travel and may affect demographic groups differently. Capturing the role of fear of crime would be very challenging, including several potential interaction effects with other variables. Future crime trends and feelings of safety are also highly uncertain.

3.7 Summary of factors: determinants of WFH decision making

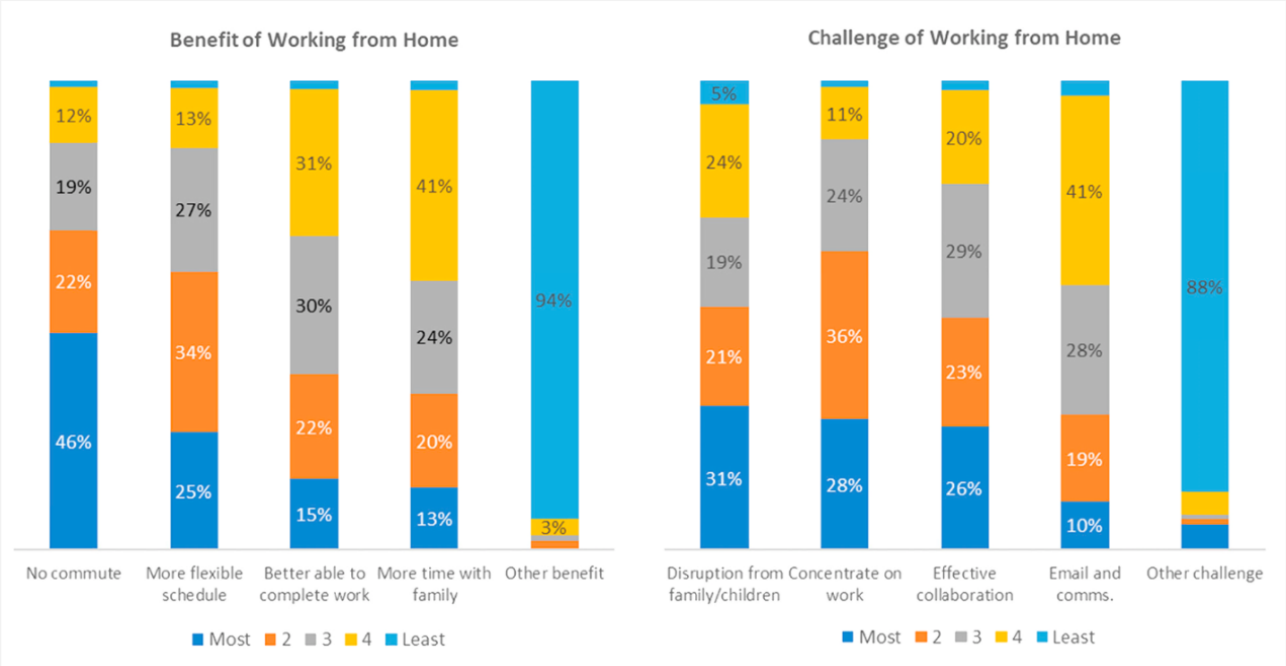
WFH impacts have been considered against four domains and main relationships summarised (Figure 3.17).

Figure 3.17 Summary of the literature review – drivers of WFH outcomes



The variables represent the potential drivers for WFH. For additional context, Beck and Hensher (2020) also examined the impacts associated with WFH, which may in turn act as behavioural drivers. Figure 3.14 shows the benefits and challenges to WFH they identified and how they ranked the main opportunities or constraints. The main theme in support of WFH included not having a commute, with the main barriers being themed around productivity. The role of family appears to represent a lower-level benefit (more time with family) for some and a major constraint (disruption from family/children) for others. This suggests that the benefits would be perceived in conjunction with other benefits (in modelling, this would be estimating the interaction effects), whereas as a negative, the role of family seems more independent. Although a model could make sense of the relationship (deploying an orthogonal scale through stated preference surveys), the outcome would be difficult to interpret in a meaningful way. Figure 3.14 presents a mix of opinions around specific motivators or detractors, and these would likely change from one day to another. As such, modelling WFH has been referred to as hitting a moving target.

Figure 3.14 Benefits and challenges of WFH (reprinted from Beck & Hensher, 2020, p. 107)



To develop frameworks, some of the more stationary variables will need to be identified, particularly those that can be readily observed and measured. The remaining variables would need inclusion somehow, either as:

- **dummy variables** – scaling to a binary 1 or 0, which is clearly limited for most variables
- **synthetic utility** – derived through contingent valuation or an alternative method where respondents place a value (perhaps monetised) on a given attribute (such as comfort)
- **scenario planning** – instead of forecasting, include sensitivity testing or better still scenario planning for those variables considered pivotal. This will include the unpredictable employer policy. The outcome of this planning will need to mathematically complement the framework.

4 Impact of COVID-19 on transport in New Zealand

4.1 Synopsis

The literature review considers WFH from a behavioural (causal) perspective, whereas this chapter considers the actual outcomes of WFH on transport systems. This information potentially provides a basis for validating the inclusion of WFH in a model versus the status quo. Choice models tend to be 'validated' against observed elasticities (Department for Transport, 2020). Also, models in New Zealand are tending to be based pre-COVID-19 due to a lack of understanding as to longer-run trends and a reluctance to base models on data that might not represent the longer-term transport environment.

The impacts from COVID-19 are still being felt on the transport network over three years after New Zealand was put into its first lockdown. This occurred on 25 March 2020, and New Zealand has experienced several lockdowns and restricted movement periods since then. COVID-19 has resulted in changes to how people work and therefore how they travel to work. WFH is becoming significantly more accepted by employers, with a lot of employees being given the flexibility to choose how they work. The impacts of COVID-19 on WFH and the transport implications are outlined in this chapter.

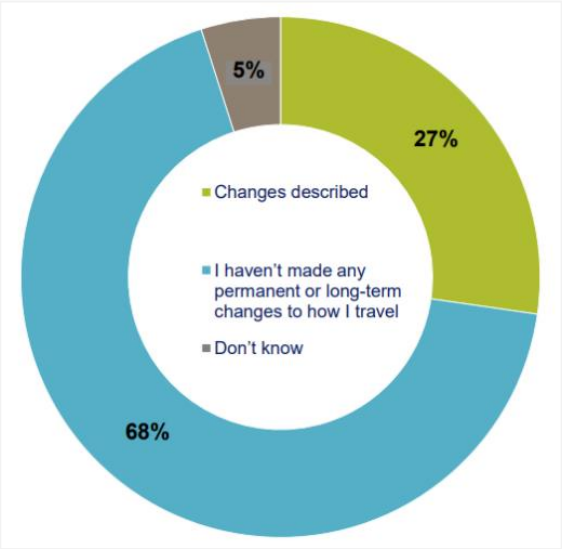
4.2 Outcomes

The outcomes of COVID-19 impacts are set out in terms of overall travel demands, mode of travel, and specific location (considering the major centres).

4.2.1 Overall demands

A key study monitoring the transport impacts of COVID-19 found that, prior to the initial COVID-19 lockdown, 9% of people mainly/completely WFH (Waka Kotahi NZ Transport Agency, 2022a, p. 18). By 8 November 2022, the percentage of people mainly/completely WFH was 21%. This suggests a larger portion of people are choosing to WFH rather than in the office. The research also suggests that the percentage of those WFH is remaining relatively steady and indicates that this could be the new normal where one in five employees work mainly or completely from home.

Figure 4.1 Changes to how people travel now compared with pre-COVID-19 (reprinted from Waka Kotahi NZ Transport Agency, 2022b, p. 33)



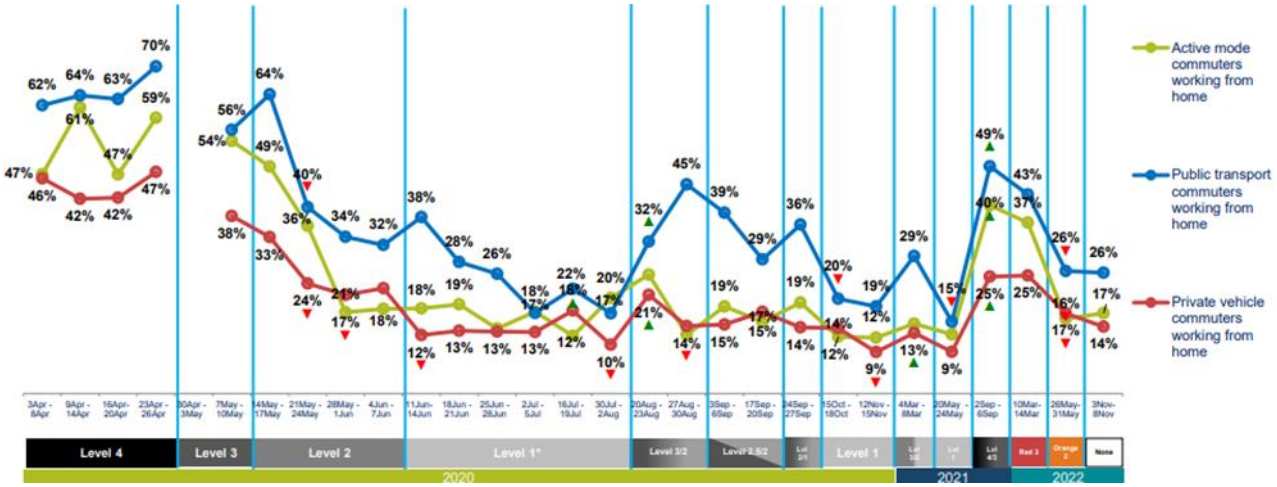
Travel behaviours were also assessed to determine if changes have occurred as a result of COVID-19 (Waka Kotahi NZ Transport Agency, 2022b). This found that 27% of those surveyed have changed how they travel post-COVID-19 (Figure 4.1). It should be noted that the question that was asked to generate these results was not targeted at travel to and from work – general travel behaviours instead were investigated.

Other research completed in May 2021 (Ableу, 2021) suggests that demand for driving across the country is generally trending towards the pre-COVID-19 baseline. This is the case for Auckland, Wellington, the rest of the North Island and the top of the South Island. Canterbury/West Coast and Otago/Southland, however, were at approximately 90% of this baseline in May 2021. Walking and public transport behaviours have not returned to the pre-COVID-19 baseline. Walking behaviours were at approximately 95% of the baseline in May 2021, whereas public transport behaviours in May 2021 sat at approximately 65%.

4.2.2 COVID-19 impacts on transport by mode

Public transport, active modes and private vehicles were three modes assessed to investigate potential changes (Waka Kotahi NZ Transport Agency, 2022a). The proportion of people surveyed who WFH by usual commuting mode is shown in Figure 4.2.

Figure 4.2 Proportion WFH by usual commuting mode of transport (reprinted from Waka Kotahi NZ Transport Agency, 2022a, p. 22)



4.2.2.1 Private vehicles

The percentage of private vehicles commuters who WFH has reduced from 46% in early April 2020 to 14% in early November 2022. This suggests that the majority of private vehicle commuters that were WFH during the first COVID-19 lockdown are now working back in the office. However, there is still a portion of private vehicle commuters that are now WFH.

Another study shows that private vehicle commuter number have recovered to approximately what they were pre-COVID-19, with an average of 4.8 days per week using private vehicles (Waka Kotahi NZ Transport Agency, 2022b).

4.2.2.2 Active modes

The percentage of active mode commuters who WFH reduced from 47% in early April 2020 to 17% in early November 2022. This suggests that, similar to private vehicle commuters, the majority of active mode commuters have returned to working in the office. However, there is still a portion of active mode commuters that are instead choosing to WFH.

Since the first COVID-19 lockdown, the number of days walking on average has not recovered to previous numbers. However, this study did not analyse the recovery of cycling.

4.2.2.3 Public transport

The percentage of public transport commuters who WFH reduced from 62% in early April 2020 to 26% in early November 2022 (Figure 4.2). This indicates that public transport uptake has been the slowest mode to recover in comparison to active modes and private vehicles.

Public transport users travel to work 2.8 days per week – prior to COVID-19, this was 3.23 days per week (Waka Kotahi NZ Transport Agency, 2022b).

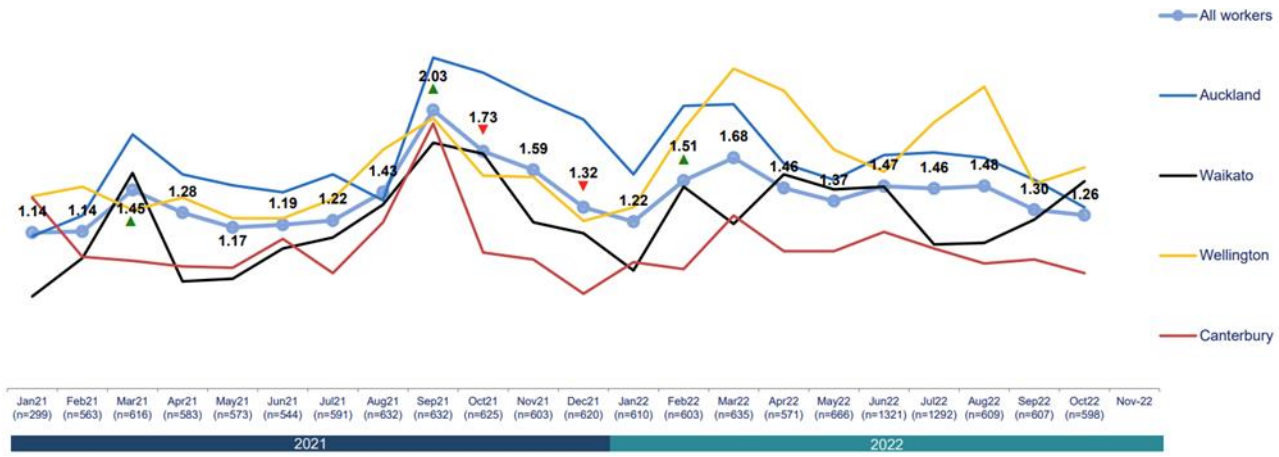
Public transport has seen the slowest return to pre-COVID-19 numbers due to concerns of increased exposure to community cases (Waka Kotahi NZ Transport Agency, 2022c). However, this study was completed during the Delta lockdowns and may not be reflective of the current environment.

There is also an increased association with WFH among those normally using public transport in Auckland (Waka Kotahi NZ Transport Agency, 2022b). Unlike for those normally commuting by car where WFH rates are reasonably constant by day of week, those normally commuting by public transport would be 25% more likely to WFH on a Friday compared to a Tuesday or Thursday.

4.2.3 Location specific

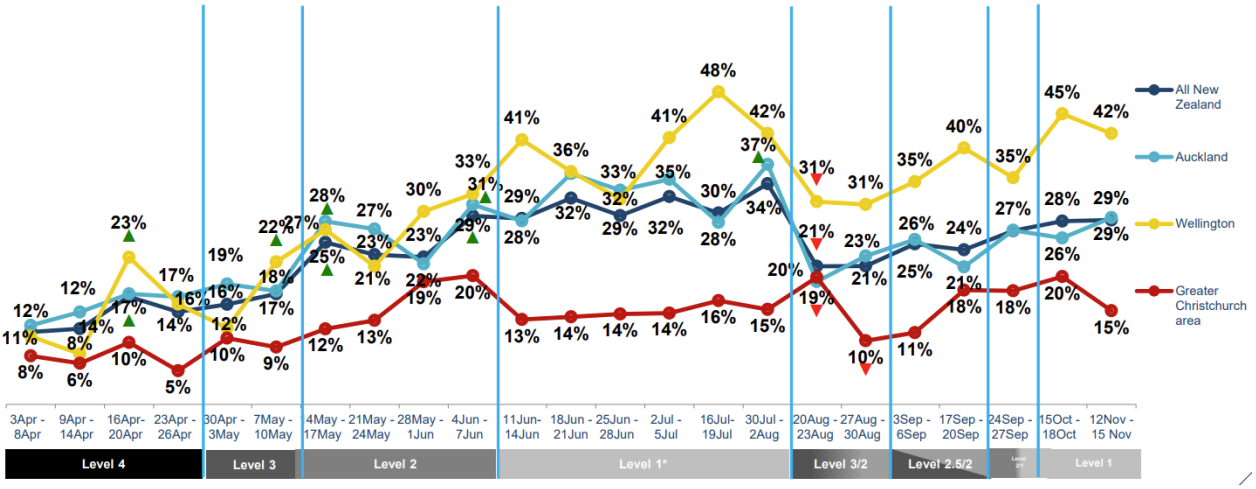
The demand from WFH and the ongoing transport impacts have been assessed for Auckland, Waikato, Wellington and Canterbury. WFH rates were found to be higher in Auckland, Waikato and Wellington in comparison to Canterbury and the average population (Figure 4.3). The rates of WFH vary throughout the country. Wellington had the highest rates of WFH as of October 2022 and Canterbury had the lowest. It could be suggested that other factors influence the choice to WFH, not just COVID-19.

Figure 4.3 Rates of WFH based on location (reprinted from Waka Kotahi NZ Transport Agency, 2022a, p. 31)



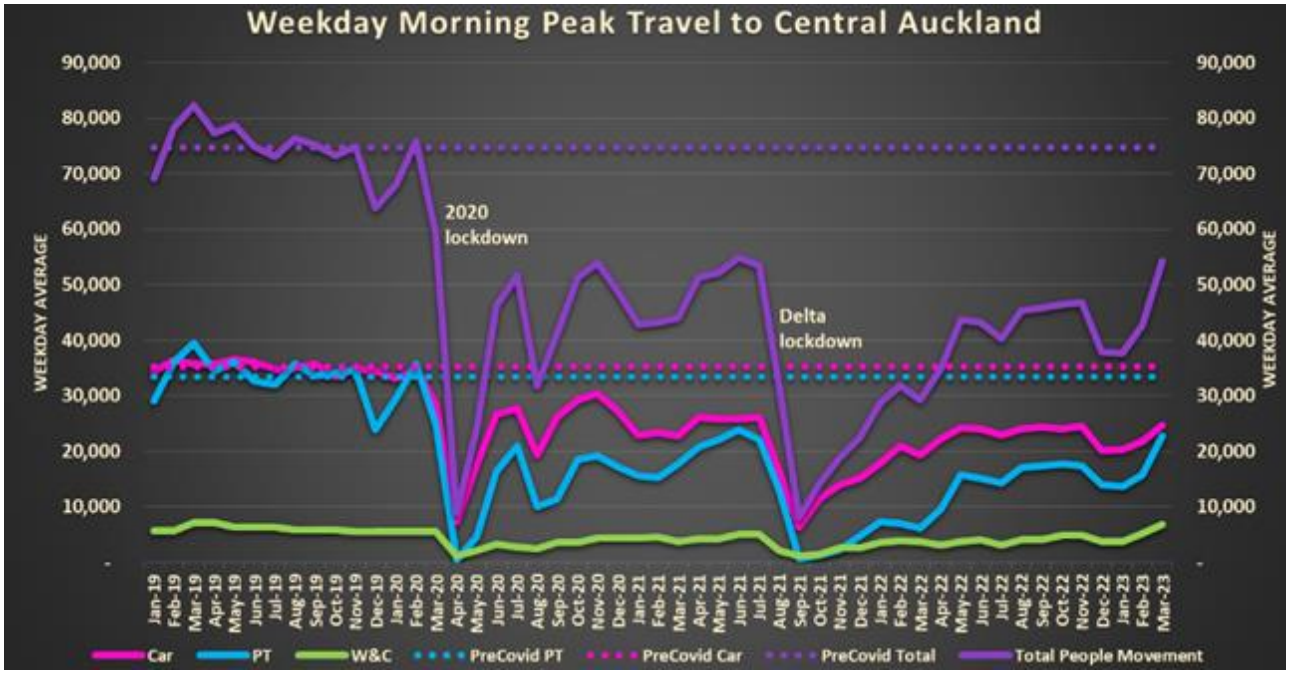
An earlier survey investigated consideration of using public transport (Waka Kotahi NZ Transport Agency, 2020b). Wellington had the highest levels and Greater Christchurch the lowest (Figure 4.4). This data does not, however, indicate more recent public transport considerations as the data was collected in 2020. This data also shows those who were surveyed that would consider using public transport, not those who use public transport as their mode of transport.

Figure 4.4 Consideration rates of public transport usage (reprinted from Waka Kotahi, 2020b, p. 19)



Notably, public transport as a mode has experienced the most significant decrease in trips (Figure 4.5). Auckland has experienced the most significant decrease in public transport AM peak trips (43%) compared to other modes (31% and 4% for private vehicle trips and active mode trips respectively). Private vehicle and active mode trips have also decreased since COVID-19, suggesting that people are not coming into the office as frequently as they were pre-COVID-19.

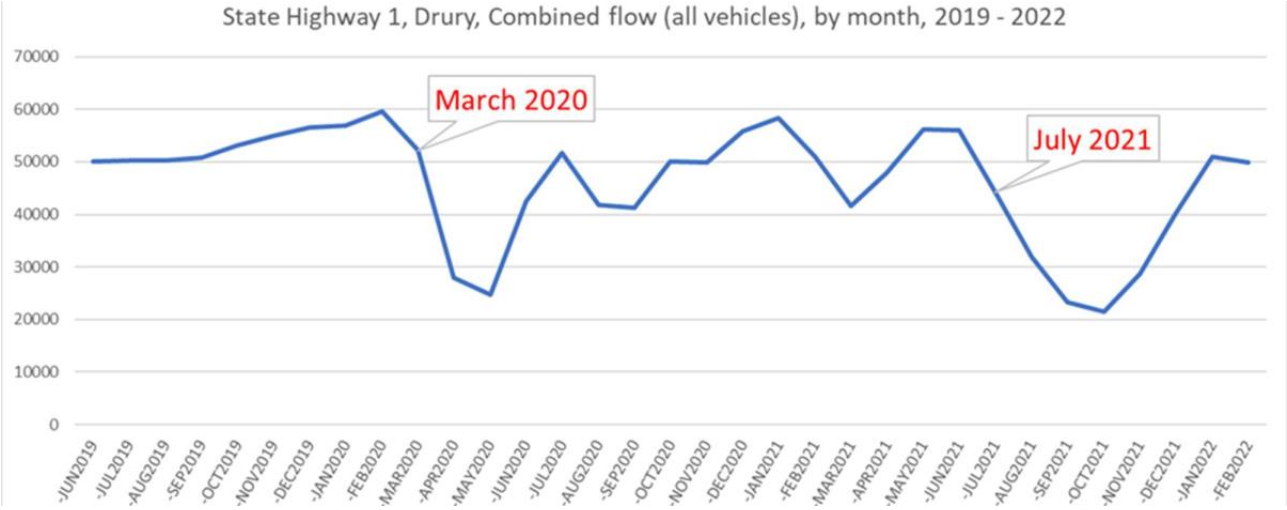
Figure 4.5 Weekday morning peak travel to Central Auckland



The relatively high impact on public transport is also suggested in Figure 4.6, which shows traffic flows on the Waikato Expressway (at Drury) and appears to point to a recovery in pre-COVID-19 traffic flows by March 2022. Correlation between the car flows in Figure and traffic flows in Figure 4.6 appears strong – the two lines rise and fall in the same places, dictated by lockdowns, except the SH1 traffic flow appears to return to normal whereas flows measured into Auckland CBD do not. One possible factor could be that SH1 at Drury serves a significant industrial hinterland, noting that certain industries include roles that cannot be WFH while the CBD is largely occupied by industries that can WFH. Even accounting for this, there would still be Waikato-based employees working in the CBD, which could be reasonably expected to account for

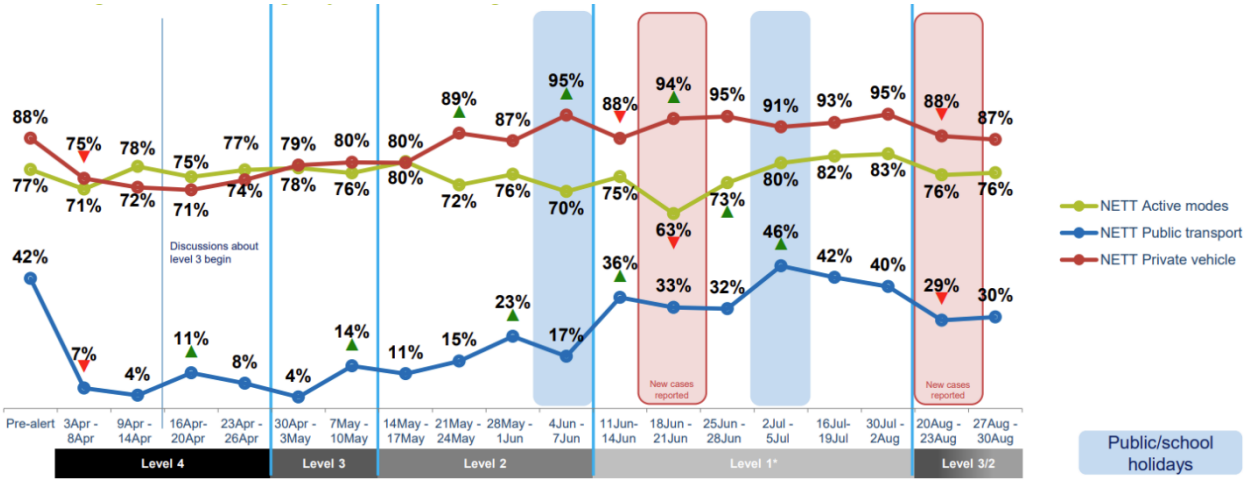
post-COVID-19 flows on SH1 not returning to pre-COVID-19 levels. Another possible explanation could be a reduction in vehicle occupancy. A lower vehicle occupancy could still reveal a drop in the number of people entering the CBD, without necessarily resulting in a significant drop in car traffic. If pre-COVID-19 occupancy is estimated to be 1.2 persons per vehicle, the maximum drop in the number of people would be 17% – not accounting for the 27% reduction in Figure 4.5. One other possibility could be the role of peak spreading and the use of WFH to delay departure to avoid traffic. Because Figure 4.5 includes only the AM peak, this possibility would not be captured.

Figure 4.6 Traffic count data on the Waikato Expressway (SH1) – annual average daily traffic by month



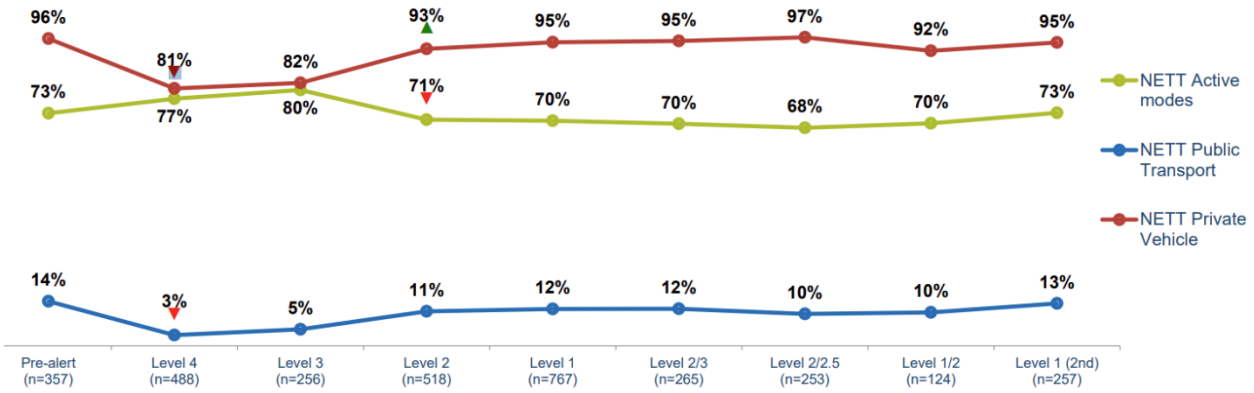
Survey participants in Wellington and Greater Christchurch were asked how often they used various modes of transport per week (Waka Kotahi NZ Transport Agency, 2020a, 2020b). Wellington has seen that private vehicles and active modes are all but recovered from pre-COVID-19 trips by the end of August 2020 (Figure 4.7). Public transport trips, however, are slower to recover. The survey results indicated that people are travelling on public transport 12% less than they were pre-COVID-19. The limitation with this survey is that the analysis was only completed up until the end of August 2020. Therefore, trends could have altered slightly with the lockdowns and alert level settings that were experienced in late 2020 and throughout 2021/22. A conclusion should not be made that all modes have recovered.

Figure 4.7 Changes in mode usage in Wellington (reprinted from Waka Kotahi NZ Transport Agency, 2020a, p. 18)



The Greater Christchurch survey suggests that Greater Christchurch had completely recovered to pre-COVID-19 travel behaviours for private vehicles, active modes and public transport by the middle of November 2020 (Figure 4.8). However, this is a limitation as more recent statistics have not been collected. Thus, trends in 2021 and 2022 have not been analysed and a conclusion for this period of time cannot be drawn.

Figure 4.8 Changes in mode usage in Greater Christchurch (reprinted from Waka Kotahi NZ Transport Agency, 2020b, p. 16)



4.3 Conclusions

This study on COVID-19 effects is considering so-called short-run trends and generally indicating some significant changes to travel behaviour. Once a model of WFH is developed, monitoring will be important to eventually reveal the long-run impacts of COVID-19 and WFH on the transport system.

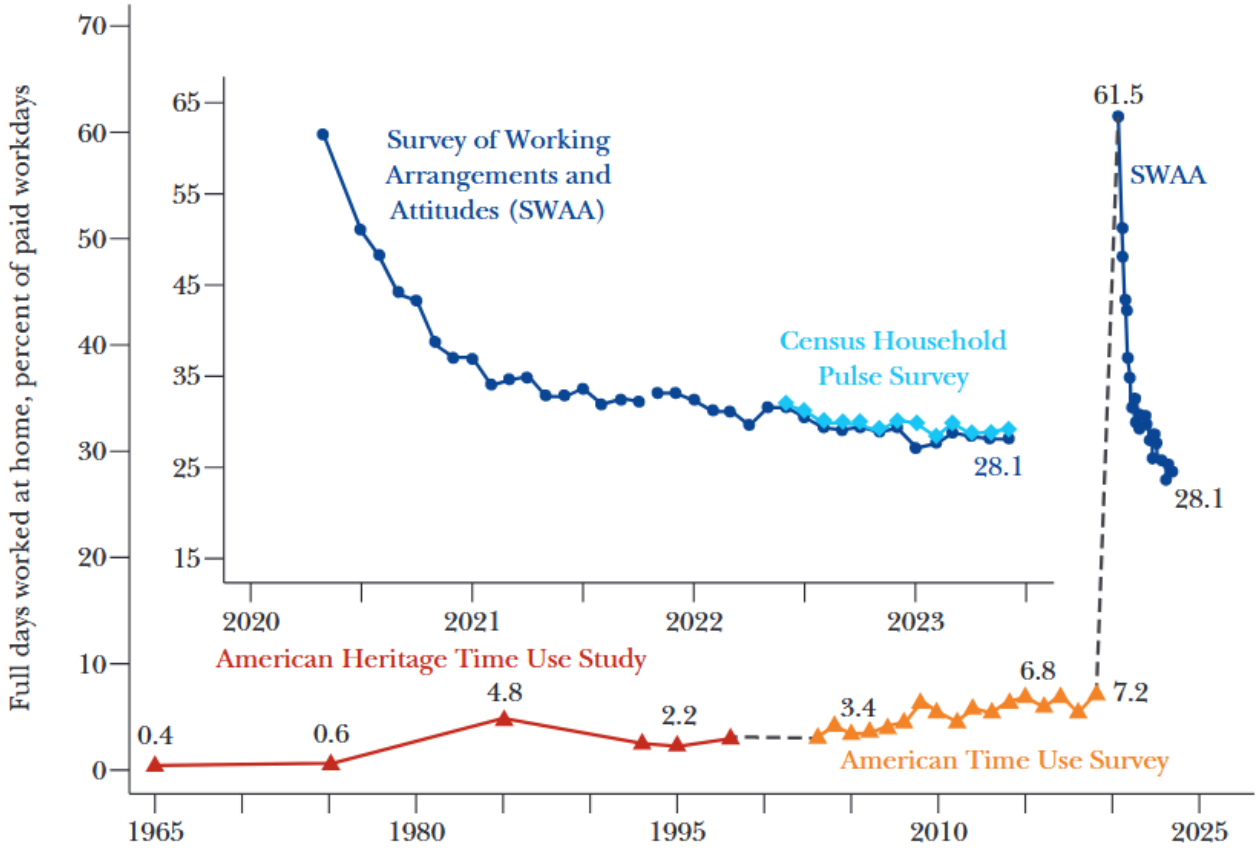
WFH rates tend to be higher in Auckland and Wellington, whereas Canterbury residents are more likely to work from the office. In Auckland, it may be a response to avoiding longer commute times, with commutes from the suburbs taking an hour or more.

Of interest is the evidence of behaviour change where private vehicle, active mode and public transport observed demands are trending towards pre-COVID-19 levels. This suggests a change in the composition of travel purpose, which will likely be revealed during the next census or Household Travel Survey. A key question will be whether WFH continues and at what rate. The difference between some employers' and employees' beliefs as to productivity at home is creating some conflict such as the extremities of the legal action lodged against Commonwealth Bank of Australia by its staff union (see section 3.2.2).

Research by Barrero et al. (2023) is an indication of the legacy of WFH from the peak WFH outcomes associated with the pandemic. Figure 4.9 shows a curve peaking at a rate of >60% of full days worked (covering the entire workforce from ages 20–64), declining towards 2023 and seemingly settling around 28% of workdays. In the 2023 survey, 59% of workers were commuting to the workplace daily, while 12% work permanently remotely and 29% have a hybrid working arrangement. This indicates a potential long-term shift in WFH practice in the US. While pre-COVID-19 rates are not shown, they are published as 7% in 2019. The four-fold increase is attributed to:

- the latent development of broadband, enabling communication technologies
- the catalyst of a pandemic and lockdowns
- the favourable surprise of many workers at the ability to be productive from home
- the adoption of flexible working practices by employers as a means to enhance recruitment, including the post-COVID-19 period where resources, including human resources, were increasingly scarce.

Figure 4.9 WFH over time in the United States (reprinted from Barrero et al., 2023, p. 24)



The slope of the curve in Figure 4.9, if extrapolated, would suggest WFH is a new normal. However, change is non-linear and therefore very difficult to model. An example of how this might fit a bigger picture could be found in the Kübler-Ross curve (1969), otherwise known as the change curve. Initially developed to map the stages of human grief, the change curve is widely applied to many different circumstances surrounding behavioural responses to sudden change events. The main feature is an initial loss of engagement followed by a period of increasing acceptance leading to integration of the new normal – a permanent step change.

There would therefore be three possible futures:

- **Decline** – likely to be very gradual, based on the slope in Figure 4.9.
- **Stability** – a permanent state of 28% of workdays being conducted from home.
- **Growth** – a Kübler-Ross extrapolation.

Even if the future were in decline, if it occurred at the rate of the slope in Figure 4.9, it could be 20 years before reaching zero – a period that would include an average of 14% of days WFH. If the trend does remain constant, 28% of commuted trips (approximately 20% of all trips in New Zealand) would represent an overall decrease of 6% of trips, mostly during peak periods. This is a significant amount of travel to consider.

The relationship between flow rate and delay tends to raise exponentially after the degree of saturation reaches beyond 0.7, a characteristic of peak period travel in many New Zealand cities. Therefore, a reduction of 6% of trips could have a disproportionate impact on travel efficiency, including at the rate energy is consumed.

Much of this decrease would likely be at the expense of public transport patronage, which could undermine public transport fare box recovery and its greater role in attracting more energy-efficient travel behaviour.

5 Significance and relationships between variables

This chapter sets out to rationalise the behavioural variables identified from the literature review into the context of place and role in a forecasting tools. This includes estimating the potential statistical significance (whether it qualifies to be included) and readiness to observe and measure (how it can be included) and noting the characteristics of the variable for purposes of adapting plausible methods, including models. Rationalising the variables took place over several steps.

5.1 Characterising variables

The first step synthesised and mapped the relationships between the variables, informed by the breadth of the literature review. Figure 5.1 shows the hypothetical causal connections between variables and WFH, with stronger (more evidence) relationships shown in more solid lines and weaker (less evidence) relationships depicted in dashed lines. The faintest lines were theoretical though not unfounded. The bolder the colour, the greater the presence of the variable in research sources.

Figure 5.1 also illustrates collinearity or independence between the variables – an essential stage in forming a hypothesis shortlist of variables believed to explain WFH and their eventual rejection or acceptance into a specification. This provides useful insights as to how the variables could progress into a model and why some variables will not be deemed as independent.

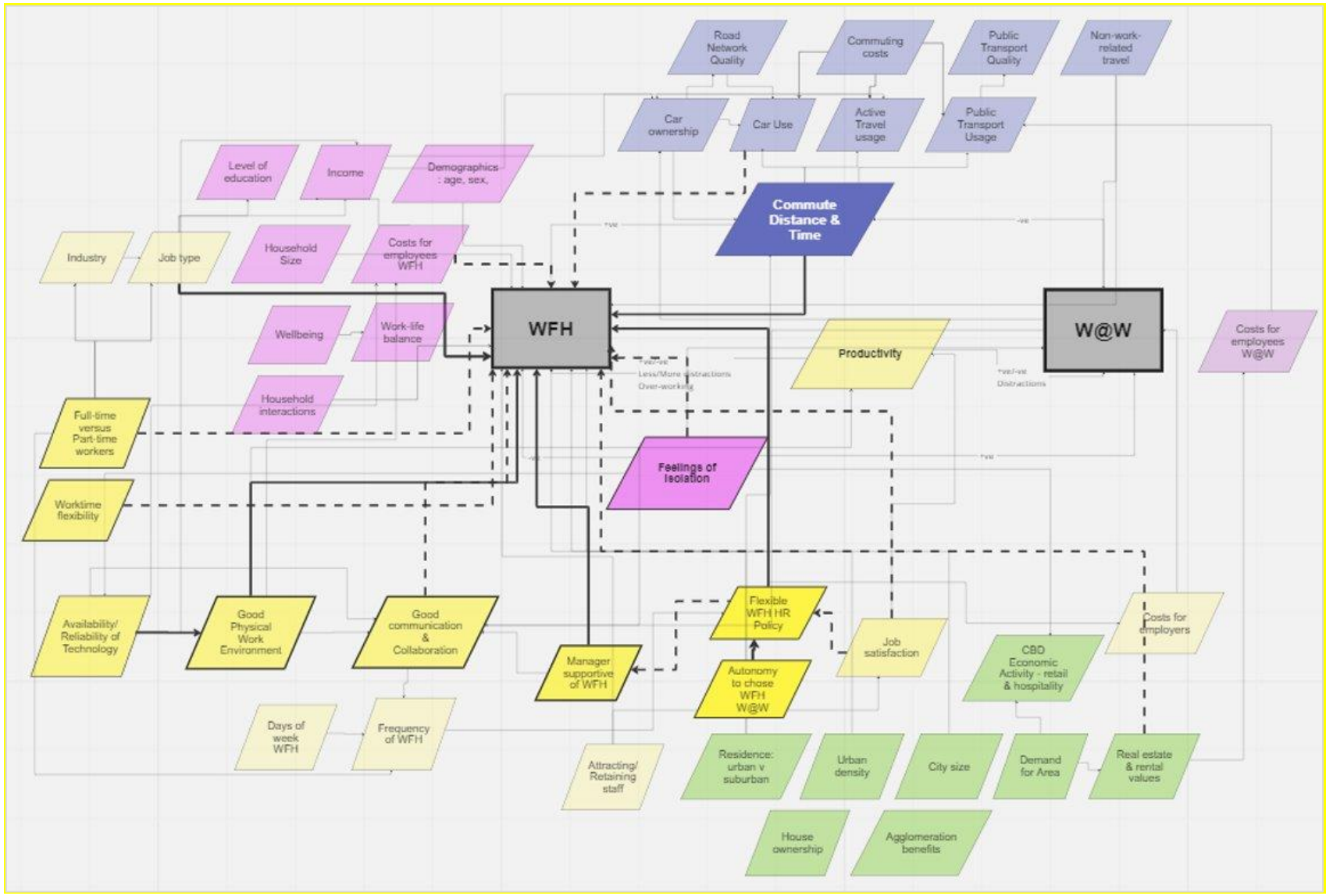
This method can also serve to highlight potential practitioner's bias, noting that, with many forms of modelling, the specification and framing of variables is subject to the beliefs of the practitioner. The potential for bias was managed through comparing the beliefs of the team – there was consensus that Figure 5.1 represents a reasonable and realistic network of relationships.

Examples of insights from Figure 5.1:

- Level of education and income might explain WFH but they also explain job type.
- Job satisfaction is considered a weak explanative factor of both WFH and the development of flexible WFH HR policy. The market would direct unsatisfied employees to correct their level of satisfaction (change jobs), noting New Zealand's characteristically competitive labour market.
- Commute distance and time is derived from mode choice, in turn derived from income. This is supported by evidence that those using public transport would be far more likely to WFH. The idea of costs feeding into public transport usage would be more than simply money – it would be the perceived costs of dealing with overcrowding and transfer penalties. Therefore, predictors of public transport use – many of which are already used in models – could also be used to predict WFH outcomes. Increased car ownership is associated more with work at work.
- The role of technology and appropriate home set-up – the impacts on good communications and collaboration and therefore flexible WFH HR policy. No one would be permitted to WFH if they were unable to do the work.

Next, variables were categorised as detractors or enablers of WFH with the assumptions noted (details are provided in Appendix D:Table B.5.1). A model of the future must be developed to allow adequate headroom to accommodate changes in whatever form of simulation is adopted. Consideration was also therefore given to the possible futures impacting on the variables and how the variable may continue to hold a role as detractor or enabler. In some cases, the role of a variable might flip over time – for example, employer policy could be a detractor in an environment where there is suspicion of WFH productivity outcomes or an enabler in a future environment where WFH is accepted by leaders and where cost reductions (associated with increasing rental values) are priorities. This outcome – being a change of sign from positive to negative – would represent a problem for the model, requiring adjustments.

Figure 5.1 Synthesis of relationships between variables.



5.2 Rationalising variables

Following the characterisation of potential variables, it was possible to consider which were more or less significant and assess other properties that may present statistical or modelling challenges or opportunities. Factors considered were:

- the hypothetical significance of each variable based on the available evidence
- consideration of independence or confounding with other variables
- the metrics contained within each variable and how they are measured
- assumptions of how variable data might behave, including against possible outcomes considered below.

5.2.1 Variable significance and independence

Based on evidence identified in the literature review, variables were categorised by the likelihood of the variables being independently able to explain the outcome of WFH – their statistical and substantive significance. The top two – industry type and employer policy – are considered highly significant. A hypothesis of independence for each variable was then developed, including any foreseeable collinearity that could bias or limit the goodness of fit of a model. The variable deemed to have the strongest relationship was considered the independent variable (for more detail, see Appendix D:). It is also worth noting all variables progressed were generic – relevant to both alternatives in a choice set. Having been regressed from the outcome of WFH to demonstrate significance, the variables would then be arranged in a covariance matrix in order to statistically examine the relationships. The covariance is calculated as the sum of the variance for each variable divided by the number of data points and the outcomes arranged in a covariance matrix:

$$Cov(x,y) = \frac{\sum(x_i - \bar{x}) - (y_i - \bar{y}\,)}{\mathrm{n}}$$

$$\sum = \sigma^2 \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

This provides a basis to examine the covariance between variables. Where there is strong correlation between variables, there is unlikely the opportunity for both variables to be truly independent. The model would be slanted towards explaining the relationship between these variables instead of describing the alternative. In the case of WFH, an example would be the confounding relationship of employer policy and productivity. One would expect that productivity would be a lagged variable of employer policy. If modelled on the time series basis that captures lagged variables (for example, using structural equation modelling), the inclusion of both of these variables may be appropriate. However, if included in a discrete choice method and the datasets were highly corelative, it would possibly be inappropriate to use both. The variable considered as most significant in explaining WFH outcomes would be selected and the other(s) set aside. It would likely not be considered further in a discrete choice model, but its rejection may yet detract from the model. It may be possible to consider interaction effects with other variables, which may improve the model fit. Even if it did not feature in the choice model, it may also be useful in a prior fuzzy stage or considered within scenario planning analysis. For example, scenario planning would use tools such as consistency analysis, which considers the state given variables would need to be in for a given alternative to prevail.

A total of nine variables were considered not to be independent and are greyed out in the summary (Table 5.1). However, there would still remain need for some testing to gauge the value of interacting these variables with the independent variables. For example, employer policy is considered collinear with productivity and employer and employee costs. This stands to reason. If productivity were to become a real

or perceived issue, employers would issue policies limiting WFH opportunities. It could also be reasonably assumed that employer policy would have a stronger influence on WFH outcomes than the two other variables it is considered confounded with. Consequently, the two variables are greyed out as they cannot be considered independent within the same model as the dependent employer policy variable. Table 5.1 takes the hypothesis one stage further and, through analysis of the literature review, aims to understand the statistical behaviours of the variables. Greyed-out variables are excluded either on grounds of believed significance or on grounds of independence (collinearity or autocorrelation) explained below. Table 5.1 summarises the rationalising of variables, bringing together information about the variables gained from the assessments to develop plausible hypotheses and assumptions for using each in a model. It also includes the plausible statistical behaviours of the variable datasets derived from the literature review.

Table 5.1 includes certain error parameters, including:

- **identification problems** – variables that are difficult to measure/frame measurement parameters around
- **transfer errors** – variables or circumstances that relate to a given model situation (such as geographic) but would require re-estimating for use in an alternative circumstance
- **ordinance/distribution** – a well-fitted distribution, usually normal (ordinant)
- **stationarity** – a single distribution parameter within a series
- **autocorrelation** – the correlation of error across different time periods invalidating the premise of independence
- **heteroskedasticity** – the escalation of variance – for example, in relationship to access to resource where more resource gives rise to more possible outcomes.

Table 5.1 Assumptions made of the behaviour of variables

Variable	Metric	Data behaviours						Hypothesis/assumption
		Identity issues	Transfer errors	Normality/distribution	Stationarity	Autocorrelation	Heteroskedasticity	
Industry and employment type	Category (type)	✓	✓	✓				Some types more likely to WFH than others. Possibly identified as an alternative rather than a variable. Would require strategic models to run a number of WFH options, would increase resource requirements. Possible to limit to commercial (office), light industry, heavy industry.
	Number of employees	✓	✓	✓		✓		Employees of smaller companies more likely to WFH. Potential for autocorrelation within different size organisations.
Employer policy	Number of days permitted to WFH	✓						Employer policy will strongly impact WFH outcomes. Number of days permitted to work – difficult if non-constrained (everyone could WFH on Friday). Either interaction effect with industry type or a factor used at the end of the process.
Employer and employee costs	WFH set-up costs ($)				✓		✓	Set-up costs for employer would be confounded with policy. Cost-related heteroskedasticity for employees: increased resource = increased choice = increased variance. Also potential for series autocorrelation.

Variable	Metric	Data behaviours						Hypothesis/assumption
		Identity issues	Transfer errors	Normality/distribution	Stationarity	Autocorrelation	Heteroskedasticity	
Home working environment quality	Dedicated space (binary)						✓	A dedicated, comfortable space will increase probability of WFH. There may be resource-related heteroskedasticity: increased resource = increased choice = increased variance. Some characteristics (such as quality of heating) difficult to quantify, taste variations. Contingent valuation method might be deployed.
	Comfort (utility)	✓	✓	✓	✓	✓		
Trip characteristics and quality of access to the transport system	Distance							More expensive trips more likely to transfer to WFH. Problem of how WFH option impacts on generalised cost (the perceptions of cost). Will be good to solve utilities for physical travel with WFH as an alternative to avoid the outcomes of the irrelevance of independent alternatives fallacy. There may also be interaction with car ownership of quality of access to the transport system given the body of evidence that associates WFH outcomes with public transport usage. However, variables could be confounded if not handled properly: better access to public transport = more likely to use public transport = more likely to WFH is not likely to be equal to increased WFH outcomes based on access to public transport alone.
	Time							
	Cost of trip							
	Generalised cost							
	Distance to public transport stop (m)							
	Public transport headways (time)							
	Active travel options (relative metric)							
Communication, collaboration	Perceived utility	✓						Opinions of connectivity will drive WFH outcomes. Subjective measure – a matter of individual opinion and tolerance thresholds. A more universal metric might be productivity. Also note that WFH can be either an enabler or detractor of communication and collaboration depending on personality type.
Car usage and ownership	Number of cars in household						✓	Access to more cars = reduced probability of WFH. Resource-related heteroskedasticity: increased resource = increased choice = increased variance.
Reliability of digital access	Connection reliability	✓	✓	✓	✓	✓	✓	Better perceived quality of digital connectivity will increase likelihood of WFH. A binary question of connectivity or not would be resolved through employer policy. In terms of quality of digital connections, this would be a subjective measure – a matter of individual opinion and tolerance thresholds.
	Connection speed		✓				✓	Faster upload and download speeds will be associated with more WFH outcomes. Measuring speed can be very location specific and may be more of a perception. Logarithmic distribution of perceptions with rate of increase tapering off at say 50 MB/s.
Household interactions and conflict	Number of persons per room							More crowding = more conflict = less WFH.

Variable	Metric	Data behaviours						Hypothesis/assumption
		Identity issues	Transfer errors	Normality/distribution	Stationarity	Autocorrelation	Heteroskedasticity	
Real estate, rental demands, values	Corporate perceived cost							A reduced tolerance for cost of space (potentially driven by a seemingly cheaper alternative of WFH) will shape employer policy and probably WFH outcomes. Therefore, this variable is not independent.
Income	Salaried income (NZD)						✓	Higher earners more likely to WFH. This variable might be considered confounded with industry type but would be more likely to be independent under more restrictive employer policy regimes.
Education level	Highest attained qualification (scaled category)		✓		✓		✓	Strong correlation between education level and WFH opportunities – likely to be confounded with income and/or employment type.
Productivity	Corporate performance	✓	✓					No hypothesis possible – corporate information on productivity (to the extent useful to modelling) would be commercially sensitive. Different businesses would be impacted in different ways. In any case, the matter of productivity would be manifest in employer policy.
Family and social influence	Number of dependants			✓	✓		✓	Can be either a detractor or enhancer depending on personality type. May be confounded with industry type/company size.
Social connectedness and wellbeing	Perceived freedom within social construct	✓		✓	✓			Can be either a detractor or enhancer depending on personality type. May be confounded with industry type/company size.
Urban characteristics – city size, density	Population, density categories	✓						Larger, more dense (high-rise) cities will include more employers associated with WFH outcomes. However, this implies being confounded with employer types, which can be specified within a given model area.
Location, proximity to CBD	Distance from CBD central point (m)	✓		✓		✓		Commercial employment sites closer to CBDs and on the edge of town may be associated with higher perceived access costs and therefore more WFH outcomes. Distribution (distance/perceived cost) likely to be parabolic, non-stationary. Could be used to enhance the generalised cost function.
Cultural and social attractions	Perceived utility	✓		✓				Use of contingent valuation could reveal the role of coffee culture as an indicator of the value of culture in drawing people away from home. This could counteract the perceived costs associated with accessing the CBD (a push and pull effect).
Agglomeration effects	Density of certain industry types		✓	✓	✓	✓		Agglomeration effects can impact markets in multiple ways, including some covariance (such as increasing rental values) may also reduce distance transaction costs. A difficult variable to manage, more likely to be confounded with employer policy.
Property tenure			✓					Tenure does not explain WFH as an outcome. Some circumstances beyond income (such as immigration status, industry type) influence outcomes.

Variable	Metric	Data behaviours						Hypothesis/assumption
		Identity issues	Transfer errors	Normality/distribution	Stationarity	Autocorrelation	Heteroskedasticity	
Job satisfaction, career prospects		✓						This variable would be self-correcting – if one is not satisfied, one would change job in the longer run.
Gender						✓		Inconclusive correlation, likely to diminish in future as opportunities are increasingly not defined by one's natural circumstances.
Age						✓		Inconclusive correlation, likely to diminish in future as opportunities are increasingly not defined by one's natural circumstances.

The final rationalised shortlist of variables is presented in Table 5.2.

Table 5.2 Shortlist of independent variables

Variable category	Variable unit
Industry and employment type	Category (type)
	Number of employees
Employer policy	Number of days permitted to WFH
Home working environment quality	Dedicated space (binary)
	Comfort (utility)
Reliability of digital access	Connection reliability
	Connection speed
Family and social influence	Number of dependants
Household interactions and conflict	Number of persons per room
Location, proximity to CBD	Distance from CBD central point (m)
Cultural and social attractions	Perceived utility
Trip characteristics and quality of access to the transport system	Distance
	Time
	Cost of trip
	Generalised cost
	Distance to public transport stop (m)
	Public transport headways (time)
	Active travel options (relative metric)
Car usage and ownership	Number of cars in household
Income	Salaried income (NZD)

The next steps are to identify a suitable process for capturing and including these variables for the purposes of informing future planning decisions.

6 Approaches to modelling in New Zealand

Ultimately, transportation modelling has been developed to support evidence-based decision making. Much transportation modelling practice in New Zealand uses tools with origins in a time where access was facilitated via physical mobility and the growth of physical mobility was inextricably connected to the growth in energy. Since these times, New Zealand and the world have witnessed the rise of digital mobility and increasing activities of governments and societies to address climate change. Policy responses to COVID-19 – naming restrictions in movement to prevent the mass loss of life – have demanded the realisation of a more digital age manifest through a rise in WFH.

Many of the tools used to perform modelling pre-date these disruptions. Although many have been retrofitted to include an additional mode (such as cycling) or a longer time period, many modelling tools are not keeping pace with changes in where, when and how people move and increasing levels of uncertainty. Therefore, there may be challenges including WFH and derived variables never before included.

Uncertainty is an inevitable element of forecasting, and there are guidelines in place for its communication and management, particularly in an investment decision context. The leading approach is sensitivity testing – effectively stress testing an economic evaluation against a particular parameter to which the forecast outcome is sensitive. Since COVID-19, the variable of WFH has been named as one such parameter. However, there is limited ability to define a suitable test, and execution of the test is achieved through manipulating a latent variable given that behavioural explanatory variables of WFH are neither generally represented in models or included as independent variables.

The demands being placed on models are also increasing in response to global challenges, as defined below. The key interventions considered include the ability to:

- model emissions under the emissions reduction plan
- model VKT, noting a policy to reduce by 20% by 2030
- model road user charges to a standard addressing investment assurance criteria
- model rail/light rail schemes to a standard addressing investment quality assurance criteria.

Although there are several sensitive factors that could impact on these, the role of digital access is arguably the greatest that is not explicitly represented in models. As will be explained below, a high or low preference for digital connectivity – most notably WFH – could significantly change the forecast performance outcome of these interventions. Therefore, inclusion of WFH in model frameworks to a robust standard will serve the purpose of more informed decision making and better outcomes.

The task of accommodating WFH variables into a model is complex given the diverse typology of variables and ability to scale them relative to one another. Even working through these issues of heterogeneity and hierarchy, there will be challenges associated with capturing some of the subtleties (or taste variations) of the variables. More complex forms for regression analysis can accommodate taste variation (see Appendix B:). There are also a range of tasks that models can perform, each being potentially better suited to accommodating certain WFH explanatory variables than others. These tasks are predicated around simulation and forecasting.

Therefore, options to include WFH in models must consider varying approaches, including methods of managing bias and uncertainty. To do this, there must be a clear understanding that models have two functions: to simulate and to forecast. For a more detailed description of forecasting and simulation methods, see Appendix B:.

6.1 Modelling theory and applications – background

Transport modelling has been used for half a century to provide insight into investment decisions. Known as four-stage modelling (4SM), the classic form involves trip production, trip distribution, mode selection and assignment simulation. It has arisen following the rise of computing and has provided powerful insights into potential user costs and benefits of possible interventions at the point of planning, thus informing value for money prospects. Modelling has reached a critical period of evolution. 4SM was developed in the automotive era characterised by a steady flow of oil and steady growth in GDP with relatively little attention paid to negative external costs incurred through fossil fuel-driven growth. It was an era where road building was regarded as progress, with the 1988 UK Department for Transport programme named Roads for Prosperity (Dietz, 2015). It is also noteworthy that most roads constructed as part of the significant urban expansion of the era were privately funded whereas public transport alternatives usually required subsidising.

In the early 2000s, the phenomenon of decoupling GDP growth from VKT was deduced throughout many of the OECD group of nations. The rise of the digital age had enabled more instantaneous communication and more convenient access to goods and services. Simultaneously, the 1990s–2000s witnessed a period of sustained economic stability, and the rise of disposable outcomes and the service sector also led to a renaissance of higher-density urban living throughout much of the OECD. There have been alternatives to automation developing as a crucial means of access and participation within economies.

Furthermore, the political desire to cater for automation had also peaked following the increasing urgencies of climate change. Massive geopolitical changes were also raising questions around the stability and sustainability of established trading relationships and arrangements, further fuelling speculation around energy security. Investment in alternative energy has exploded in the new millennium.

In the late 20th century, transport modelling was a more straightforward exercise from the perspective of managing forecasting risk and uncertainties. This era saw advances in computing such as Van Vliet's computation of the Franke-Wolfe algorithm in SATURN and the rise of microsimulation in the early 2000s. These tools enabled insight into the benefits of expanding capacity to accommodate growth of a single mode of transport. Complexities such as estimating the interaction between automotive and non-automotive transport was a simpler exercise given a comparative lack of interest – particularly in active travel – compared to the present day.

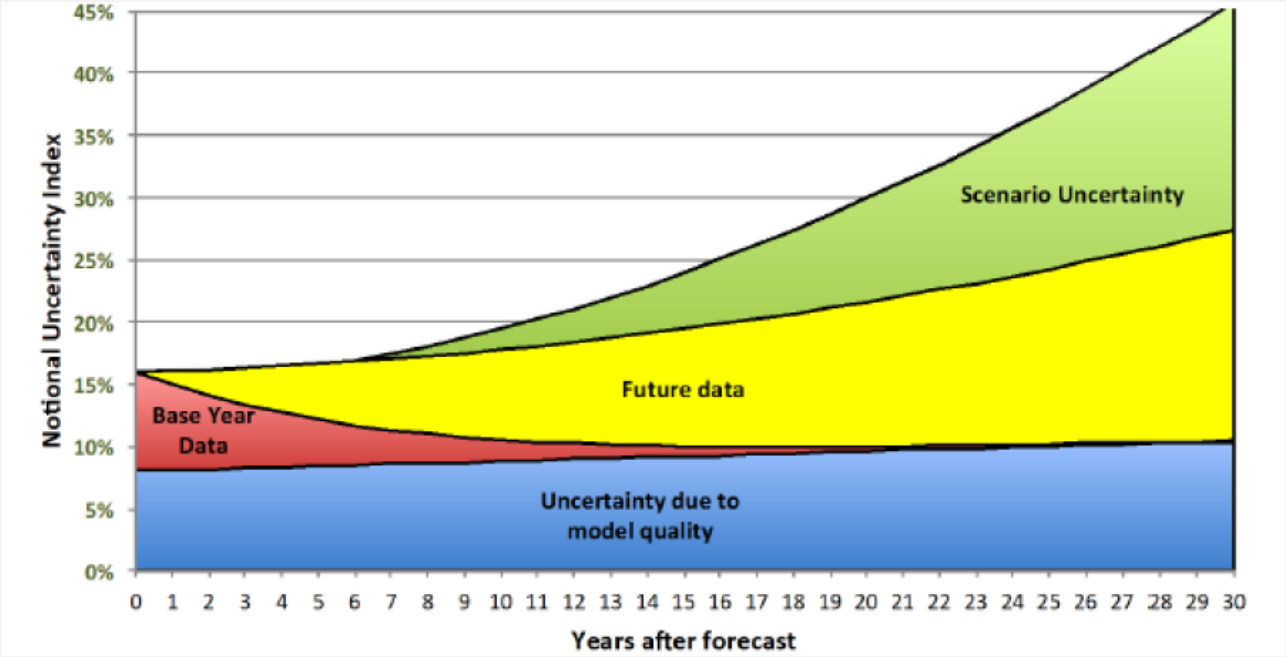
4SM involving trip production, trip distribution, mode selection and assignment simulation was widely developed and theoretically capable of forecasting multimodal demands, including public transport. However, many of the models built did not fully utilise capabilities enabling more critical multimodal demand forecasting due to the added cost and a lack of demand for these capabilities. Therefore, when appraising the step change of including WFH in modelling, it is a fair assumption that, for some models, including WFH would represent more than one step change.

Society has also changed – daily itineraries are now considerably more complex. An example of societal change is the ongoing progress made towards closing the gender gap in the workplace and the increased number of roles of players in a household. This has created an increase in touring. The renaissance of active travel and rise of micromobility raises the possibility of multimodal touring. The access to real-time information supports adaptive travel habits.

Traditional 4SM can incorporate touring but can only ever do so on an aggregated basis and only covering certain modes of travel in certain coarse time segments. Furthermore, the issue of uncertainty has increased as modelling attempts to forecast more complex travel behaviour in a market with increasing choice and therefore increasing unpredictability.

Byett et al. (2017) explored the issue of uncertainty from a New Zealand perspective, illustrating estimated sources of uncertainty from the perspective of the forecasting task (Figure 6.1).

Figure 6.1 Notional sources of uncertainty in forecasting (reprinted from Byett et al., 2017, p. 14, citing Willumsen, 2014)



There are aspects of Figure 6.1 more or less within the practitioner's control. Model quality can be managed through application of the transport model development guidelines (Waka Kotahi NZ Transport Agency, 2019) and the specific validation requirements. These include methods to validate both demands and operational performance (such as vehicle travel times) but also require development of an uncertainty log. Uncertainties associated with any stage or type of risk can be sensitivity tested – the parameter dialled up or down and the corresponding analytical outcome evaluated for its sensitivity to that parameter. Scenario uncertainty can be managed by very specific means either connected to or outside the model itself such as scenario planning.

The impact of risk and bias are well documented and will need to be taken into account with method selection and development. A pivotal study (Flyvbjerg, 2008) presented the findings of post-construction analysis into the accuracies of forecasting for a large number of infrastructures projects and attempted to attribute causes for error. One shortcoming in transport modelling highlighted at the time was found to be the general management of uncertainty. Uncertainty can be managed through various steps such as:

- recognising the usefulness of a tool – its best use as a tool but also its limitations
- keeping an assumptions log and transparency around assumptions
- transparent reporting of unvalidated outcomes – it is simply not possible to develop a perfect model as normalised data collection methods prevent this
- managing and accounting for unvalidated outcomes in conclusion and through application of the results
- developing sensitivity tests to compensate for flaws or other uncertainty to examine the level of project risk exposed to these issues.

However, there is an emerging paradigm shift as levels of uncertainty have become so significant that sensitivity tests are being increasingly relied upon. The inclusion of WFH variables could compound uncertainty and confidence issues. Therefore, alternatives to classic approaches to forecasting such as scenario planning are to be considered and explained further. For now, 4SM remains the most widely practised in New Zealand and will likely remain so until at least the end of the decade.

There are multiple modelling techniques, but most do not include a full four-step process of trip production, trip distribution, mode selection and assignment simulation. 4SM (described further in Appendix B:) is also known as strategic modelling or land-use transport integration modelling. The discussions around modelling capabilities are also framed through the lens of a strategic model. Due to their high-level nature, strategic transport models are described as aggregated in terms of network density, number of zones and timeframes. A strategic model is a complex mechanism weaving together social and operational data towards the purpose of expressing regional network demands from some causal perspectives. The purpose of these models, relative to other methods, is well described in the transport model development guidelines (Waka Kotahi NZ Transport Agency, 2019) and may be summarised as providing high-level insight into a programme or city/regional-wide initiative at a city or regional level. Examples of the use of a strategic model include supporting the economic case of an indicative business case for major infrastructure.

Several examples of 4SM are operating in New Zealand to varying degrees of complexity. The actual purpose served is sometimes determined by capabilities. Representing a relatively significant investment, a strategic model is considered an asset requiring careful management in terms of its use and applications.

4SM is often the primary tool in a suite of tools, each serving different purposes. For example, in Christchurch, the CTM model (developed in Cube Voyager by Stantec) is a strategic tool. The network is reasonably coarse, simulating the Greater Christchurch area within 400 zones, a fraction of the total road network (mostly arterial and collator routes), and representing peak hour network demands as 60% of the two-hour period total. The CTM demand matrix informs subsequent tools in the suite, including the CAST model developed in SATURN, of 3,000 zones across most of the network and consisting of three calibrated time slices per period. Outcomes from CAST can inform more detailed tools, including microsimulation.

The different model stages and their criteria for validation are shown in Figure 6.2.

Figure 6.2 Model purpose by category (reprinted from Waka Kotahi NZ Transport Agency, 2019, p. 14)

PROJECT APPLICATION	PURPOSE CATEGORY						
	A: REGIONAL	B: STRATEGIC NETWORK	C: URBAN AREA	D: NZ TRANSPORT AGENCY LARGE PROJECT	E: SMALL AREA /CORRIDOR	F: INTERSECTION / SHORT CORRIDOR	G: HIGH FLOW, SPEED, MULTI LANE
AREA DEMAND RESPONSES, LAND-USE/TRANSPORT PLANNING, POLICY INVESTIGATION	S	N	N	N	N	N	N
LARGER TRANSPORT SCHEME FEASIBILITY, SCOPING STUDY	S	S	P	P	N	N	S[5]
LOCAL AUTHORITY TRANSPORT INTERVENTION & LAND-USE PLANNING	S	S	S	P	P	P	N
OPTION TESTING, DESIGN REFINEMENT, ECONOMICS	P	P	P	S	S	S	S
DEVELOPMENT FORECASTINGS AND/OR IMPACTS	P	P	P	S	S	S	S
DETAILED DESIGN, TRAFFIC MANAGEMENT	N	N	P	P	S	S	S
ITS, INCIDENT MANAGEMENT, ACTIVE MODE DESIGN AND IMPACT	N	N	P	P	S	S	S

S STRONG CORRELATION

P PARTIAL CORRELATION

N GENERALLY NO CORRELATION

For avoidance of doubt, this research project is concerned with working in type A models, although the outcomes would cascade through the subsequent levels. Note the escalating finer levels of detail towards model types E, F and G. This research project also notes the validation criteria requirements of the guide.

6.2 Methods for forecasting mode choice

Within 4SM, the third stage – mode choice – requires a method to forecast choice. Many fields, including transportation, economics, marketing and social sciences, apply discrete choice models to understand and predict individuals' decision-making processes when a set of discrete alternatives are available. These models aim to capture the choices individuals make and relate them to the characteristics of the alternatives as well as individual-specific factors.

Table 6.1 includes a useful synopsis of the methods and their advantages and disadvantages that could account for choice. The methods range from a trend extrapolation to forecasting methods.

Table 6.1 Summary of forecasting methodologies (reprinted from Asgari, 2015, p. 22)

Methodology	Advantages	Disadvantages	Data and Research Needs
Trend extrapolation	Requires minimal data and analysis	Ignores trends in underlying factors that might alter currently observed relationships.	Time-series data on telecommuters and telecommuting frequency. Analysis of probable maximum adoption.
Analysis of telecommuter characteristics	Accounts for underlying trends. Relatively simple models required.	Based on correlations and does not reflect causal relationships.	Time series data on characteristics of telecommuters, especially occupation. Forecasts workforce characteristics.
Analysis of factors affecting the choice to telecommute	Accounts for causal factors at the individual level.	Models give probability of individuals choosing telecommuting but do not directly provide an aggregate telecommuting forecast.	Research on factors affecting the choice to telecommute. Forecasts of choice factors. Development of method for aggregating results.
Transportation forecasting models	Incorporates telecommuting into widely used planning models. Accounts for trade-offs between telecommuting and other travel choices.	Telecommuting represented as a simple alternative to other possible choices. Wide margins of error and insensitivities in models.	Travel surveys designed to identify telecommuting. Development of choice models.

Trend extrapolation employs a simulation-based method to allow an insight as to potential effects but without ability to speculate on the role of choice variables, which would be required to support specific enquiries such as relationships between WFH and public transport use.

The bottom and most comprehensive category includes forecasting. Stated disadvantages include wide margins of error. It is likely that a mix of approaches would be adopted, potentially using some of the analysis as basis for validation of more complex methods or in part informing a less-comprehensive initial step of confirming the existence and/or strength of relationship (the testing of null hypotheses) before proceeding to a more comprehensive and resource-intense method and with a greater degree of confidence in the hypothesis.

Transportation forecasting methods are the most comprehensive method of potential consequences of a certain intervention, including so-called winners and losers. This degree of analysis can inform on market consequences (such as impacts on public transport demands and therefore the commercial consequences for operators) as well as environmental (such as net impacts of an option towards the emissions reduction plan) and social justice (such as those affected by changed public transport catchments).

The prevailing method for predicting the probability that a decision maker will choose one alternative mode of travel over another is usually solved by logistic regression – the concept of defining a point on a trend in terms of the weights of the explanatory variables. Modelling of mode choice considers the cumulative logistic distribution of the probability of choice in relation to changes in cost, which forms a classic S shape.

The model outcome will be one that fits to a trend – it is the simulation of a trend, not of reality. Therefore, care must be taken both in terms of how fitting the outcomes are and also the degree of resemblance to reality (such as response testing of demand changes in the model to published arc elasticities). Care must be taken in analysing data quality (sample size, representation) and ensuring that a model is not overfit or tending towards offering so-called false precision if the quality of data does not allow.

The approach to modelling WFH, including choosing specification and method, requires careful planning. There are key parameters, all of which require a deeper level of understanding in developing a detailed modelling methodology. For further details on parameters, see Appendix B:.

7 Summary of variables and method options

It is clear that representing WFH in transport models will require multiple variables. It is also clear that neither the variables nor the current suite of modelling tools are immediately suitable for WFH. In order for feasible and robust means of incorporating WFH into models, methods will therefore need to be adapted and additional approaches identified. Of particular importance is the need to ensure the resulting method is appropriate to the variables needed to robustly model WFH.

7.1 Application of variables

Table 7.1 shows the 20 variables shortlisted for potential use in modelling. However, their characteristics mean they are not necessarily interchangeable across methods. Many variables are more suited to the more detailed population synthesiser of ABM rather than 4SM, which considers variations of population in zones – typically covering a neighbourhood block. In the Canterbury transport model, there is roughly the equivalent of one zone per thousand people. For some of the variables, it would be difficult to imagine a degree of variance in, say, the number of dependants or internet speed between one zone and another.

Table 7.1 Description of shortlisted variables and the best-suited method

Variable category	Variable unit	Coeff. ref.	Type	Best modelled in:		
				4SM	ABM	Neither
Industry and employment type	Category (type)	Et	Alternative	✓	✓	
	Number of employees	En	Categorical		✓	
Employer policy	Number of days permitted to WFH	Epol	Numerical			✓
Home working environment quality	Dedicated space (binary)	HWs	Binary		✓	
	Comfort (utility)	HWc	Derived		✓	
Reliability of digital access	Connection reliability	Dr	Derived		✓	
	Connection speed	Ds	Categorical		✓	
Family and social influence	Number of dependants	Wd	Numerical	✓	✓	
Household interactions and conflict	Number of persons per room	Wc	Numerical	✓	✓	
Location, proximity to CBD	Distance from CBD central point (m)	Ld	Categorical	✓	✓	
Cultural and social attractions	Perceived utility	Lu	Derived	✓	✓	
Trip characteristics and quality of access to the transport system	Distance	Td	(estimated)			
	Time	Tt	(estimated)			
	Cost of trip	Tc	(estimated)			
	Generalised cost	GC	Calculated	✓	✓	
	Distance to public transport stop (m)	Tptd	(estimated)	✓	✓	
	Public transport headways (time)	Tpth	(estimated)	✓	✓	
	Active travel options (relative metric)	Ta	Derived	✓	✓	
Car usage and ownership	Number of cars in household	Cn	Numerical	✓	✓	
Income	Salaried income (NZD)	Id	Categorical	✓	✓	

The ABM – in this case, including the national ABM model currently under development (Project Monty) – has two advantages in managing variables:

- The geographic area (national) and greater variance in variables such as internet speed.
- The possibility of archiving variance in the population through the population synthesiser and interacting with schedules – potentially better able to both capture and take advantage of the variance.

Table 7.1 also describes the variables in four categories:

- **Numerical** – possible answers can be directly applied (such as number of cars = 1, 2, 3).
- **Categorica**l – numerous possible answers, requires categories (such as income as brackets).
- **Derived** – requires a synthetic valuation method.
- **Estimated, calculated** – functions performed within the transport model.

Employer policy

Employer policy is included but will be difficult to apply to a framework. The opportunity to work, say, three days per week may result in an all or nothing response – there is no evidence of induced WFH by policy (except for government mandate). There is evidence of hysteresis in user behaviour change – the role of habit in decision making gives a user inertia, meaning that behaviour can fluctuate between two alternatives before settling. Other manifestations of habit can result in all or nothing outcomes. A user response to employer policy would be more of a long-run consideration and might be considered to be self-correcting – the employment market would adjust and those who seek to WFH will gravitate to roles that more allow it. There may be periods of hysteresis in the labour market as supply (days allowed to WFH) fluctuates around the ability to recruit. This outcome would generate non-stationary datasets, which would raise future challenges of incorporating any of this in models

On this basis, the matter of the number of working days permissible might be included as a simple dampening factor applied to the choice equation – dampening the WFH outcomes based on policy restriction. Sitting outside of the choice architecture means it can be adapted easily (without needing to re-estimate models) and could be managed through the scenario planning framework.

Industry and employment type

In practice, the parameter Et could also be an alternative, generating a separate employment type WFH and working at work probability. The consequence would be to multiply the analysis required by a factor of at least four times (depending on how many categories were considered).

At the model stage of population synthesiser, populations not within qualifying industries could be siphoned out and bypass the WFH discrete model stage directly to the mode split stage.

The practicalities associated with specifying Et as an alternative include the disaggregation of the home-based work trip purpose into, say, four types (of varying degrees of WFH association) – increasing the size of the model and the associated run time and data processing implications. This might be amplified in a direct demand method where trip production, distribution and mode choice are solved simultaneously (for example, the Auckland Strategic Transport Model).

Mode of transport

For ease, the multiple variables defining one's choice could be combined into a generalised cost coefficient. This is a measure already calculated in a 4SM framework.

Aspects of one's physical trip can probably contribute significantly to the ability to predict WFH outcomes. However, this will vary by mode of transport selected. Ideally, the parameter would be defined by a respondent's preferred mode to work. The management of this varies.

7.2 Estimation methods

7.2.1 Contingency valuation

Contingency valuation is a useful method for generating hypothetical values for variables from users where there are no obvious methods of observing values or equivalent units of measurement. (The full definition of contingency valuation methods is given in Appendix B:.) Contingency valuation methods might be considered in terms of the nature of the variable but also the nature of the model the outcomes will be applied to.

Table 7.2 includes the variables and those that would require a synthetic valuation method. For example, comfort is not measurable yet defines much of human behaviour. It is an area where respondents would likely be aware and could value their own importance of comfort. This valuation would likely be tied to something tangible such as a percentage of their income, thus generating scaled parameters.

Contingency valuation methods can also consider some of the confounded variables to strengthen knowledge of those relationships and also enable the possibility of interacting variables that may otherwise have been estimated using different methods.

Table 7.2 Hypothesised significant variables and those that may be derived via contingency valuation methods

Variable category	Variable unit	Coeff. ref.	Type
Home working environment quality	Comfort (utility)	HWc	Derived
Reliability of digital access	Connection reliability	Dr	Derived
Cultural and social attractions	Perceived utility	Lu	Derived
Trip characteristics	Active travel options (relative metric)	Ta	Derived
Confounded variables (for treatment via scenario planning or interaction with independent variables)			
Communication, collaboration	Perceived utility		Derived
Social connectedness and wellbeing	Perceived freedom within social construct		Derived

There would be two options that would include using contingency valuation methods to derive values for all variables versus using a mix of approaches (Table 7.3).

Table 7.3 Options for extent of contingency valuation method use (summary)

All variables measured through contingency valuation method		Mix of data collection, including contingency valuation	
Input parameters derived from single scale – useful for a multinomial logit or ordered approach	✓	Targeted use of contingency valuation methods – incorporates direct observations	✓
Substitution of direct observation – lesser outcomes – for some variables	✗	Differences in data acquisition and possible scaling consequence manageable – for example, nested logit	✓

In practice, the difference between the two approaches would be found within the integrity of the input data itself. There would need to be a method for converting heterogeneous data into a single format – there are different ways of managing this process. Substituting an observable dataset into a synthetic one would surely compromise the integrity of the model, particularly noting the well-documented challenges associated with gaining accurate valuations. Contingency valuation methods would be a convenient method for estimating input parameters for unmeasurable or qualitative variables such as comfort. However, the majority

of variables would not require synthetic valuation, further suggesting that a mix of survey methods would be preferred.

There are ways of managing the heterogeneity of the datasets and flow-on effects to modelling:

- Gather all information required in Table 7.1 using different questioning formats, behind which is a common scaling parameter or main effects plan (of, say, five degrees of freedom, -2 to +2).
- Use a specialised approach to modelling such as nested or ordered logit, which can manage heterogeneity.

The benefits of using a single survey allows for the possibility of panel data. Longitudinal survey panel data gives the modeller access to the same respondent over a period of time, offering far greater accountability over variance and other statistical considerations. It also allows observation of changes in behaviour and the ability to estimate some of the drivers of the behaviour change. Derivatives of choice change over time at different rates. For example, one interpretation of Figure 4.9 would be that the role of COVID-19 has resulted in a long-run 28% share in the number of workdays WFH – an equivalent quadrupling of the pre-COVID-19 value. There will be other forms of disruption, many smaller in effect. The use of panel data will assist in understanding behavioural choices and demand elasticities, including how users value those parameters that cannot be measured such as comfort.

It might also be noted that many of the more subtle impacts on WFH outcomes will probably not be manifest through surveys. This might include fashion and other tidal drivers of choice making, which may only be derived through exhaustive surveys.

Contingency valuation questions are based on hypothetical states, perhaps even asking the respondent to contemplate a scenario they have not experienced first-hand. A survey could be undertaken to look at workers' decisions in relation to factors such as home office set-up (heating/warmth, lighting, seclusion, furnishing/equipment), improved broadband and childcare. The respondent would be directed to consider only those marginal cost differences associated with additional days WFH, and existing costs such as childcare would need to be disregarded.

However, panel surveys require significant investment and planning and careful management of the sample to increase survey responses and minimise attrition. Some of the associated benefits could include improving longer-term investment forecasts. Even so, the data requirements for contingency valuation would require onerous and challenging survey questions and may need face-to-face interview methods such as already conducted by Stats NZ.

Sample bias would need to be controlled carefully as the outcome of WFH is associated with certain socio-economic characteristics. It is possible that a sample may be biased towards industries associated with WFH, and a successful model will need to be based on understanding the characteristics of the full spectrum of WFH outcomes.

7.2.2 Fuzzy logic

Fuzzy logic is a high-level method for identifying significant relationships, accepting/rejecting hypothesis. It can be a powerful initial step, identifying weaknesses in the data before proceeding to a fully blown method. It can be used to reduce risks associated with model performance (including specific issues described in Appendix B:. Fuzzy methods can be derived from best-worst survey methods, identifying individuals' priorities against a small scale from which parameters can be estimated. This can then form the basis of a more developed model for more accurate forecasting.

7.2.3 Structural equation modelling

Structural equation modelling was used effectively by Jain et al. (2022) to ascertain relationships between variables, arranged in terms of the planned behaviour theory model. The method was used effectively at modelling lagged variables and visually displaying relationships.

This has advantages over discrete choice methods, including that it:

- can explicitly assess measurement error
- can estimate lagged variables
- reveals a structure and more insight into specific goodness of fit.

Structural equation modelling has been combined with choice methods and may form an interim model step, simultaneously estimating high-level parameters (as would fuzzy logic) but also with the benefits above.

7.3 Logit models – viable architectures

7.3.1 Multinomial logit

The multinomial logit would operate by explaining the entirety of WFH outcomes in single step, shown below, where the utility factors (u) are subsequently explained. The utility factors have not been set out in their entirety, representing a chain of some 19 generic variables (they all apply to both alternatives) plus interaction effects that might be identified.

Probability derived from logit

$$P_{WFH} = \left\{ \frac{e^{U_{WFH}}}{e^{U_{WFH}} + e^{U_{W@W}}} \right\}$$

$$P_{WFH} = 1 - P_{W@W}$$

Where:

Synthetic utility, inputs to logit

$$U_{WFH} = ASC_{WFH} + \beta_{1WFH_{ET}} + \beta_{2WFH_{En}} + \beta_{3WFH_{Epol}} \ldots\ldots + \beta_{19WFH_{Id}} + \varepsilon_{WFH}$$

$$U_{W@W} = ASC_{W@W} + \beta_{1W@W_{ET}} + \beta_{2W@W_{En}} + \beta_{3W@W_{Epol}} \ldots\ldots + \beta_{19W@W_{Id}} + \varepsilon_{W@W}$$

The alternatives WFH and W@W denote working from home or working at work respectively.

This method can be dismissed quickly, notably because of the inability for a single error term to manage the variance and heteroskedasticity of a large number of heterogeneous variables. There are a finite number of parameters a single model can realistically manage.

The parameter Et (employment type) would also be an alternative, expressed as:

WFH Industry 1

…..

WFH Industry n

And:

W@W Industry 1

.....

W@W Industry n

7.3.2 Nested logit

In a nested logit model, a covariance matrix is developed to understand the interaction effects between variables and to highlight potential for confounded variables. Interpretation of the covariance matrix is part of estimating a model specification (including types and parameters).

Ortúzar and Willumsen (2011) identify other critical considerations:

- Alternatives that are more similar than others.
- Grouping variables separately that include certain characteristics (such as heteroskedasticity) and compensatory error term.
- Differences in taste variation.
- Variables of multiple responses from an individual (through panel data).

There are several ways the hierarchy may be framed.

Variable characteristics

In this case, five parameters would be derived from synthetic valuation methods and six estimated inside the model.

These variables might be nested accordingly, increasing ability to manage error distribution associated with heterogeneity.

Distance distribution or trip characteristics

This is a classic split in transport modelling given the relation between perceived cost and distance can be either non-stationary or heteroskedastic.

Preference

This is known as an ordered logit model and could be derived from a survey where all variables are derived using a contingency valuation method (benefits and disbenefits of this approach are described in Appendix B:).

Theory

Theoretical frameworks can provide the basis for hierarchical nesting.

For example, planned behaviour theory consists of three staged approaches to decision making ranked in order of significance.

Subjective norm – social obligations:

- Do the individual's social circumstances predict an outcome of WFH?

Perceived behavioural control – state of environment:

- Is the individual's environment conducive to WFH?

Attitudes – trip characteristics:

- Are the costs of the physical trip sufficiently high that the individual will WFH?

This framework is, of course, purely hypothetical unless proven.

Table 7.4 includes the workings of the variables into nests on the hypothetical basis that the arrangement is found to be valid, for example, through examination of the covariance matrix.

Table 7.4 Nested logit order by planned behaviour theory

Nest	Variable	Unit	Coeff. ref.
Subjective norm **(Us)**	Industry and employment type	Category (type)	Et
		Number of employees	En
	Family and social influence	Number of dependants	Wd
	Household interactions and conflict	Number of persons per room	Wc
	Home working environment quality	Dedicated space (binary)	HWs
		Comfort (utility)	HWc
Perceived behavioural control **(Up)**	Reliability of digital access	Connection reliability	Dr
		Connection speed	Ds
	Location, proximity to CBD	Distance from CBD central point (m)	Ld
	Cultural and social attractions	Perceived utility	Lu
Attitudes **(Ua)**	Car usage and ownership	Number of cars in household	Cn
	Trip characteristics	Distance to public transport stop (m)	Tptd
		Active travel options (relative metric)	Ta
	Trip characteristics and quality of access to the transport system	Distance	Td
		Time	Tt
		Cost of trip	Tc
		Generalised cost	GC
		Public transport headways (time)	Tpth

This structure works by estimating the probability of the first nest with that probability forming the start point for the second nest. Therefore, the probability is diminished by the third nest.

$$\mathrm{Us} = \mathrm{Us} \,/\, \mathrm{Us,p,a} = 1$$

And therefore:

$$P_{WFH} = \left\{ \frac{e^{U_{S_{WFH}}}}{e^{U_{S_{WFH}}} + e^{U_{S_{W@W}}}} + \frac{e^{U_{p_{WFH}}}}{e^{U_{p_{WFH}}} + e^{U_{p_{W@W}}}} + \frac{e^{U_{a_{WFH}}}}{e^{U_{a_{WFH}}} + e^{U_{a_{W@W}}}} \right\}$$

Figure illustrates the concept through the application of the WFH model as a primary split followed by a conventional generalised cost model governing the model choice of the residual demand. The architecture could be considered at a direct demand level, meaning the stages of distribution and choice could be solved simultaneously.

Figure 7.1 is not implicitly written to reflect 4SM (as the correct terminology would include the subscript $_{ij}$ – denoting the spatial dimension). Figure 7.1 could work through an ABM also, with all trips effectively representing a population synthesiser. The variables selected are not represented in transport models, and further, many would have limited value in an aggregated 4SM. For example, what basis would there be to vary the presence of dedicated WFH space between city block zone and another? Most of the variables

relating to the quality of the home working environment would likely not be calibrated in 4SM, and there would be questionable value including them at all. ABM, with a more complex population synthesiser, would be the more likely method to make effective use of these variables.

Figure 7.1 WFH choice model within broader framework

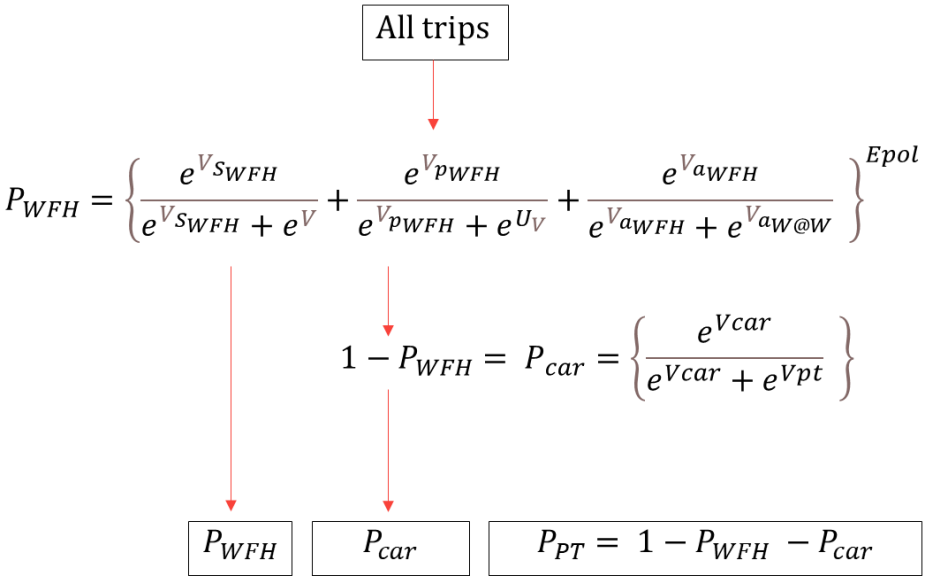
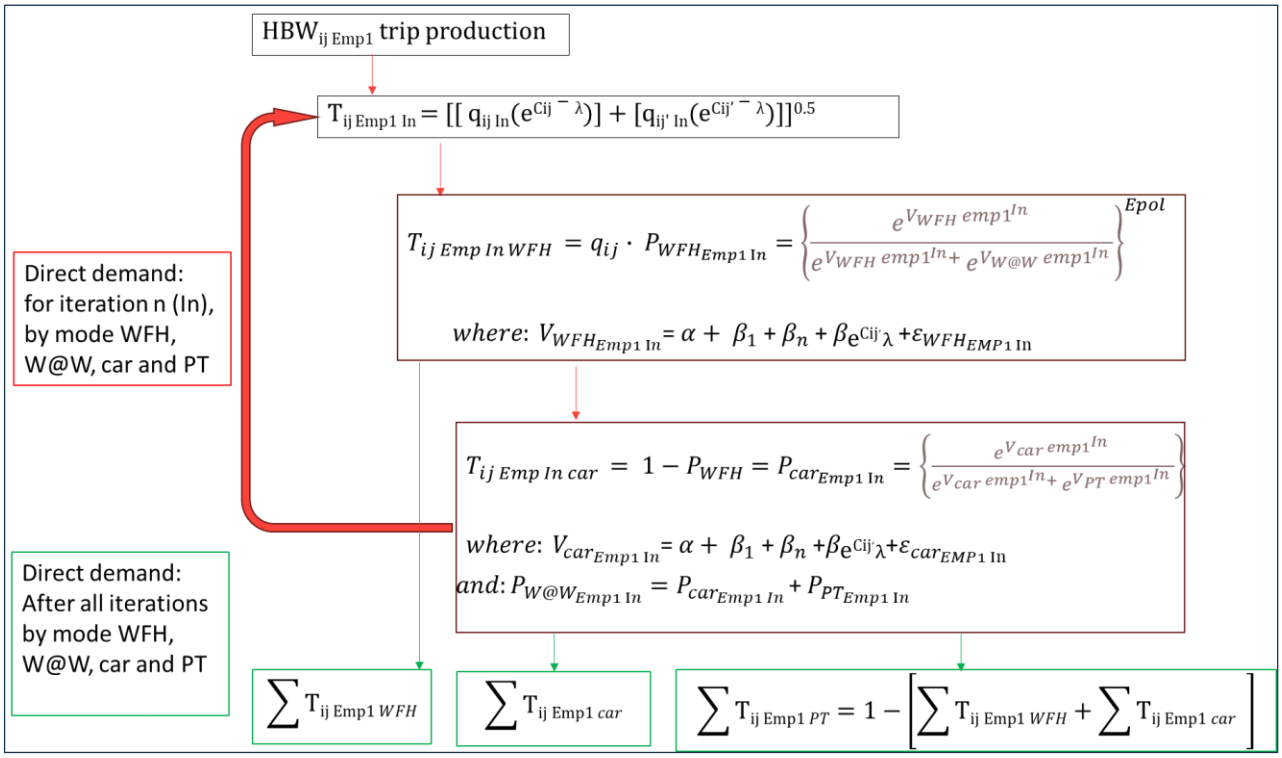


Figure 7.2 considers the method inside a direct demand sequence, a feature of strategic 4SM, including the Auckland Strategic Transport Model. It works by simultaneously solving an origin–destination matrix by mode. Figure 7.2 also helps visualise the feasibility of adding another mode and allows for some insight into feasibility. It begins by splitting up home-based work trips into composite industry – say, four categories, noting the significant relationship between industry type and WFH. The consequence of this is an (arithmetic) quadrupling of model resources associated with home-based work trips. Figure 7.2 describes a method of successive averages across an iterative framework, assigning trip lengths in accordance with the distribution, framed by cost (C_{ij}) and the scaling parameter ($-\lambda$).

Figure 7.2 Concept – the nested logit (simplified) inside a direct demand sequence



In this hypothetical framework, the cost could either be held constant between iterations, potentially aiding model convergence, or estimated at this stage. If held constant, the cost parameters could be estimated for each ij pair by sampling the network. If dynamic, the cost estimate would increase as a power, relative to demand, establishing a stronger relationship between increasing travel costs and the probability of WFH. However, it should be noted that outcomes from one nest do not correlate with outcomes from another and so interpretation will need to be managed with care.

A derivative of this cost could include distance. A theory could be that, the further away from work one lives, the more likely they are to WFH, assuming, of course, they have broadband.

Consideration should be given to the variance of C_{ij} -λ parameters between trip purpose. In practice, home-based work trips could be assigned via a different scaling parameter to, say, home-based education (where students often live closer to their place of study). The interaction between the -λ parameters and the β should also be handled with care. The importance of costs 'is more critical in the choice of mode than in the choice of destination' (Ortúzar & Willumsen, 2011, p. 213). Therefore, the value of the λ parameter ought to be greater than β. An advantage of nested logit includes the possibility of differing values of λ between the nests. This could allow the possibility of more complex choice processes to be modelled depending on how the nests are specified. The logit formula in Figure 7.2 does not show the nests themselves to save space. The hierarchies could be defined by either of the ways suggested above.

The parameter $Epol$ again sits outside of the logit sum, allowing for alternative estimate methods given the power and unpredictability of this parameter.

After n incremental assignment iterations, the outcome is shown as the sum total trips from zone I to j by the three modes considered. Active travel is not shown – although this example is purely hypothetical. The outcome from this matrix would be an assigned WFH matrix. If skimmed and differenced from loaded network skims, the value of reducing demands on the transport system could be measured and monetised. This model could also reveal impacts on public transport demands and specific parts of the network that would benefit most from a reduction in demands. Differencing to account for WFH would need to be done

within a common architecture (to avoid method bias), and therefore the concept above might include a dummy parameter to render WFH as irrelevant in order to achieve a base model where WFH is the subject of investigation.

A key limitation of applying this method to the problem is the reliance on habit and limited ability to consider more randomised decision making. A further development of the method itself may come in the form of scaling parameters to ensure that the composite structure reflects the utility maximisation principles (Ortúzar & Willumsen, 2011, p. 238).

7.3.3 Mixed logit and heteroskedastic mixed logit

The mixed logit form can reflect taste variation and/or heterogeneity effectively through the integration of a combination (a mix) of multinomial logit models (L_{iq}, estimated with parameters θ) and their dimensions, ($f(\theta)$) integrated.

This concept is set out:

$$P_{iq} = \int L_{iq}(\theta)\, f(\theta)\, d(\theta)$$

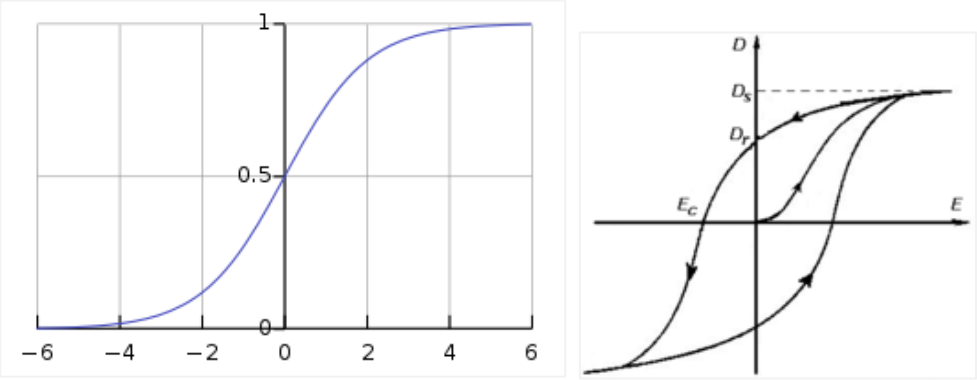
The mix can be specified in accordance with the variable distribution parameters and error structures – even the inclusion of heteroskedastic and auto-regression error distribution.

Integration of multiple distribution parameters is widely regarded as the most adaptive model choice although is not a widespread method in New Zealand. Other setbacks of mixed logit are that there is limited ability to know when optimisation has occurred. Machine learning is an evolving technology that may overcome this.

7.3.4 Hybrid method – panel data modelling

Methods to date have not considered temporal effects on choice – past behaviour influences future behaviour. User behaviour has inertia – users don't generally change behaviour straight away in the presence of a new alternative. There are parallels between this behaviour and hysteresis – the behaviour of magnetic waves when interrupted by an alternative pull. This is shown in Figure – the hysteresis curve demonstrates oscillation in demand until settling. Ortúzar and Willumsen (2011) consider this and the value in modelling with panel data.

Figure 7.3 Logit response curve (left), hysteresis curve (right)



The adaptation of mixed logit to accommodate the evolving panel data is shown in Figure 7.4.

Figure 7.4 Mixed logit panel probability (reprinted from Ortúzar & Willumsen, 2011, p. 260)

$$P_{iq} = \int_{\theta_q} \prod_{t=1}^{T} \left(\frac{e^{V_{jqt}(\theta_q)}}{\sum_{A_{i\epsilon A^t}(q)} e^{V_{iqt}(\theta q)}} \right) f(\theta q | b, \Sigma)\, d\theta_q$$

The mixed logit panel probability equation shows the probability of option A_i at time t as the integration of the product of a series of logit regressions corresponding to individual q at time t. T is the number of panel surveys corresponding to individual q, and previous estimates of utility of option A_i are represented as V_{iqt}.

Effectively, this function allows for the representation of time in choice probability and, importantly, the role of previous decision making.

A complexity associated with the method is interpreting the point where the model achieves the best fit. Additional data can either improve or detract from the model fit. The mixed logit functions are complex – the role of including taste variation in the same model as the mixed logit panel probability equation involves adding another integral within the product, which generates significant additional processing time. It also increases the complications of understanding when the model has achieved optimum fit.

The simultaneous consideration of taste variation could be developed through the expansion of the mixed logit panel probability equation to include a further integral inside the brackets. This outcome would result in a highly complex model that would include foreseeable resourcing issues and uncertainty as to whether any existing model frameworks could accommodate it.

7.4 Scenario planning methods

A challenge identified above is that some of the variables estimated from the literature review were considered likely to have a relationship with WFH outcomes but unlikely to operate independently in a model. The impact of covariance would mean the model describes relationships between the variables rather than describing the relationship between variables and the alternative. These variables are listed in Table 7.5.

Table 7.5 Previously identified covariant variables

Variable	Metric	Hypothesis Significance	Covariant with	Data type
Employer and employee costs	WFH set-up costs ($)	Probably significant	Industry type, employer policy	Categorical
Communication, collaboration	Perceived utility	**Likely significant**	Industry type, employer policy	Derived
Productivity	Corporate performance	May be significant	Industry type, employer policy	Categorical or derived
Real estate, rental demands, values	Corporate perceived cost	**Likely significant**	Industry type, employer policy	Categorical or derived
Urban characteristics – city size, density	Population, density categories	May be significant	Industry type, employer policy	Categorical
Education level	Highest attained qualification (scaled category)	**Likely significant**	Industry type, income	Categorical
Social connectedness and wellbeing	Perceived freedom within social construct	May be significant	Industry type, company size	Derived

Table 7.5 suggests a theme of covariance with industry type and employer policy. The former has been identified as an alternative – it is proposed that WFH must be estimated by employment type. The latter – employer policy – is considered potentially unmanageable and requiring a separate stream of work to properly comprehend.

While many of the variables tend to be endogenous, there are likely exogenous considerations behind what employer policy will be in 20 years' time. While business has the specific goal of returning on investment (an exogenous consideration), it could influence WFH policies if driven by a desire to reduce property expenditure.

Scenario planning provides an alternative to modelling. It requires participation of subject matter experts to:

- frame the big questions in a structured way – for example, by using a PESTLE framework (Table 7.6) (for more details on the PESTLE format, see Appendix C:
- consider the plausible and more or less likely outcomes using tools such as:
  - cross-impact analysis
  - cluster analysis
  - consistency analysis.

There are similarities between some of the tools developed between discrete choice modelling and scenario planning such as the covariance matrix fulfilling a similar role to cross-impact analysis. However, the benefit of scenario planning is to be able to extrapolate out trends but then interact them in a future state to analyse what must hold true for these extrapolations to be realistic.

Table 7.6 Hypothetical PESTLE considerations that could affect future corporate policies towards WFH

Political

- A political agenda to develop knowledge economies in New Zealand and a realisation of need for city shaping.

Economic

- What would be the role of digital infrastructure in maintaining New Zealand's high ease of doing business rating? What could the longer-term prospects of financing infrastructure for movement look like?

Social

- Work-life balance and changes to what is socially acceptable. Will we still be laughing at videos of children interrupting the conference calls of key figures in society?

Technological

- The future role of artificial intelligence. Will human-based roles become more or less automated?

Legal

- What will be the outcome of the Commonwealth Bank of Australia case (see section 3.2.2)? How wide reaching will it be?

Environmental

- How will WFH feature in future architecture? If future urban models are more compact and spatially constrained, will the possibility of operating more than one workspace be limited by cost?

Five of the variables shown in Table 7.5 are mainly derivatives of future employer policy and therefore will be part of the process of contemplating how that might change. They may well still be interacted with other variables in a choice model, but in doing so, this further increases complexity, especially around interpreting outcomes and attributing outcomes to specific causes.

Scenario planning will form part of all recommendations simply because it provides a basis to manage unpredictable variables and in a manner that can be understood and accepted. Caution will be required in the interactions between the modelling and scenario planning processes.

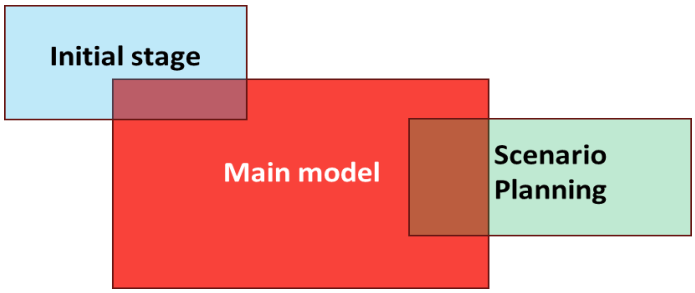
It is recommended that outcomes of scenario planning be used as scaling parameters that live outside of the discrete choice framework.

7.5 Recommended combinations

There is no single technique that can be used to predict WFH – the recommended options will comprise of combinations of methods working together. Both initial staging (such as fuzzy logic) and scenario planning, where variables are simply unpredictable, would likely prove useful alongside modelling with the conclusions triangulated across the methods.

Therefore, both initial staging and scenario planning form part of the basis of the option frameworks summarised in Figure 7.5.

Figure 7.5 Recommended conceptual framework formats



The combination of structural equation modelling and choice modelling is termed structural choice modelling (Rungie et al., 2011). It involves using structural equation modelling to create latent variables within the choice model specification – a powerful combination providing insight into causality and on a temporal basis.

Based on the examination of methods above, a scenario matrix of three options is derived (Table 7.7).

Table 7.7 Options matrix

		Main model			Application		Scenario planning
		Nested logit	Mixed logit	Hybrid	4SM	ABM	
Initial stage	Fuzzy logic	Option 1 Option 1A	Option 2 Option 2A		Option 1 Option 2	Option 1A Option 2A	Option 1 Option 1A Option 2 Option 2A
	Structural equation modelling			Option 3 Option 3A	Option 3	Option 3A	Option 3 Option 3A

The options include the Figure 7.5 form and are separated out into two sub-options – one for 4SM and the other (with the suffix A) anticipated to reflect ABM.

The anticipated differences between ABM and 4SM:

- ABM can represent more of the variance of variables where variance is distributed within society (captured though the population synthesiser) rather than spatially.

- Cost, available knowledge, degree of risk – 4SM is a more tried and true method. For example, Option 1 (partly conceptualised in Figure 7.2) represents structural modification. The national ABM (Project Monty) is still under development. Including a mixed logit framework would likely represent a significant step in development.
- There is limited skill and resource available experienced in using ABM, making it (for now) the least accessible alternative by the field.

7.5.1 Option 1/1A

Option 1/1A (Table 7.8) is the combination of fuzzy logic, nested logit and scenario planning along the lines of the architecture described in section 7.3.2. Option 1 develops this framework in 4SM and Option 1A in ABM. It could be developed with cross-sectional data.

Table 7.8 Option 1

Benefits of Option 1/1A	Drawbacks of Option 1/1A
Phased estimation of parameters, making use of disaggregated methods (fuzzy logic) to initially reject/accept hypothesis at minimal cost.	Inability to consider time series data or taste variations.
Compatibility with either modelling paradigm, currently a structure widely used in 4SM and the ABM population synthesiser.	Outcomes of one nest cannot be correlated with outcomes in another.
Ability to manage heterogeneous variables.	Inability to consider causality.
An accessible method requiring limited processing resource.	
Management of critical uncertainty by means of scenario planning solved independently of the super structure.	

7.5.2 Option 2/2A

Option 2/2A (Table 7.9) is the combination of fuzzy logic, mixed logit and scenario planning along the lines of the architecture described in section 7.3.3. Option 2 develops this framework in 4SM and Option 2A in ABM.

Table 7.9 Option 2

Benefits of Option 2/2A	Drawbacks of Option 2/2A
Phased estimation of parameters, making use of disaggregated methods (fuzzy logic) to initially reject/accept hypothesis at minimal cost,	Inability to consider time series data.
Ability to manage heterogeneous variables and heteroskedasticity.	Outcomes of one nest cannot be correlated with outcomes in another.
Ability to account for taste variance.	Inability to consider causality.
Management of critical uncertainty by means of scenario planning solved independently of the super structure.	Increased complexity, not widely practised in New Zealand.

7.5.3 Option 3/3A

Option 3/3A (Table 7.10) is the combination of structural equation modelling, panel data modelling and scenario planning along the lines of the architecture described in section 7.3.4. Option 3 develops this framework in 4SM and Option 3A in ABM.

Table 7.10 Option 3

Benefits of Option 3/3A	Drawbacks of Option 3/3A
Phased estimation of parameters making use of structural equation modelling to refine hypothesis and provide insight into causality.	Outcomes of one nest cannot be correlated with outcomes in another.
Ability to manage heterogeneous variables and heteroskedasticity.	Increased complexity, not widely practised in New Zealand.
Ability to manage taste variance as well (but see also drawback).	Requires commitment of highly specialised resources to develop over a number of years.
Ability to incorporate time series data – effectively including panel data into the mix (being an enhanced form of mixed logit).	Including both dimensions of taste variation and time series (panel data) involves a process of integrals of integrals implying longer run times.
Management of critical uncertainty by means of scenario planning solved independently of the super structure.	In practice, this probably wouldn't work via a direct demand assignment method (as envisaged for the nested logit), likely requiring a more significant modification in strategic transport model architecture to accommodate.

8 Method selection

8.1 Development of criteria

The criteria for method selection was developed in a steering group workshop with the research team. The process included consideration of the practicalities, risk, performance and stakeholder views. The practical aspects included being able to resource the required data and build a model that the industry could use. Risks related to developing ever-sophisticated methods and the ability of the model to perform at the required level and deliver on the intended purpose from a technical and stakeholder perspective**.**

The criteria are listed in Table 8.1.

Table 8.1 Criteria and description

Criteria	Description
Data resource required to develop, need for method change	Data collection needs to be resourced and would possibly require a business case justifying why existing data (Household Travel Survey, census) is not sufficient. This would be especially true for sourcing panel data as part of a specialised survey format. Cost would also include the development of the survey.
Transferability issues (such as regional differences)	There are regional variations on the variables that most affect transport choice.
Ability to engage with heterogeneous data and reflect variance	Some of the variables would likely exclude variance across the population rather than across space making ABM more suited to take advantage. It is assumed that variables that don't exclude variance in space would be excluded from 4SM as ineffective.
Potential forecasting integrity	A well fit base model, parameters behaving within a defendable range of elastic and cross-elastic outcomes.
Delivery risks (based on complexity)	The risk of overspend or lateness, expected to increase with a more complex model and requiring a more scarce resource availability to deliver.
Ability to interrogate, provide insights to meaningfully inform planning/intervention	A method that can predict operational changes by mode, spatially and offer insights into causality. A tool that could meaningfully contribute to spatial plans and major investment decisions.
Cost/resourcing implications for model build (excludes data)	The relative costs associated with method development. This may range from modifying existing tools to developing new and highly sophisticated ones.
Views of key stakeholder	Includes the wider industry, SMEs, model (asset) owners/managers. Some of the concepts raised would represent new approaches to practice and likely to attract a variety of opinions as to feasibility and degree of appropriateness.
Ease of use, accessibility, interpretability	The purpose of models is to support sound evidence and, in part, assurance of investment quality. The ability to deliver this outcome depends on availability of methods that are accountable and accessible to the field.

8.2 Multicriteria analysis

Multicriteria analysis was used to score the options in two ways – numerically (Table 8.2) and qualitatively (Table 8.3). In summary, Option 1/1A (combination of fuzzy logic, nested logit and scenario planning) would be preferred, being of least cost, least complexity (risk) and most accessible. It scores lowest in potential forecasting integrity, remembering that these scores are relative – the score of -2 doesn't mean the model would be unreliable but would be less able to capture the complexities associated with taste variations and time series. Conversely, the score of +1 attached to Option 3A is, as yet, theoretical and largely depends on the ability to capture all the choice attributes in an all-encompassing survey.

Table 8.2 Scoring of options (on scale of +2, -2)

Criteria	Scale	Option 1	Option 1A	Option 2	Option 2A	Option 3	Option 3A
Data resource required to develop, need for method change	+2 = low resource -2 = high resource	2	1	2	0	-1	-2
Transferability issues (such as regional differences)	+2 = high transferability -2 = low transferability	1	0	1	0	1	0
Ability to engage with heterogeneous data and reflect variance	+2 = high capability -2 = low capability	-1	1	-1	1	-1	2
Potential forecasting integrity	+2 = high integrity -2 = low integrity	-2	-1	-2	0	-1	1
Delivery risks (based on complexity)	+2 = low risk -2 = high risk	1	0	0	-1	-1	-1
Ability to interrogate, provide insights to meaningfully inform planning/intervention	+2 = high capability -2 = low capability	-1	0	0	1	0	2
Cost/resourcing implications for model build (excludes data)	+2 = low cost -2 = high cost	1	0	-1	-2	-1	-2
Views of key stakeholders							
Ease of use, accessibility, interpretability	+2 = most accessible -2 = least accessible	2	1	-1	-2	-1	-2
Total	+ = positive outcome - = negative outcome	3	2	-2	-3	-5	-2

Table 8.3 Qualitative (explanatory) scoring

Criteria	Scale	4SM/ABM	Option 1	Option 2	Option 3
Data resource required to develop, need for method change	Lower resource Higher resource	ABM population synthesiser could make use of all variables – more data	Cross-sectional data	Taste variations	Panel data and taste variations
Transferability issues (such as regional differences)	Higher transferability Lower transferability	ABM is a national model, more exposed	No difference	No difference	No difference
Ability to engage with heterogeneous data and reflect variance	Higher capability Mid capability Lower capability	ABM population synthesiser could make use of all variables	Cross-sectional data	Taste variations	Lagged data and taste variations
Potential forecasting integrity	Higher integrity Mid integrity Lower integrity	ABM population synthesiser could make use of all variables	Cross-sectional data	Taste variations	Panel data and taste variations
Delivery risks (based on complexity)	Lower risk Mid risk Higher risk	More knowledge around 4SM methods	More conventional	More complex	Extra complex

Criteria	Scale	4SM/ABM	Option 1	Option 2	Option 3
Ability to interrogate, provide insights to meaningfully inform planning/intervention	Higher capability Mid capability Lower capability	ABM population synthesiser could make use of all variables	Cross-sectional	Insights into time series	Insights into causality, time series
Cost/resourcing implications for model build (excludes data)	Lower resource Higher resource	ABM under development	Adapting existing tools	Longer-term project, panel data based. highly specialised	Longer-term project, panel data based, highly specialised
Views of key stakeholders	More supportive Less supportive				
Ease of use, accessibility, interpretability	More supportive Less supportive	Either method is already complex	An approachable method	A complex method, not widely practised	A specialised method
Summary			Less expensive, less effective	More expensive, more effective	More expensive, potentially most effective

Option 1 would be developed using cross-sectional data rather than panel data, resulting in a lower cost requirement than panel data. However, in reality, the survey would likely be repeated (for purposes of model updates) and, containing questions of the contingent valuation methodology, surveys would likely be delivered in an interview format. On this basis, it is possible that the relative cost differences wouldn't be so significant.

There are step changes in score between options bound for development under 4SM (1, 2, 3) and ABM methods. This is the product of:

- availability of skills (suitably trained developers and operators) in the field – it is also a method under development, which detracts from the score
- ability to incorporate more variables and more variance – a method likely to be more responsive to changes to the independent variable values and potentially more useful, which adds to the score.

Option 3 (combination of structural equation modelling, panel data modelling and scenario planning with 4SM) scores lowest because it is deemed both expensive and less effective. It is associated with the hybrid model but less able to gain traction on the capabilities this method could bring simply due to a primary reliance on space-based distribution of variables rather than population based.

The score of Option 2A (combination of fuzzy logic, mixed logit and scenario planning with 4SM) is actually lower than Option 3A – overall, the assessment deems it similarly expensive to Option 3A but slightly less effective. Option 2A still requires higher surveying costs to capture tastes through clustered survey methods. The development method still requires specialised input and would likely not be accessible to much of the field. The disbenefits of an inaccessible method include the limited realisation of technical benefits and subsequent benefits to investment assurance outcomes.

For these reasons, more simple methods may be preferred that balance the criteria of accessibility with accountability.

As the approach is exploratory, the following caveats apply:

- No logic process has been followed in developing the criteria relative to specific problems. Transport planning usually addresses criteria through developing investment logic maps where problems are specified and weighted. No such process has been undertaken.

- Assessment is not weighted in any way. If cost were weighted higher than performance, Option 1 and/or 1A would be favoured. If performance, then Option 3 or 3A.
- The scoring is relative, not absolute and not scaled. In reality, if one method would cost, say, 10 times more, a five-point scale is clearly inadequate.
- Key stakeholders have not been formally engaged, and this part of the assessment is incomplete.
- The variables considered and subsequent methods derived are still the subject of hypothesis not yet tested.
- The New Zealand ABM is still under development, and the application of panel data modelling to it might be optimistic at this stage.

9 Recommendations and next steps

Based on work to date, a triangulation approach is recommended that combines fuzzy logic, nested logit modelling and scenario planning with either 4SM or ABM (Option 1/1A). The combined methods are recommended as a feasible means of incorporating WFH as a mode into transport models. It is compatible with most existing tools and would be navigable by a sufficient number of suitably trained professionals in New Zealand.

The use of nested logit modelling means that the method can be used with either the current practice of 4SM or ABM. This will help futureproof the method in the possible event of ABM methods succeeding the current 4SM paradigm.

The non-weighted assessment of the methods reported here tends to favour the simpler approaches, primarily on grounds of resourcing and accessibility. While potentially offering some more technical benefits, a more complex method would in practice likely be used by a very limited number of practitioners and is therefore less likely to have a widespread impact. On the other hand, wider use of a simpler method could have more impact and provide a greater supply of investment quality assurance.

This research has been developed based on the interpretation of the literature review, including the statistical inferences of several studies. Data analysis and testing of null hypothesis of variables in the recommended method has not yet occurred and forms the next stage of proving the framework recommended.

There has not been stakeholder or widespread conversation within the modelling community, and therefore the assessment might be considered incomplete at this stage. With that in mind, the following steps are recommended to further refine the method and investigate important gaps in knowledge.

9.1 Further steps for methods refinement

There is further work required to refine and implement the recommendations, including:

- engaging subject matter experts and key stakeholders
- planning a cohesive programme
- making a case for investment – both the data collection and model development would represent an investment that requires justification
- engaging with data and statistical acceptance or rejection of the findings of this research
- further model development aimed at informing the impacts of increased WFH behaviour on physical networks and potentially adding value to the planning of digital networks.

There are also practical implications to consider, including the condition of the regional tools that would be called upon to run a modified choice framework. There are some three-stage or four-stage tools – mostly of smaller centres – that do not currently predict mode choice using frameworks presented. Therefore, the number of step changes represented by the recommendation would vary from one model to another. It would likely be several years, perhaps longer, to execute a full roll-out were this method proven.

Success will rely on adoption and recognition of the resourcing requirements of composite methods within the recommended framework. Scenario planning needs to be planned and programmed with a similar degree of care to that of the model, noting that it, too, consists of moving parts. It seems likely that its success will be influenced by the degree of attention paid during planning stages.

9.2 Further steps for research

Over the course of the research, four pertinent issues emerged. While out of scope for this work, we recommend further exploration.

Work from anywhere

This has huge potential, especially as it can be observed. One might decide around a primary work location for a given day, supported by making up one's contracted time on public transport or in a café. The ability to undertake the latter would likely undermine the decision to WFH. This research has not considered evidence as to how widespread this occurrence already is. 4SM would be challenged not least of all by the tour aspect of one's home-based work trip but also bound to a more aggregated estimation of utility for the varying stages of the trip.

A population synthesiser, on the other hand, would be able to develop a wider range of utility values, reflecting the differences in the value of time spent on public transport. The Project Monty ABM population synthesiser could theoretically be placed to simulate work from anywhere because of the process involved in calculating an agent's schedule based on the sum of tasks summing to a maximum utility value.

If a person's daily utility includes the requirements that they fulfil, say, eight hours of work and the model includes the possibility of working on public transport, the odds of selecting public transport in such a model would increase. The ABM model includes a number of personalities, meaning the architecture already exists. However, it would be a tough question to answer especially if many are opportunistic – they don't consciously plan to work on public transport and that this doesn't affect their locational decision making, but under survey conditions, they would return that they occasionally work on public transport from which a 'partially sighted' model would result. There may also be questions around the availability of any data with regard to working from anywhere.

Day of the week/modelling more than one week

This has also not been specifically developed. It is difficult as models presently include periods within a single day. This includes choice parameters endogenous to that day. The choice of one day would likely affect another. While there are potential solutions to capturing this in a model, the question really is around why certain days of the week are more popular than others.

A hypothesis is that there is an interaction effect with flexible working hours and the possibility of an early Friday finish at home – an early start to the weekend. Employees seeking to do less work on a Friday at home might explain the differences in perceived productivity that exist between employers and employees (see section 3.2.2). This is one of likely many reasons, but the weekend itself will likely interact. If these interactions and causes were understood within an acceptable degree of likelihood, a way to model it might be simply to factor the $Epol$ (employer policy) estimated externally to the model.

Travel demand management

Travel demand management is a successful suite of measures employed to elicit behaviour change towards supporting policy outcomes. One of the ways it is believed to be effective is through travel planning that uses a series of surveys and engagement to raise awareness around travel options available.

This process helps the user to better understand their true travel costs and to perceive them in a different way. To WFH is increasingly seen as a means of travel demand management. The changes in perceived cost are difficult to model, especially if these perceptions are more fluid in a world of ever greater choice and service.

Other options for not travelling

Home-based work trips are not the only trip types where digital connectivity offers a substitute to movement in space. Home-based education, telemedicine and, to some degree, online shopping might also be considered, although with great difficulty in the case of the latter given the likelihood of induced demand caused by ease of digital access. There is clearly work for continued development.

Considering the shortcomings, the recommendation is to develop a three-part process of initial regression and a detailed model integrated within existing tools and engage meaningfully with scenario planning as a well-considered approach to the unpredictable.

10 Discussion and conclusion

The results of the study presented here have identified a feasible method for incorporating WFH as a transport mode into transport models. By triangulating across a combination of fuzzy logic, nested logit modelling methods and scenario planning, transport decision makers/modellers would be able to incorporate the important WFH factors in a statistically robust manner. The nested logit method in combination with fuzzy logic and scenario planning can be used in both 4SM and ABM, ensuring it will be fit for purpose as transport modelling evolves.

Following a review of literature related to the drivers of WFH, 20 variables were shortlisted for inclusion in modelling across four domains: work and employment factors, transport and accessibility, social and demographic factors, and land use and environment. Variables were selected on the basis of the strength of evidence for a significant relationship (statistically and/or theoretically) along with their suitability and utility in various modelling methods.

Underlying data is suggesting that WFH is here to stay. If US data (Barrero et al., 2023)) is applied to the New Zealand context (noting no identified New Zealand data is available at this stage), an indictive long-run effect of COVID-19 would be a 28% share of workdays WFH. In New Zealand, this would equate to an average reducing of around 7% of all trips although not evenly distributed by mode or time.

The methodology included engaging heavily with behavioural scientists in the research of identifying variables and early rationalisation of significance and inter-relationships. One desired outcome was that variable selection would not be biased by considerations of model specification. To this end, the technical specifications considered have been derived in parallel and response to the identity of the variables and their foreseen challenges. In essence, the intent of the work is to present a method that (in the absence of statistical analysis) could be close to a final method.

A key limitation would be the ability to derive accurate data. The science of survey specification will be critical, including minimising probabilities of survey biases. There would be two foreseeable data collection challenges – the ability for respondents to capture the real values of some of the variables and the availability of accurate business data in understanding productivity and flow-on effects to corporate policies on WFH. Neither issue is readily surmountable. Contingent valuation is a realistic method for incorporating variables that would have an identification problem and could be framed around a stated preference or revealed preference approach, although each has its own limitations. A key consideration in practice would be respondent fatigue – a survey must be limited to a reasonable response timeframe. While there may be an option to split the survey up, this would deny the opportunity to derive a common main effects plan capable of scaling all responses together. The second matter of accessing business data to inform flexible/WFH policy outcomes is more challenging. Although there are existing surveys, including by the Ministry of Business, Innovation and Employment in New Zealand and the Australian Productivity Commission, these can tend to be retrospective. Business intent is commercially sensitive information, and no business would publicly acknowledge that its staff are less productive for WFH. Some businesses may share details of productivity increases, meaning that business data could be biased, and the nature of the sample (in terms of size, typology and so on) should be appropriately scrutinised.

There are also challenges in any tool developed being able to capture behaviours that may be considered as short run and long run. Capturing a short-run forecast for WFH may be seen as aiming at a moving target, as behaviours may change on a daily basis and working location arrangements be made adaptive to circumstances affecting other parts of daily life such as the influence of dependants. Modelling of the pre-digital world considered habits and hysteresis – the notion of travellers settling into a groove. Habits can be ways of increasing certainty – of arriving at a certain time or being able to board a public transport vehicle at a time prior to the system reaching capacity. WFH is a means of adapting to challenges and the rising costs

of commuting in New Zealand. Population growth and the growth for movement has outpaced infrastructure investment and therefore levels of service have declined and journey time reliability is more uncertain. The increasing frequency of weather events such as Cyclone Gabrielle in 2023 are adding to movement constraints, and climate change forecasts suggest an increase in monsoon conditions in Auckland. The post-COVID-19 world has generated other deterrents to attending the physical work environment, including some high-profile anti-social behaviour in the main city centres.

There is also the question of flexible working practices generally and how the home could be one of many places of work. Flexible working could be potentially captured in ABM, which works by assigning trips and mode over the course of a day with a given trip selected by the extent to which it increases utility (estimated on a cumulative basis). In theory, the utility maximisation could extend to the extent to which work might be undertaken on a given leg (such as public transport) or more commuted trips being deferred in time (an increase in what is currently known as peak spreading). The ABM methodology could also be stochastic, enabling varieties of possibilities.

There is still no certainty that short-run responses to the rise of WFH have been fully captured and understood. As of December 2023, there was another wave of COVID-19 infections being reported in the media, which some may perceive as an indication that a full return to business as usual is yet to happen.

Business as usual, if defined from the pre-COVID-19 world, may never return. Global economic instability and derived consequences such as war and anti-social behaviours are also occurring, and the full ramifications are yet to be seen. An arguable driver of continuing flexible working practices in New Zealand is related to the highly competitive labour market and historically low unemployment. If the New Zealand labour market were to become less competitive – an outcome expected following corrective monetary policies towards inflation – there may be less incentive for businesses to allow WFH or flexible working practices. This is true for businesses that would perceive benefits of time in the chair in the office as more than worth the costs of the extra floor space and servicing. The circumstances surrounding business responses to flexible working options are both complex and sourced via highly sensitive information and deemed as beyond forecasting in a transport model. An alternative approach would be via scenario planning, which could bring together business experts. This initiative would likely benefit other sectors also and may already be under way or planned in another sector.

Longer-run responses to WFH would include changes to the housing market, including the types and locations of properties sought. It may be too soon for insight given that, on average, around 2% of the New Zealand stock changes hands annually and this rate has reduced following a slow-down in the housing market in response to central bank monetary policies and flow-on effects to lending rates. There are many possible outcomes, including the increased attractiveness of remote living, following the opportunities to reduce travel costs. This has been a historical outcome seen around the world associated with provision of high-speed transport connecting cities and regions (and the so-called distance decay theory that suggests reducing perceived costs/km over longer distances) and providing access to more affordable housing. If a commuter needed only travel occasionally, sensitivity to distance from the city may reduce. However, there is more to location than travel considerations. Location decisions vary based on tastes and preferences such as a preference for city living (and access to culture and the arts). These tastes might correlate with, for example, creative industries, which may be more likely to support flexible working practices. Therefore, long-run location choices are complex and may prove to be supply driven. Latent government policy in New Zealand has identified high-density living within established urban areas as more desirable from the perspective of improving energy efficiencies, emissions reduction and reducing the rates of servicing (infrastructure and so on). In effect, location responses to WFH would be constrained by supply, especially noting the national population growth forecasts, the forecast undersupply of housing and the planning instruments that exist to direct housing growth areas.

Therefore, there may be no or limited additional land-use modelling associated with WFH. This would depend on how the trend plays out and might include, for example, recalibration of the -λ scaling parameter used to assign trip length distribution.

A wide range of methods have been considered, and none by themselves can fulfil the task. Each method is associated with a school of thought themed around overcoming limitations. Modelling in the traditional sense has been found wanting in recent times given the increasing complexities of travel and options available to users, which are considered by some to have exceeded the capacity of these methods. Some may consider a natural successor of traditional modelling to be less forecast centric and more decision based. Many indicators point to the need for widespread behavioural changes as part of adapting to emerging challenges such as climate change. Some would suggest the modelling of alternatives to necessary changes as distracting and therefore question the continued value of modelling.

Some would see the succession of 4SM as an improved methodology such as ABM and/or using some of the more sophisticated choice analysis options described. While these methods will remain imperfect, they do have capabilities to adopt a broad range of behavioural variables distributed across population rather than in space. From this perspective, these methods have the capability of simulating options and showing their benefits and therefore supporting decision-making dialogue.

4SM itself is still the most widely used throughout much of the world given that it includes well-established assets that can be more cost-effective to update than replace. They do also provide value, albeit this will likely diminish more over time and may eventually require replacing. The possibility of 4SM being adapted in ways currently unforeseen cannot be ruled out. It may also be true that New Zealand transport models are not being used to their full potential and so adopting the recommendations in this piece could constitute more than one step change in practice for some regions.

In either format, models can be useful in measuring the consequences of decision making and are a necessary part of demonstrating investment quality assurance for major interventions and therefore part of the broader commitment to achieving competitive use of public resources. A key theme in modelling practice discussions around the world is how models are used and represented. The limitations of a simulation or forecast are now typically discussed between project teams and uncertainty management strategies agreed upon. Nobody expects a model to be perfect, but when used as a tool in the correct context, it can be useful and insightful.

Some of the variables exist outside of forecasting for which alternative management methods are recommended. However, the assumptions made still fit within a simulation, and provided the basis of the assumptions is made clear, the correct context of the simulation can be represented. This may lead to a need to develop multiple futures – a practice already effectively encouraged through sensitivity testing and a basis by which the Ministry of Transport intends to apply the ABM Project Monty. Lyons and Davidson's (2016) notion of decide and provide encourages the generation of multiple futures and the selection of interventions that score under the greater number. While this is an overgeneralisation of the concept, it is an example of how models can be properly represented and reduces the probability of investing in white elephants.

In terms of arriving at a quality future insight, the use of scenario planning or similar appears unavoidable. A foreseeable issue for this is ensuring proper understanding of the process and the role of different parts and players towards realising the full potential. Points to consider are that it requires careful planning and resourcing. It is more than a convenient dumping ground for variables that don't fit the model. In this case, serious consideration was given to the key variable and the collection of (confounding) derivatives, and if done properly, the variables of choice would be defined through the scenario planning process as well as they possibly could be.

Consideration has also been given to the technical combination of the process of forecasting and scenario planning. Although they appear together in the same expression, they are developed separately and such that the change of one doesn't necessitate re-estimating of both. This method is developed for simplicity and with maintenance/update programming in mind.

The world is changing, and the extrapolation of linear trends has long proven ineffective. While scenario planning may offer glimpses of disruption, there is no panacea for seeing forward 50 years, and the inclusion of WFH in the context of transport models as we use them now is especially complicated. The notion of work from anywhere seems like a utility-maximising strategy that could benefit society. In this world, perhaps speed would no longer be the objective but rather certainty, much like the principle of moving freight on canals. However, the benefits of capturing WFH in evaluation will help to measure those benefits to society, including contributions to strategic issues such as climate change and congestion in cities like Auckland. In doing so, we will be able to measure the digital and physical outcomes together – an outcome that some leading thinkers consider to be the next paradigm and a step closer to a more connected world.

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Appendix A: Literature review subject coverage

Table B.1.1 Literature coverage of key subject areas

	Reference	Used in review	Transport	Land use	Social	Modelling
1	Arentze & Timmermans (2004)	✓	✓			✓
2	Arling (2004)	✓	✓		✓	
3	Asgari (2015)	✓	✓		✓	✓
4	Auld et al. (2016)			✓		✓
5	Beck & Hensher (2020)	✓	✓		✓	
6	Beck & Hensher (2021a)	✓	✓	✓	✓	
7	Beck & Hensher (2021b)	✓	✓	✓	✓	
8	Beck & Hess (2016)	✓	✓			✓
9	Brewer & Hensher (2000)			✓		✓
10	Ceccato et al. (2022)	✓	✓			✓
11	Centre for Economics and Business Research (2019)	✓	✓	✓	✓	
12	Faber et al. (2023)	✓	✓		✓	✓
13	Fu et al. (2012)	✓	✓	✓	✓	✓
14	Greaves et al. (2022)	✓	✓	✓	✓	
15	Green et al. (2020)	✓	✓		✓	
16	Habib & Anik (2021)	✓	✓	✓	✓	✓
17	Hensher et al. (2021)	✓	✓	✓	✓	✓
18	Jain et al. (2022)	✓	✓	✓	✓	✓
19	Kersting et al. (2021)	✓	✓		✓	✓
20	Kyriakopoulou & Picard (2022)	✓	✓			✓
21	Lyons & Davidson (2016)	✓	✓			✓
22	Mayer & Boston (2022)	✓	✓	✓	✓	
23	Moeckel (2017)	✓	✓	✓		✓
24	O'Fallon et al. (2004)	✓	✓		✓	✓
25	Productivity Commission (2021)	✓	✓	✓	✓	
26	Shabanpour et al. (2018)	✓	✓	✓		✓
27	Smargiassi et al. (2020)	✓	✓	✓		✓
28	Swardh & Algers (2009)	✓	✓		✓	✓
29	Thomas et al. (2021)	✓	✓		✓	
30	Wang et al. (2022)	✓	✓			✓
31	Zheng et al. (2023)	✓	✓	✓		✓

Table B.1.2 Literature supporting selected variables

Work and employment factors	Industry and employment type	Mayer & Boston (2022)	Beck & Hensher (2021a, 2021b)	Kyriakopoulou & Picard (2022)	Fu et al. (2012)	
	Employer policy	Green et al. (2020)	Jain et al. (2022)	Productivity Commission (2021)	Kyriakopoulou & Picard (2022)	Beck & Hensher (2021a, 2021b)
	Productivity	Zheng et al. (2023)	Beck & Hensher (2021a, 2021b)	Green et al. (2020)	Makarius & Larson (2017)	Jain et al. (2022)
	Employer and employee costs	Productivity Commission (2021)	Beck & Hensher (2021a, 2021b)	Willumsen (2014)	Moeckel (2017)	Green et al. (2020)
	Job satisfaction and career prospects	Weinert et al. (2015)	Greaves et al. (2022)	Kröll et al. (2017)	Arling (2004)	Beck & Hensher (2021a, 2021b)
	Home working environment	Mayer & Boston (2022)	Smit (2022)			
	Communication, collaboration	Mattey et al. (2020)	Miller (2021)	Beck & Hensher (2021a, 2021b)	Jain et al. (2022)	
Transport and accessibility	Trip characteristics	Mayer & Boston (2022)	Fu et al. (2012)	Lyons (2008)	Waka Kotahi NZ Transport Agency (2022a, 2022b, 2022c)	
	Car usage and ownership	Mayer & Boston (2022)	Habib & Anik (2021)	Waka Kotahi NZ Transport Agency (2022a, 2022b, 2022c)	Productivity Commission (2021)	
	Reliability of digital access	Beck & Hensher (2021a, 2021b)	Asgari (2015)	Reddick et al. (2020)	Lyons (2014)	
	Quality of access to the transport system	Productivity Commission (2021)	Moeckel (2017)	Greaves et al. (2022)	Mayer & Boston (2022)	
Social and demographic	Psycho-social determinants	Jain et al. (2022)	Haddad et al. (2009)	Hauslbauer et al. (2022)		
	Gender	Chung (2020)	Jain et al. (2022)			
	Age	Mayer & Boston (2022)	Shabanpour et al. (2018)			
	Income	Shabanpour et al. (2018)	Mayer & Boston (2022)			
	Family and social influence	Beck & Hensher (2021a, 2021b)	Productivity Commission (2021)	Chung (2020)	Bernhardt et al. (2023)	Jain et al. (2022)

	Education level	Shabanpour et al. (2018)	Zheng et al. (2023)	Fu et al. (2012)		
	Household interactions and conflict	Fu et al. (2012)	Bernhardt et al. (2023)	Green et al. (2020)	Eddleston & Mulki (2015)	
	Social connectedness and wellbeing	Greaves et al. (2022)	Green et al. (2020)	Eddleston & Mulki (2015)	Beck & Hensher (2021a, 2021b)	Centre for Economics and Business Research (2019)
Environment and land use	Urban characteristics – city size, density	Shabanpour et al. (2018)	Smargiassi et al. (2020)			
	Real estate, rental demands, values	Kyriakopoulou & Picard (2022)	Productivity Commission (2021)			
	Location, proximity to CBD	Productivity Commission (2021)	Zheng et al. (2023)			
	Agglomeration effects	Productivity Commission (2021)	Lyons (2014)			
	Cultural and social attractions					
	Property tenure	Mayer & Boston (2022)	Fu et al. (2012)			

Table B.1.3 Hypothesis of significance and collinearity

Variable	Metric	Indicative significance	Confounded?	Possible interaction effect (test for improved fit)
Industry and employment type	Category (type)	Probably		Communication, collaboration Real estate, rental demands Urban characteristics Proximity to CBD Education level Gender
	Number of employees	Probably		
Employer policy	Number of days permitted to WFH	Probably		Employer and employee costs Productivity
Employer and employee costs	WFH set-up costs ($)	Probably	Employer policy	
Home working environment quality	Dedicated space (binary)	Probably		
	Comfort (utility)	Probably		
	Distance	Probably		

Variable	Metric	Indicative significance	Confounded?	Possible interaction effect (test for improved fit)
Trip characteristics and quality of access to the transport system	Time	Probably		
	Cost of trip	Probably		
	Generalised cost	Probably		
	Distance to public transport stop (m)	Probably		
	Public transport headways (time)	Probably		
	Active travel options (relative metric)	Probably		
Communication, collaboration	Perceived utility	Likely	Industry type	
Car usage and ownership	Number of cars in household	Likely		
Reliability of digital access	Connection reliability	Likely		
	Connection speed	Likely		
Household interactions and conflict	Number of persons per room	Likely	Family influences	
Real estate, rental demands, values	Corporate perceived cost	Likely	Industry type, employer policy	
Income	Salaried income (NZD)	Likely	Industry type, age	
Education level	Highest attained qualification (scaled category)	Likely	Industry type, income	
Productivity	Corporate performance	May be	Industry type, employer policy	
Family and social influence	Number of dependants	May be		Household interactions and conflict
Social connectedness and wellbeing	Perceived freedom within social construct	May be		Industry type, company size
Urban characteristics – city size, density	Population, density categories	May be	Industry type, policy	
Location, proximity to CBD	Distance from CBD central point (m)	May be	Industry type	
Cultural and social attractions	Perceived utility	May be		
Agglomeration effects	Density of certain industry types	Probably not		
Property tenure		Probably not		
Job satisfaction and career prospects		Probably not		
Gender		Probably not	Industry type	
Age		Probably not		

Appendix B: Methods

B.1 Difference between forecasting and simulation

The task of accommodating WFH variables into a model is complex given the diverse typology of variables and ability to scale them relative to one another. Even working through these issues of heterogeneity and hierarchy, there will be challenges associated with capturing some of the subtleties (or taste variations) of the variables. More complex forms for regression analysis can accommodate taste variation. There are also a range of tasks that models can perform, each being potentially better suited to accommodating certain WFH explanatory variables than others. These tasks are predicated around simulation and forecasting.

Forecasting in transport modelling is often the action of extrapolation in the absence of foresight. Associated uncertainty risks are historically managed through sensitivity testing or other forms of range parameter testing such as discounted rates applied in economic evaluation. For example, the standard discounted rate to report net present value is 4% – ranges of 6% and 2% are also recommended to define the bounds within which the true net present value might be supposed to exist. A fundamental requirement of forecasting with confidence is the ability to replicate accurately the derivatives of choice such as to inform demand elastic responses to a given type of intervention. Although there are presently no forecasting guidelines in New Zealand, the model development guidelines highlight some validation outcomes through which a subsequent forecasting exercise might be achieved with a higher degree of confidence. These include concepts of matrix integrity, the process of deriving a future demand matrix being more or less fit for purpose depending on the extent to which it is altered in the base model, to reflect a network validation outcome. UK practice guidance (Department for Transport, 2020) includes base model validation of elasticities (arc elasticities) to test demand responses in a base model prior to being considered fit for forecasting purposes. Forecasting mode choice is fraught with uncertainty given continued interception of a future demand set with weighting variables (representing underlying willingness to pay profiles) derived from the present day. Ability to forecast well is becoming more difficult as more complex behaviours that explain choice are understood.

Simulation is distinctly different. It provides insight into operations, including broader network performance or demand elasticities to scenario changes. These scenarios usually include demands derived from a forecast, with the forecast integrity dependent on the complexity (and forecastability) of the subject. It is the simulation arm of modelling that is used to test the merits of proposed infrastructure, for example, the year at which it is recommended that demand for rolling stock will pass the threshold of requiring capacity upgrade. The Ministry of Transport's ABM Project Monty includes the simulation suite MATSim,[4] capable of simulating supply and demand outcomes on networks. Demands developed in Monty are also forecast based on population growth and so on, but the latent inclusion of a WFH variable is more of a scenario test at this stage rather than a forecast. Analysis of a simulation that combines scenario testing is capable of informing decision makers of the likely range of future operational outcomes within which the true future is likely to lie.

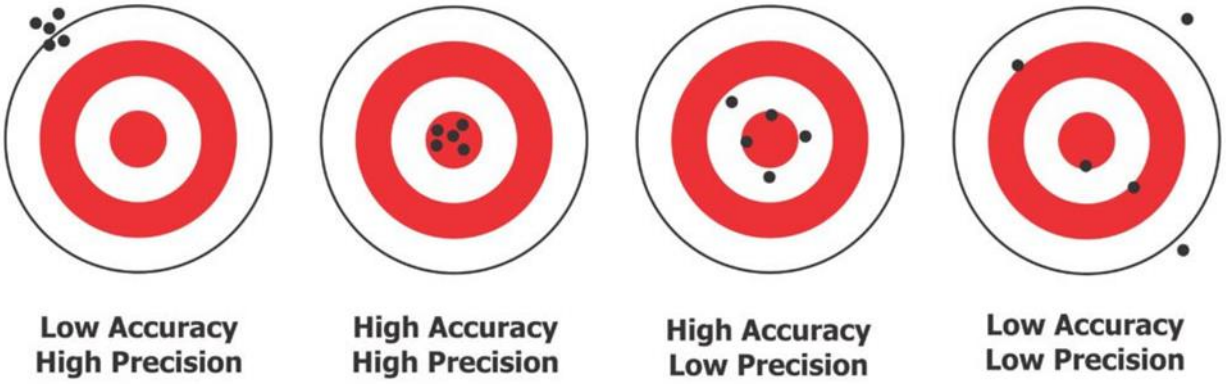
Reliance on forecasting alone can render a project open to a number of biases noted in the landmark paper by Flyvbjerg (2008). This work examines some post-construction outcomes from across the world and compares these to forecasting for road and rail projects and offers lessons in how to reduce bias and inaccuracy. A particularly interesting outcome is analysis of the time series contexts of the projects, suggesting that forecasts are not increasing in accuracy over time. Flyvbjerg summarises that relying on forecasts is risky and recommends a method specific to evaluating a certain project – that the project forecast outcomes be examined against a dataset of similar projects and their outcomes. This approach could be useful for the largest projects in New Zealand. However, it wouldn't constitute an approach that

[4] https://www.matsim.org/

could be used in context of model builds (inclusive of the set of smaller programmes and schemes) and therefore isn't included in section B.5.

Related to forecasting or simulation is the notion of precision and accuracy (Figure B.1.1). It is possible for one to be precisely wrong (high precision, low accuracy) or approximately right (low precision, high accuracy). Forecasting based on linear extrapolation of a world view of the present is largely uncontrolled and cannot account for disruptive influences. Scenario planning and system dynamics can compensate for this. Forecasting without uncertainty management yields risks from uncertainty (Flyvbjerg, 2008) yet these risks can be an opportunity to allow decision makers to play a part in shaping future society rather than having a more reactive approach that responds to trends (Lyons & Davidson, 2016).

Figure B.1.1 Difference between accuracy and precision (reprinted from Deveau, 2022)



Precision is defined by Willumsen (2014) as the measurement of resolution – the level of detail capable of being included. A technical challenge facing modellers is the fallacy of false precision. This might look like reporting simulated network delays to two decimal places where the required base model validation criteria require these simulations to be within ±15% of observation (Waka Kotahi NZ Transport Agency, 2019). Willumsen defines accuracy as the degree of closeness of measurement of a quantity to that quantity's actual (true) value. Accuracy is often held as a more useful outcome than precision, especially when one can be precisely wrong. A measure of accuracy can include goodness of fit (Flyvbjerg, 2008).

The role of simulation is required to measure the outcome of an intervention, subject to the demands that are plugged into it. Therefore, simulation is critical and supports accountable decision making. Forecasting is still one of the best approaches to overcoming the challenge of a lack of foresight, although evidence is suggesting that forecasting alone will render a view only through the lens of a biased perspective (mostly subconscious bias) and one that is rooted in attitudes developed in the past.

Therefore, options to include WFH in models must consider varying approaches, including methods of managing bias and uncertainty, and to do this, there must be a clear understanding that models have two functions: to simulate and to forecast.

B.2 Four-stage modelling (4SM): the traditional methods

Ortúzar and Willumsen (2011) have developed a source on informing available methodologies and applications. It is a go-to source, trusted across the industry. There are multiple modelling techniques, but most do not include a full four-step process of trip production, trip distribution, mode selection and assignment simulation. For clarity, 4SM is described in detail below. It is also known as strategic modelling or land-use transport integration modelling. The discussions around modelling capabilities are also framed through the lens of a strategic model. Due to their high-level nature, strategic transport models are described as aggregated both in terms of network density, number of zones and timeframes.

A strategic model is a complex mechanism, weaving together social and operational data towards the purpose of expressing network demand from a causal perspective. The purpose of these models, relative to other methods, is well described in the transport model development guidelines (Waka Kotahi NZ Transport Agency, 2019) and may be summarised as providing high-level insight into a programme or city/regional-wide initiative at a city or regional level. Examples of the use of a strategic model include supporting the economic case of an indicative business case for major infrastructure.

Several examples of 4SM are operating in New Zealand to varying degrees of complexity. The actual purposes served by these models is sometimes determined by capabilities. Representing a relatively significant investment, a strategic model is considered an asset requiring careful management in terms of its use and applications.

4SM is often the primary tool in a suite of tools, each serving different purposes. For example, in Christchurch, the CTM model (developed in Cube Voyager by Stantec) is a strategic tool. The network is reasonably coarse, simulating the Greater Christchurch area within 400 zones, a fraction of the total road network (mostly arterial and collator routes), and representing the peak hour network demands as 60% of the two-hour period total. The CTM demand matrix informs subsequent tools in the suite, including the CAST model developed in SATURN, of 3,000 zones across most of the network and consisting of three calibrated time slices per period. Outcomes from CAST can inform for more detailed tools, including microsimulation.

The different model stages and their criteria for validation are shown in Figure B.2.1. For avoidance of doubt, this research project is concerned with working in type A models, although the outcomes would cascade through the subsequent levels. Note the escalating finer levels of detail towards model types E, F and G. This research project also notes the validation criteria requirements of the guide.

Figure B.2.1 Model purpose, by category (reprinted from Waka Kotahi NZ Transport Agency, 2019, p. 14)

PROJECT APPLICATION	PURPOSE CATEGORY						
	A: REGIONAL	B: STRATEGIC NETWORK	C: URBAN AREA	D: NZ TRANSPORT AGENCY LARGE PROJECT	E: SMALL AREA /CORRIDOR	F: INTERSECTION / SHORT CORRIDOR	G: HIGH FLOW, SPEED, MULTI LANE
AREA DEMAND RESPONSES, LAND-USE/TRANSPORT PLANNING, POLICY INVESTIGATION	S	N	N	N	N	N	N
LARGER TRANSPORT SCHEME FEASIBILITY, SCOPING STUDY	S	S	P	P	N	N	S[5]
LOCAL AUTHORITY TRANSPORT INTERVENTION & LAND-USE PLANNING	S	S	S	P	P	P	N
OPTION TESTING, DESIGN REFINEMENT, ECONOMICS	P	P	P	S	S	S	S
DEVELOPMENT FORECASTINGS AND/OR IMPACTS	P	P	P	S	S	S	S
DETAILED DESIGN, TRAFFIC MANAGEMENT	N	N	P	P	S	S	S
ITS, INCIDENT MANAGEMENT, ACTIVE MODE DESIGN AND IMPACT	N	N	P	P	S	S	S

S STRONG CORRELATION

P PARTIAL CORRELATION

N GENERALLY NO CORRELATION

The four key model stages are described below.

Stage 1: Trip production (trip generation)

The first stage provides the number of trips by purpose generated inside a zone in a given time period. A zone is usually defined as an area in space and may consist of several activities – usually defined as land-use types. Trip production depends largely on socio-demographics (such as household size, composition, income) and several other factors historically, including access to cars. The origin of trips from households is largely determined through census data and the Ministry of Transport's Household Travel Survey.

Destination zone populations (trip attraction) are estimated through multiple sources. In New Zealand, the Trips Database Bureau (TDB) is an incorporated society solely serving the purpose of furthering knowledge of trip generation by land-use types – usually measured in terms of floor area. Key data sources in New Zealand include the TDB database and access to the TRICS (UK-based) database as well as pivotal NZTA research papers such as Douglass and Abley (2011).

WFH has capacity to change trip generations (such as movements per household) and trip attraction (such as population arriving at an office).

Stage 2: Trip distribution

The outcomes of trip production provide the basis for a matrix to be solved with the zone origin and destination totals having been estimated.

A distribution profile would normally be selected – the classic shape is a negative exponential distribution – reflecting the preference of users to limit their travel distance. The shape of the curve can be calibrated to an extent but the range of calibration factors is usually limited in an urban context. Ortúzar and Willumsen (2011) do advise against overcalibrating the shape of the distribution curve as a leading method of solving a matrix. However, it is likely that the trip distribution profiles of those WFH would differ from those who attend work in person.

This demonstrates a question of broader modelling architecture. For the classic approach, which solves distribution prior to choice, all home-based work trips would be distributed on the same curve. One method to capture the impacts of WFH on the trip-distance distribution curve would be a feedback loop, but this could add considerable time and therefore resource to run times.

Coming back to the classic process, upon assigning the parameters of a curve, the deterrence functions can be solved and the trips distributed from origin and to destination. Because of the doubly constrained problem that distribution within the matrix must simultaneously meet the criteria of row (origin) and column (destination) totals, demands are normally loaded incrementally, with an optimisation algorithm (a classic example being the method of successive averages) until convergence is achieved, according to:

$$A_i = 1 \ /\left[\sum B_j \, D_j exp^{-\beta C_{ij}} \ \right] \text{and } B_j = 1 \ /[\sum A_i \, O_i exp^{-\beta C_{ij}} \ ]$$

where $-\beta$ and C are scaling parameters governing the slope of trip length distribution.

In the context of a broader model hierarchy, the outcome of this stage is known as a source matrix. Being the product of a process primarily concerned with solving origin–destination trip distribution and using considerable primary data of causal variables, the source matrix is considered to possess optimum forecasting integrity.

A subsequent modelling stage that can be used in strategic modelling (but more commonly used in project modelling) is matrix estimation. This is the process of re-estimating the source matrix until validation with certain network operating parameters (such as turn counts) is achieved. Given that network data is less

indicative of origin–destination travel behaviour, the resulting amended matrix would be considered of lesser integrity, and practice limits are placed on the extent of matrix estimation that should be used. Overuse of matrix estimation would have an impact of undermining the presence of land-use responses to normalised WFH outcomes – specifically longer journeys.

Some methods of modelling solve distribution and mode selection simultaneously, inviting the possibility of an assigned WFH matrix. This could be a powerful tool towards estimating some of the economic benefits of WFH as a reduction in demand on the movement networks, including greenhouse gas emissions savings.

Stage 3: Mode selection (mode choice)

Understanding and enhancing the mode selection stage is key to the research of how to equip strategic models to consider the alternative of WFH as a mode of transport. Section B.2.1 below is dedicated to understanding the types of mode selection models available and their strengths and weaknesses. Given that this research considers the inclusion of particularly heterogeneous variables of varying degrees of stationarity, research around methods to incorporate these must explore those fundamental first principles often taken for granted by modellers.

As a submodel inside the four-step framework, mode split is commonly predicated on the trip distribution phase, either developed in sequence (in order of the four stage headings reported here) or as part of a direct demand framework that solves the first three stages in a single process.

The exception to the sequencing of the stages is practised in the US where mode split is estimated immediately after trip production and ahead of trip distribution. The main advantage to the US method includes ability to represent more of the social factors that define choice.

Given the importance of social values that define WFH decision making (see section 3.4), one modelling option could be to revise the standard architecture and include the attributes at the stage of trip distribution. However, a disadvantage to this approach is the loss of simulated demand response to network changes, particularly improved public transport (Ortúzar & Willumsen, 2011). Including mode choice ahead of trip distribution while enhancing the agency of decision making would also limit that agency from being effective in the model and represent a framework more likely to undervalue intervention.

There are methods of capturing some of the more detailed social aspects of choice in the conventional sequencing that can be achieved by merit of entropy maximisation, a process that solves distribution and choice simultaneously and is practised in the Auckland Regional Transport Model (ART3).

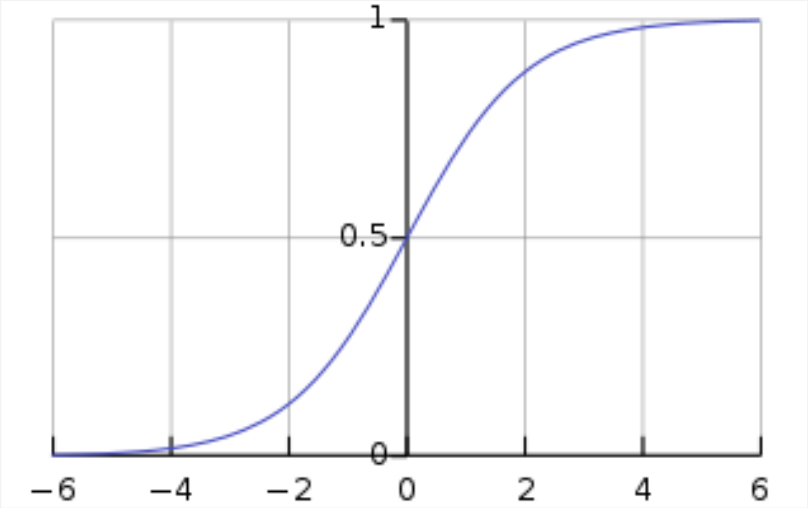
The role of network density and congestion is effectively complicit in the staging of the traditional model. Changes to the congested network – affecting the generalised cost of a given trip via a given mode – will elicit simulated behavioural responses. The modelled behavioural response will tend to be controlled, based on utility maximisation, with lower-cost responses (such as rerouting options within a network) generally exhausted prior to more significant changes such as changing mode of travel. The method of validation of synthetic choice should include arc elasticity testing.

$$Arc\ Elasticity\ (e) = \frac{\log(Q2) - \log(Q1)}{\log(P2) - \log(P1)}$$

$$Q2 = Q1\left(\frac{P2}{P1}\right)^{a}$$

More common practices of representing mode selection are developed on the principle that distribution of the probability (of using one particular mode over another), as a derivative of cost change, forms an S-shaped curve or ‘diversion curve’ (Ortúzar & Willumsen, 2011, p. 210). The entropy maximisation method that is solved using the inverse of natural log (a process known as logit) forms a similar shape (Figure B.2.2).

Figure B.2.2 Logistic curve



Logit-based methods of varying degrees of complexity are the most commonly applied method of choice selection in modelling, mostly given its convenience and general ease to operate. Other methods are being developed as computational ability allows.

Section B.2.1 includes more detailed versions of logit-based frameworks and the varying problems that each type attempts to resolve.

Stage 4: Assignment simulation

Assignment simulation in a 4SM tool typically begins with an all or nothing assignment, with subsequent incremental loading until convergence criteria are met. The convergence criteria would normally be based on the size of the difference in simulation aspects, relative to the preceding iteration, upon reaching convergence. One form of convergence occurs as the demand matrix is assigned in a manner that satisfies the Wardrop principle that an equilibrium is reached by which all trips within the network are assigned at a state of minimum cost. Additional steps would be taken to achieve demand validation.

Dynamic assignment simulation developed in the early 2000s includes machine-based learning techniques, initially incorporated into microsimulation methods but more recently possible to incorporate into 4SM or agent-based models in the form of recursive logit.

4SM is the only tool currently able to converge assignment simulation and demands, meaning that, if used to its full effect, 4SM can include iterative development that equilibrates choice-making stages and network outcomes such that WFH choice making is impacted by network conditions. Network conditions were found to be a significant determinant (see section 3.3.1).

Data from loaded networks can be skimmed – the modelled cost of origin–destination trips can be derived in matrix form. Differencing skims from different networks (or intervention options) forms the basis of economic evaluation. Developing a method that could generate a WFH matrix (a distribution in space of trips not made) could provide useful (monetised) evidence in support of policy development where WFH outcomes might be regarded as a benefit (such as improving the efficiency of energy use within the economy).

B.2.1 Methods of simulating choice variables

This section is devoted to understanding the types of mode choice model most widely practised, the limitations that require management and the different model specifications that can best manage them. These models are commonly housed inside the 4SM method.

Many fields, including transportation, economics, marketing and social sciences, apply discrete choice models to understand and predict individuals' decision-making processes when a set of discrete alternatives are available. These models aim to capture the choices individuals make and relate them to the characteristics of the alternatives as well as individual-specific factors.

Table B.2.1 includes a useful synopsis of the methods available that could account for choice. The methods range from a trend extrapolation to forecasting methods.

Table B.2.1 Summary of forecasting methodologies (reprinted from Asgari, 2015, p. 22)

Methodology	Advantages	Disadvantages	Data and Research Needs
Trend extrapolation	Requires minimal data and analysis	Ignores trends in underlying factors that might alter currently observed relationships.	Time-series data on telecommuters and telecommuting frequency. Analysis of probable maximum adoption.
Analysis of telecommuter characteristics	Accounts for underlying trends. Relatively simple models required.	Based on correlations and does not reflect causal relationships.	Time series data on characteristics of telecommuters, especially occupation. Forecasts workforce characteristics.
Analysis of factors affecting the choice to telecommute	Accounts for causal factors at the individual level.	Models give probability of individuals choosing telecommuting but do not directly provide an aggregate telecommuting forecast.	Research on factors affecting the choice to telecommute. Forecasts of choice factors. Development of method for aggregating results.
Transportation forecasting models	Incorporates telecommuting into widely used planning models. Accounts for trade-offs between telecommuting and other travel choices.	Telecommuting represented as a simple alternative to other possible choices. Wide margins of error and insensitivities in models.	Travel surveys designed to identify telecommuting. Development of choice models.

Trend extrapolation employs a simulation-based method to allow an insight as to potential effects but without ability to speculate on the role of choice variables, which would be required to support specific enquiries such as relationships between WFH and public transport use.

The bottom and most comprehensive category includes forecasting. Stated disadvantages include wide margins of error. It is likely that a mix of approaches would be adopted, potentially using some of the analysis as a basis for validation of more complex methods or in part informing a less-comprehensive initial step of confirming the existence and/or strength of relationship (the testing of null hypotheses) before

proceeding to a more comprehensive and resource-intense method and with a greater degree of confidence in the hypothesis.

Transportation forecasting methods are the most comprehensive method of potential consequences of a certain intervention, including so-called winners and losers. This degree of analysis can inform on market consequences (such as impacts on public transport demands and therefore the commercial consequences for operators) as well as environmental (such as net impacts of an option towards the emissions reduction plan) and social justice (such as those affected by changed public transport catchments).

The prevailing method for predicting the probability that a decision maker will choose one alternative mode of travel over another is usually solved by logistic regression – the concept of defining a point on a trend in terms of the weights of the explanatory variables. Modelling of mode choice considers the cumulative logistic distribution of the probability of choice in relation to changes in cost, which forms a classic S shape.

The model outcome will be one that fits to a trend – it is the simulation of a trend, not of reality. Therefore, care must be taken both in terms of how fitting the outcomes are and also the degree of resemblance to reality (such as response testing of demand changes in the model to published arc elasticities). Care must be taken in analysing data quality (sample size, representation) and ensuring that a model is not overfit or tending towards offering so-called false precision if the quality of data does not allow.

The approach to modelling WFH, including choosing specification and method, requires careful planning. There are key parameters, all of which require a deeper level of understanding in developing a detailed modelling methodology.

Decision maker

Logit models are designed to understand the choices made by decision makers. It is important to identify and define the decision makers (individuals, households or firms), whether the method of strategic modelling groups them and how they are grouped. Their decision-making context must also be understood and how this relates to the model method being applied such as whether an individual has agency. Discrete choice models are based on the assumption that individuals make decisions rationally by considering the available alternatives and their goal is to maximise their utility or satisfaction. The decision-making process involves evaluating the attributes and characteristics of the alternatives and weighting them based on personal preferences and constraints. A common flaw cited in transportation modelling includes the varying degrees of extent to which the decision maker is aware of the state of alternatives. In practice, failing to manage awareness can result in heteroskedastic relationships.

Alternatives

A set of alternative options to the decision maker need to be established. In transport analysis, it can be different modes of transportation or any other option that the decision maker can choose from. A strategic transport model typically offers a limited range of alternatives at varying degrees of forecasting capability.

Variables

The variables in a model include a mix of dependent and independent – those relating to cause and effect. The variables are estimated through research and accepted or rejected from a model depending on the strength of their relationship with a dependent variable – in this case, the outcome of choosing to WFH.

Variables can be represented in different ways:

- **Alternate specific constant (ASC)** – in the absence of a full set of correct independent variables (known as a specification issue), an ASC is used to compensate for the missing variables.
- **Attributes** – computed model coefficients representing a constant against which a corresponding independent variable is weighted. These values (along with the ASC and error term) would be derived

from a special survey where user opinions or experiences of given variables are sought using a common scoring system for all variables, the development of which is known as experimental design and includes a scale likened to a Likert scale that is orthogonal with a carefully specified number of degrees of freedom.

- **Latent variables** – variables that are inferred or explained by a group of observed variables.
- **Independent variables** – variables that explain the dependent variable or outcome without the outcome of collinearity with one another. A variable is not independent if it is collinear with other variables at the same level. This outcome needs to be avoided and tested for.

Utility function

Utility is typically a function of the attributes or characteristics of the alternatives and individual-specific factors. The underlying principle is that individuals choose the alternative that provides them with the highest utility. The probability of mode selection is distributed according to an S curve, referred to as an empirical mode split curve (Ortúzar & Willumsen, 2011, p. 210), and logit generates a similar curve. The utility outcomes for each alternative are fit to a curve generated by raising the values of utility to the inverse of natural log. The slope of the curve is determined by the scale of the attributes (such as cost), and the choice parameter is calculated to estimate its role in explaining the theoretical outcome of selection. A characteristic of logit is that greater differences between utility values will lead to an all or nothing outcome. In effect, this means a steeper curve – potentially too steep – generating extreme probability outcomes between two alternatives.

Choice probability

This represents the likelihood or probability of choosing a particular alternative among a set of options, which is typically estimated by using the logit model. It is based on the assumption of the random utility maximisation framework.

By integrating these components, logit models provide a systematic approach to model and analyse decision-making processes. They allow for the estimation of choice probabilities and the identification of key drivers that influence decision maker preferences and choices.

Estimation

The model parameters quantify the relationship between attributes of the alternatives and choices made by individuals. This is a critical step with methods called maximum likelihood estimation and generalised method of moments commonly used to estimate the parameters based on observed choice data.

Model specification

The specification of a discrete choice model requires selecting the functional form and the set of relevant explanatory variables that best capture the decision-making process. This often relies on theoretical considerations, empirical evidence and exploratory data analysis to guide the model specification process.

Model validation

This is an important step to ensure the reliability and predictive accuracy of the trend being represented. Model validation involves assessing how well the estimated model fits the observed data and evaluating its ability to predict individual choices. There are different techniques to evaluate the model's performance and assess its predictive power, which is not the primary focus of this section.

In summary, discrete choice models provide a framework for understanding and predicting individuals' decision-making processes when faced with a choice among discrete alternatives.

This model is extensively applied in transportation research to understand individuals' decision-making processes and predict their choices among a set of alternatives. Among various methods, logit models are commonly used in discrete choice modelling, which is based on the principle of random utility maximisation. The key assumption is that individuals make rational decisions by selecting the alternative that maximises their utility, which can be a mix of observed and unobserved features.

A common way to validate the performance of the transportation choice model (and the outcome of the application of this model and aggregated simulation of a loaded network) is through testing elastic response of the model against observation. For example, if the published elasticity for driving against fuel price is -0.1 (for every 1.0 unit of fuel price increase, demand for driving declines by 0.1) but the model would predict -0.5, this would indicate that the model is too price sensitive. There will be a reasonable amount of calibration, which can be time consuming. Practitioners might develop and test models incrementally or within microcosms to affirm the statistical health and performance of the estimated choice parameters before running them through the full-scale process.

B.2.2 Potential limitations to manage

Measurement errors

These can include:

- poorly specified survey questions and /or survey techniques
- a different approach to measuring trip making between the modeller and survey sample – travellers are often unaware of their true travel time, and there is a difference between so-called clock time and cognitive time
- use of wrong survey type – using stated preference to derive user opinions of their attitudes to particular costs where revealed preference may be more effective.

Sampling errors

- Noting that optimum survey sample sizes are calculated.

Specification errors

Defined in Ortúzar and Willumsen (2011, p. 67), these include the following:

- Inclusion of an irrelevant variable likely to generate sampling error in a non-linear specification.
- Omission of a relevant variable, which the inclusion of an error term can resolve but is challenging when the omitted variable is correlated with those internalised variables.
- Not allowing for taste variations of individuals and hidden heterogeneity within a dataset.
- Inability of some methods such as multinomial and nested logit to capture taste variations without explicit market segmentation.
- Other errors such as applying a linear function to represent a non-linear effect or the omission of habit or inertia.
- Selecting an oversimple binary choice method, which will restrict value. For example, in a simple binary choice model for two alternatives with a generalised cost difference of 10 minutes, the same probability outcomes would result were this applied to 30-minute or two-hour trip lengths. Therefore, scaling parameters are required and specification around how best to accommodate these.

Transfer errors

This is the inappropriate application of a model, usually from one location to another. In New Zealand, O'Fallon et al. (2004) found differences in underlying user preferences between Wellington and the other major cities, suggesting a case for the continued development of regional models in New Zealand.

However, in the context of WFH, there may also be an issue in the context of considering the matter of transferability in time. Research by Waka Kotahi NZ Transport Agency (2022a) shows the significant difference in WFH decision making by day of week by those usually travelling by public transport, suggesting a potential need for a framework capable of simulating more than one day.

Aggregation errors

While there is a case for the continuation for regional models, these same models are effectively aggregated in every sense, including population, which disallows the granting of agency to decision makers and it is practically difficult to apply detailed social economic trends such as gender or age. Demands for certain modes where age and gender have a bearing on likely take-up such as walking and cycling are traditionally not well represented by these methods.

The research will also consider the development of a WFH choice framework within a disaggregated method such as the national agent-based model under development by the Ministry of Transport, which considers individual decision makers and grants them agency.

Independence of irrelevant alternatives

This situation exists where two alternatives out of an existing hypothetical three are included in a model, assuming that a third is irrelevant. In practice, the existence of the third alternative as a choice would impact on decision making. A classic name for this is the 'red bus – blue bus problem'.

Keyes and Crawford-Brown (2018) focused on mode choice using multinomial logit regression models, which examine associations between variables and the likelihood of choosing one option over another. While this approach provided insights into mode choice behaviour, it did not allow for separate utility functions for each mode.

Identification issues

Ortúzar and Willumsen (2011, p. 254) summarise these issues as follows:

- Theoretical identification – too many parameters for the model to handle.
- Empirical identification – parameters can be estimated but data cannot support. For example, limitations in sample size will reduce confidence in the distribution.

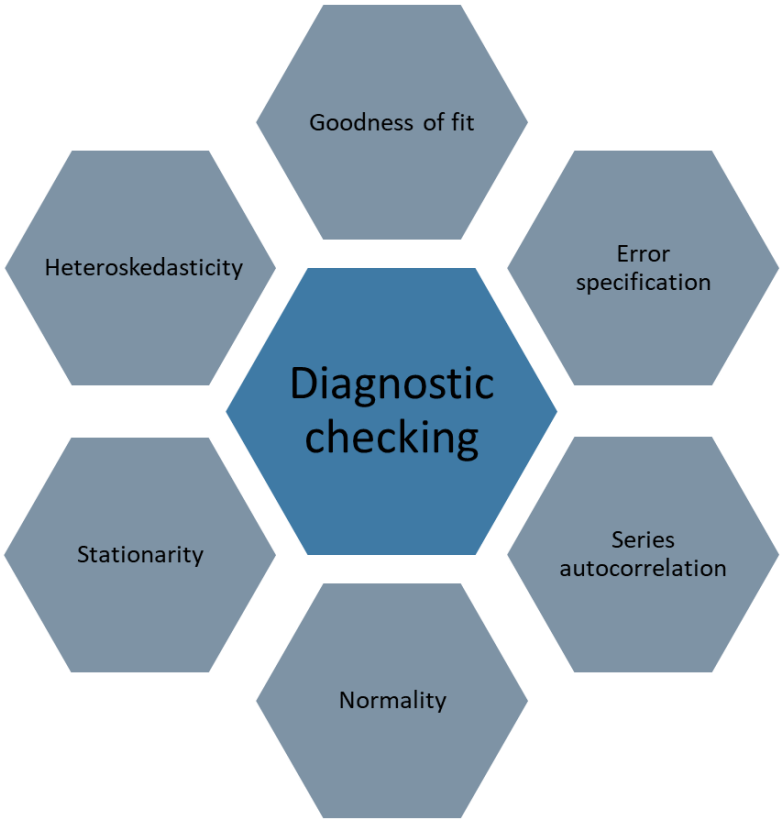
Interpretation issues

Logit tests require goodness of fit between variables and an understanding between relation and correlation to be useful. In specifying a model, testing for the following outcomes would be required (Figure B.2.3):

- **Goodness of fit:** Usually measured as an r^2 statistic, it is a measure of the conformity of the linearity of the model against the observed outcome.
- **Error specification:** The Ramsey Regression Equation Specification Error Test examines whether the non-linear relationship between variables can improve the results.
- **Series autocorrelation:** Autocorrelation refers to the correlation of error terms across different time periods in time series data. It violates the assumption of independence, leading to inefficiency in parameter estimation and invalidation of statistical tests.
- **Normality (ordinance):** The normal distribution of residuals is important as it directly impacts on the accuracy and confidence of hypothesis test. This specifically matters when the sample size is small.
- **Stationarity:** Non-stationarity is a common issue in time series analysis where the statistical properties of the data such as mean and variance change over time. It requires appropriate techniques such as differencing or incorporating time trends to address the non-stationarity.

- **Heteroskedasticity:** This is a situation where the variance between two variables increases, often indicative of something uncaptured. A classic example might be the relationship between household income and travel expenditure with the variance for higher incomes likely to be greater than for lower. In extreme cases, a method such as applying a weighted variance might provide a better reflection in the outcomes. An indication of a heteroskedastic outcome is where the p-value (the probability of the dataset being within a normal distribution) is less than the significance value (number of standard deviations from the mean) in a two-tailed test situation. Some more sophisticated model forms such as mixed logit can overcome potential problems caused by heteroskedasticity through integration.
- **Multicollinearity:** Another outcome that undermines independence of variables is multicollinearity, which occurs when variables that are supposed to be independent (such as qualification or income) and are intended to predict the dependent variable (in this case, the outcome of choosing to WFH) correlate with one another, therefore rendering them not independent. This will result in redundant information in a model and undermine the performance.

Figure B.2.3 General diagnostic checking in econometric models



The tests and checking above are generic and particularly important for general linear models. For the logistic methods, other assumptions apply including:

- in binary and ordinal logistic regression, dependent variables must be binary and ordinal respectively
- generally observations require to be independent
- there is little or no multicollinearity between independent variables
- independent variables are linearly related to the log odds
- this approach requires a large sample size to provide reliable outcomes.

The model for simple logistic regression is written logit [P(Y=1)] = β0 + β1 * X + error. The odds equal the probability that Y=1 divided by the probability that Y=0. Now that we know how odds are related to probability:

$$\text{Log odds} = \text{Ln(Odds)} = \text{Ln(P(Y=1)/P(Y=0))} = \text{Ln(P(Y=1)/[1-P(Y=1)])}$$

B.2.3 Methods used

Contingent valuation

Contingent valuation is a technique to estimate the value of benefits when monetary values are not directly priced – goods that cannot normally be bought or sold in a normal market. Through surveys, individuals are asked how much they would pay for specific benefits to understand either their willingness to pay or willingness to accept compensation values. For evaluating non-tangible benefits such as scenic views, intangible experiences and benefits to others or the environment, this is a very useful approach.

Since it relies on people's stated preferences and not observed actions/values, it can lead to discrepancies between stated and actual willingness to pay. This is accentuated when surveys are poorly designed or if the benefits aren't adequately interpretated. Therefore, skilful survey design is an important step that can require significant cost and time.

Contingent valuation consists of a sequence of actions. First, the structure and approach of the survey are established, containing clear explanations of the subject and the hypothetical market. Second, the survey is executed, managing potential biases arising from the interviewer or the starting point. Lastly, the collected data is examined and interpreted within the correct context of the process and accounting for its limitations.

Contingent valuation is a successful method in assessing the value of non-marketable benefits. This, however, must be applied carefully due to potential biases and the hypothetical nature of the scenarios described to respondents. Transport choice modelling predicts the probable outcomes of mode selection by simulating door-to-door trip making, which includes many and often evolving events that can affect choice by influencing user attitude while the user may not recall the events that have shaped the attitude. Many of the microchoices and events that influenced them may not be remembered, including under survey conditions. Therefore, a potential obstacle facing the task of eliciting value from a transport user is simply the inability of the participant to accurately recall and therefore value their experiences.

In the transport area, contingent valuation provides a valuable tool for transport planners, policy makers and researchers. It allows for better understanding of the preferences and values of individuals regarding various transportation-related attributes.

Further examples of how contingent valuation can be applied in transport context are:

- assessing transportation infrastructure projects
- valuing travel time savings
- evaluating environmental benefit
- estimating the value of safety improvements
- public transport fare assessment
- assessing behavioural changes.

Kim et al. (2017) note the usefulness of contingent valuation method to estimate the demand responsive transport fare for buses. Similarly, Saptutyningsih and Karimah (2019) used the contingent valuation approach to value public transport improvement. A report on valuing freight transport time and reliability was published in New Zealand in June 2020 (Wallis & King, 2020). This developed the value of freight shipper time and reliability by using a pre-existing stated preference method, a review of international literature and

limited interviews with a selection of New Zealand freight shippers and was linked to previous studies to estimate freight time and reliability values across domestic freight market segments.

Another example of using contingent valuation (Clough et al., 2015) provided guidance for valuing injury and mortality risks in New Zealand. It recommended that the application of willingness to pay for small changes in risks is appropriate and widely used in OECD countries. It also emphasised that, due to different levels and nature of risks associated with various areas such as transport, health and workplace safety, the contingent valuation model should have customised versions and that it is also important to update this method as the population grows and other influential phenomena change through time.

Multinomial logit

Multinomial logit is the simplest form of logit but has limited capability to forecast complex relationships. It also applies a consistent weighting parameter that does not allow for differences in population without being required to segment them. Multinomial logit cannot overcome the independence of irrelevant alternatives problem or handle heterogeneity in data. It tends to all or nothing outcomes when the quantity of an alternative tends to be excessive.

Nested and cross-nested methods

The nested logit model has been applied in different fields such as transportation, marketing and environmental studies, where choices commonly demonstrate hierarchical patterns.

Nested logit is a popular econometric approach to study individual choice behaviour when options can be grouped into nests. It is developed on the base of a standard logit model that allows for the correlations and dependencies among choices within the same nest. The model has two stages to select a nest from the available options and then make a choice within the chosen nest to maximise the utility function.

The first stage represents a group of similar options, and consumers consider the overall utility of each nest. The choice outcome of the second nest could be a derivative of outcomes of the first. Nests could be different elements relating to themed aspects of choice making.

Once a nest is chosen, in the second stage, consumers evaluate the individual options within the selected nest and choose the one that maximises their utility.

In the case of WFH, a nested approach could initially consider the following:

- Digital or physical access – is the decision maker likely to WFH?
- If they choose to travel, which mode of transport will they select?

The nests could also apply the principles considered by Jain et al. (2022) relating to attitudes, subjective norms and perceived behavioural control (**Figure**). The nests can be hierarchical.

If framed adequately, the outcome of such a model would include an origin–destination matrix of trips that have been substituted by WFH – a digital access matrix. A hypothesis (previously demonstrated in section 3.3.1) would be the increased probability of public transport trips being substituted for WFH outcomes, which this tyle of nested logit would also be able to speculate.

Mixed logit

Mixed logit, also known as the random parameters logit model, is an advanced econometric method to examine individual decision making in situations. This method allows capture of heterogeneous alternatives in preferences as well as accommodating random variations. This is a key advantage of this approach over the standard logit models.

Flexibility of the method is derived from the inclusion of random parameters. Each parameter is presumed to be selected from a particular distribution, including the variety of preferences of decision makers.

Allowing individuals to make choices based on their own unique set of preferences leads to a more realistic representation of real-world decision-making processes. This ability to capture individual-specific preferences makes the mixed logit model a powerful tool for various applications such as market research, transportation planning and environmental policy analysis, where accounting for diverse and random preferences is essential for generating more accurate predictions and policy recommendations.

Mixed logit is a more complex approach that builds in different attribute weightings without segmentation. Therefore, it overcomes the independence of irrelevant alternatives problem and is a method that can include multiple distributions, including random, and therefore allow a stochastic analysis.

The ability to include taste variations would add significant value, noting the aggregation of input variables in a traditional 4SM architecture.

Multiple stage methods

Methods can be iterative, depending on the types of variables included and the extent of belief in the hypothesis. It can include an initial coarse level of analysis – enough to accept or reject the relationship between variables, while avoiding a more complex full model run and analysis ending in rejection and needing to be repeated. Examples of prior methods include:

- the use of fuzzy logic (see Hassan et al., 2019)
- the use of an alternative method to prove relationships such as least squares analysis of rank correlation methods (see Jain et al., 2022)
- the use of contingent valuation methods ahead of a forecast tool development
- a mix of approaches.

B.3 Activity-based modelling (ABM)

> *… the time has come to revisit the choice of the most appropriate transport model form.*
> (Willumsen, 2023)

ABM is a relatively new concept in New Zealand. Whereas traditional 4SM would predict trips between aggregated land-use zones occurring within a fixed time period within a day (usually defined around network peak demand times), ABM focuses on assigning trips to the individual across the whole of day via a schedule. This method allows the possibility of considering more complex behaviours that underpin how a person chooses to travel across a day.

The key requirements of ABM model are that:

- all kinds of people need to be represented
- as do their actions
- as well as the state of the environment they exist within.

The Ministry of Transport's ABM Project Monty attempts to:

- collect and unify everything about New Zealand's transport
- improve understanding of current, future and intervened changes
- include strong focus on people and provide more insights about larger cities
- produce a framework for extensibility, reproducibility and traceability.

Maximising the utility function is suggested in this model. It is also assumed that actions are linked and influence the following actions during the day. Behaviours in this environment are not fully determined – instead, emergent behaviour is permitted.

Whereas 4SM will tend to include discrete time periods, ABM will adopt a whole of day. Logit itself is normally used to model and understand individual choices among discrete alternatives. It well explains situations where there are limited choices and where we want to understand the factors that influence an individual's decisions. The advantage of this approach is manifold. ABM can internalise more demographic information more effectively. In 4SM, attributes that do not vary much from one zone to another (noting that zone will capture hundreds or even thousands of people) would bear little significance in the simulation. Gender is a classic example. Therefore, the ABM is less bounded and has more freedom. The disadvantage of this is the run time and complexity. New Zealand's first ABM model Project Monty under development by the Ministry of Transport is still in an experimental phase with relatively few personnel trained to use it.

In ABM, agents can be identified as various elements, including travellers, vehicles or even traffic signals. This method studies the dynamics of decision making by individuals and the interaction between the agents. It is a useful approach to work with large and complex datasets as well as dynamic systems where individual behaviour and interactions play crucial roles. Previous studies applied ABM to simulate traffic flow, congestion, route choices and the effects of various policies on a detailed level. Agents in agent-based models dynamically adapt their decisions within a changing environment. They also allow accommodation of different types of data, including categorical, numerical and textual information.

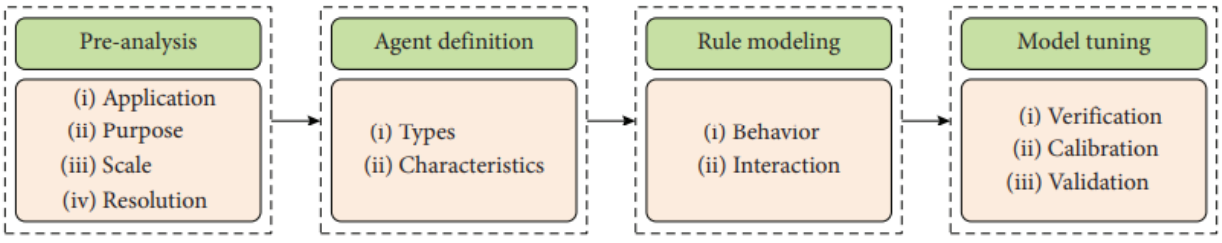
Machine learning[5] is another term that, in many modelling areas, is closely tied with agent-based modelling. It is a form of artificial intelligence (AI) designed on an algorithm that develops and learns from data and experiences to predict the future. Applying machine learning technique into ABM empowers the system and improves the accuracy and predictive power. This makes it an effective tool for understanding and analysing sophisticated environments and activities.

The adoption of complex mathematical approaches in transportation comes with some challenges. Interpreting the results and understanding the underlying mechanisms is far more complex compared to traditional models like the logit model. Additionally, the black-box nature of the simulation method can make it difficult to explain the predictions or provide policy recommendations based on the model outputs.

ABM may use a range of machine learning, logit or both (recursive logit) to simulate decision making. The value of versatility and attention to detail provides enhanced prediction accuracy and the ability to handle complex data patterns.

In traffic and transportation studies, agent-based modelling shares a similar structure and steps (Figure B.3.1).

Figure B.3.1 Agent-based model structure (reprinted from Huang et al., 2022, p. 4)



With existing agent-based model approaches, three limitations that need to be considered are:

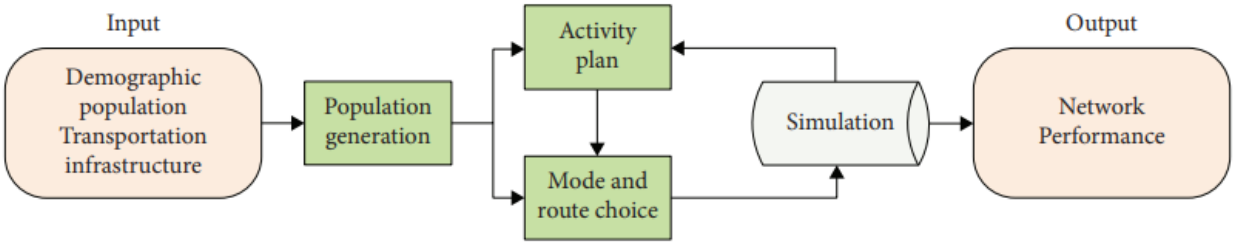
- incomplete and limited calibration and validation procedures

[5] Comparing differences between various approaches, logit versus ABM is more straightforward. Machine learning algorithms together with other methods such as ABM improves choice models but they are not directly comparable with the logit approach due to different focuses in pattern recognition and prediction.

- limitations in agents' behaviour modelling
- limitations in innovative approaches to improve computing efficiency.

Figure B.3.2 illustrates one example of modelling structure. The system generates demand and activity plans of the population based on demographic and infrastructure characteristics. Each agent decides on individual travel mode and route choice. This decision by agents is then fed into a microsimulation, which will generate certain network performance. This process continues to enable the system to be revised and improved through many iterations of the simulation.

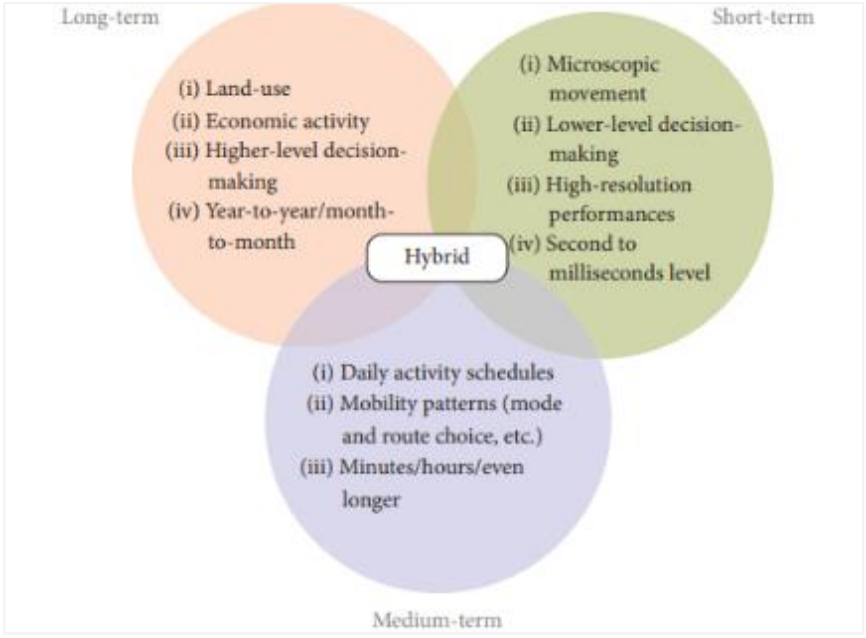
Figure B.3.2 Model structure of an agent-based platform in transport applications (reprinted from Huang et al., 2022, p. 7)



The time scale in agent-based modelling depends on the event mechanism in the model, and this may vary between seconds to days in the same model (Figure B.3.3):

- Short-term model – covers microscopic level (such as pedestrian flow or traffic flow models).
- Medium-term model – refers to the (mesoscopic) simulations that involve mode and route choice or activity schedules for the scale of minutes or even longer.
- Long-term model – represents at the temporal scale of months to years. It does not deal with the simulation of the activities at the microscopic or mesoscopic level. However, behaviours can be modelled microscopically to represent the evolution during time. This is widely applied in studying demography, household relocation and housing market travel demand.

Figure B.3.3 Key points of different models (reprinted from Huang et al., 2022, p. 9)



Agent-based modelling is a complex simulation approach that has evolved over time to ensure that the outcomes are reliable and closer to reality. One good example of this is a study called Ohio 3C Model Improvement, which specifically related to telecommuting and mode sensitivity. This, however, does not specify how plausible it is for an industry to have a maximum telecommuting rate. For example, the model cannot distinguish between the chance of WFH by waiters and, say, software engineers. Furthermore, WFH in the existing model is implicit and not explicit. As the result, those WFH behave as those taking a day off, which is unlikely to be the case. Enhancements in ABM reinforce its trustworthiness by aligning simulated results with actual observations, thereby increasing its effectiveness as a powerful instrument for insightful analyses.

The Maricopa Association of Governments (MAG) aims to have a better understanding of possible changes on the transport system by COVID-19-related policies in 2020/21 along with the potential lasting impacts of higher telecommuting rates. MAG applies a two-step so-called trip-based model. A trip-based travel model is simulated by using behavioural models, including trip generation, trip distribution, mode choice, diurnal factors and trip assignment. This model set-up is simulating different activities and trips, including commercial vehicle travel, inter-regional travel, airport air passenger travel and Arizona State University student travel.

Shabanpour et al. (2018) commented that ABM focuses on sequences of trips of an agent rather than individual trips, meaning it was able to capture the comprehensive relationship between them. Hajinasab et al. (2016) employed a simulation model to examine the travel behaviour of passengers in response to new transportation measures such as policies and infrastructure investments. They utilised a multi-agent-based model to analyse commuter travel choices in a specific region in Sweden. This analysis incorporated convenience factors, encompassing walking and cycling distances, as well as the number of changes involved in travel alternatives. Through the validation of their model, they underscored the practicality of their approach to travel behaviour modelling.

Kaghoa et al. (2020) highlighted the increasing usage of agent-based modelling and its application in transport planning. They provided an overview of this methodology and its deployment in transportation. The paper outlined some of the tools utilised for agent-based simulation and addressed the present challenges associated with this approach. The trend of employing simulation methods to tackle a range of transportation-related enquiries is growing.

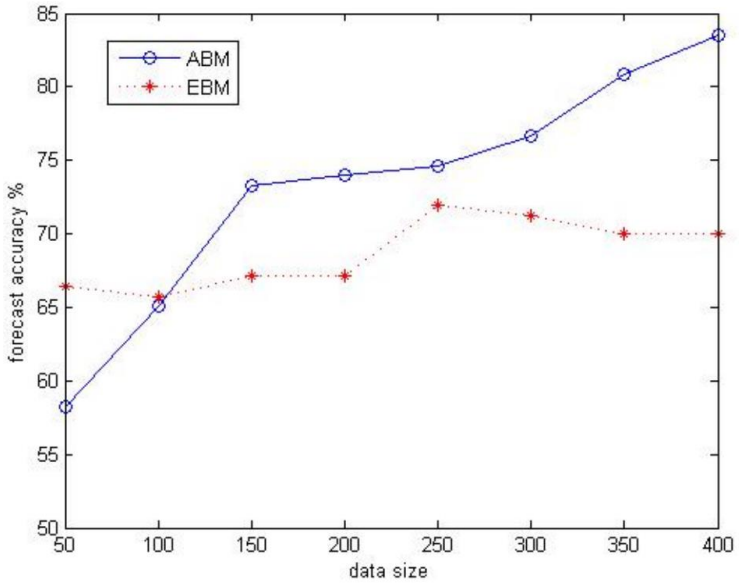
Wise et al. (2017) utilised ABM in an urban modelling system. Recognising the expanding urban population, they viewed ABM as a promising technique to comprehend changes and their impact on transportation. Their study reviewed the inclusion or exclusion of transportation in ABM, concentrating on urban areas, and put forth suggestions to overcome inherent limitations.

Other example in the realm of machine learning is by Pineda-Jaramillo (2019) who assessed various algorithms commonly used in transportation analysis and also proved that the random forest model, one certain algorithm, achieved significantly higher predictive accuracy than multinomial logit and mixed logit models. These studies highlighted the ongoing debate between logit models and mathematical methods in transportation analysis. While logit models have been widely used and provide insights into behavioural interpretations, empowered simulation methods (such as the simulation of algorithms to mimic transit card data) can offer higher predictive accuracy in many cases. Researchers continue to explore and refine both approaches to enhance our understanding of transportation choices.

Mao et al. (2015) thoroughly compared the ABM approach with the equation-based method (EBM) theoretically and empirically. They effectively compared ABM and the logit model in this paper as the logit model is the most common EBM method in transportation behavioural studies. Applying stated-preference data and web-based travel behaviour data, they found that both methods are at a similar level in terms of prediction accuracy. However, ABM is more stable under noisy data. ABM performance is better when

working with larger datasets, but the accuracy of EBM results does not respond to data size as such. In other words, as the size of the data grows, the prediction accuracy of EBM has not changed significantly (Figure B.3.4).

Figure B.3.4 Comparison of ABM and EBM models' dependence on data size (reprinted from Mao et al., 2015, p. 3620)



Holm et al. (2016) developed an approach via combining discrete choice experiments (DCE) and ABM and tested their model using a case study of a Swiss wood market. They concluded that agents could obtain plausible decisions through DCE. While this is not in the transportation field, they showed that combining ABM and DCE is a promising approach that may provide the base to be applied in other areas as well.

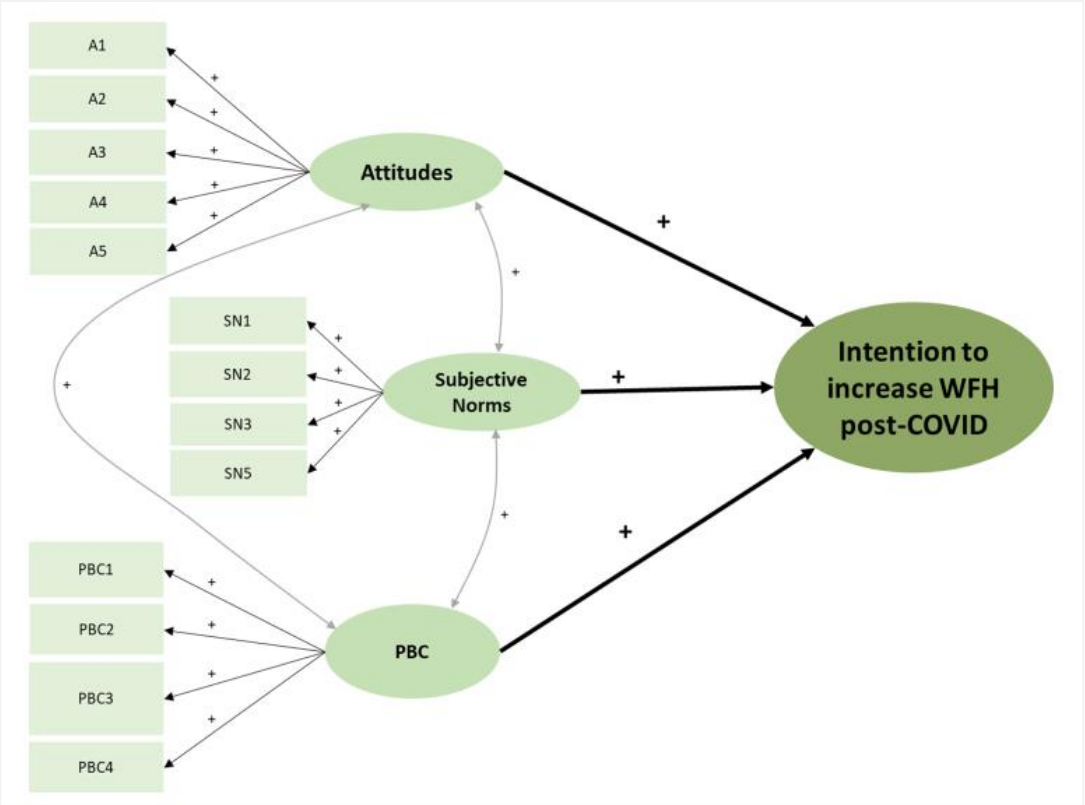
Orsi and Geneletti (2016) studied travel mode choice using an agent-based model and a discrete choice submodel. They applied this approach to empirically test it at the Dolomites UNESCO World Heritage Site in Italy. Their findings demonstrated the reliability of this approach, providing managers with an effective transportation tool to rely upon.

B.4 Structural equation modelling

Structural equation modelling is a method of estimating relationships between observed and latent variables while simultaneously estimating the relationship between the latent variables themselves. Structural equation modelling, being structured, is visually set out as a framework. An example is given in the paper of Jain et al. (2022) (see section 3.4.1). A graphic of the structural equation modelling framework is shown in Figure B.4.1, with attitudes (A1–A5), subjective norms (SN1–SN5), perceived behavioural control (PBC1–PBC4) and intention as the latent variables, which:

- are measured by combining the observed variables (A1–A5, SN1–SN5, PBC1–PBC4)
- interact with one another
- subsequently describe the outcome – in this case, intention to increase WFH post-COVID-19.

Figure B.4.1 Hypothesised framework for intention to increase WFH post-COVID-19 based on theory of planned behaviour (reprinted from Jain et al., 2022, p. 58)



Jain et al.'s (2022) study used data from a survey with a seven-point Likert scale questionnaire to determine attitudes associated with WFH. Two groups were surveyed – those who wanted to WFH and those who didn't want to WFH. A separate model would be developed for each group.

The survey outcomes for each group were tabulated and compared and then the rank correlation between each variable was estimated using the Spearman's coefficient specifically designed for rank-order correlation (therefore useful for testing and comparing data of differing statistical distributions and including outliers). Cross-correlation was estimated between variables (Figure B.4.2).

A null hypothesis (of potential significant relationships) was developed – effectively set out as Figure B.4.1 – and tested using the lavaan package in RStudio.

In this case, the input data was derived of rank-order (ordinal) rather than of data that might conform to a statistical distribution parameter. Models are often estimated under a hypothesis of maximum likelihood, meaning that the parameters used to estimate the relationships would need to generate results that would be likely to conform to statistical distribution. In this case, having no basis for distribution, least squares estimations were used.

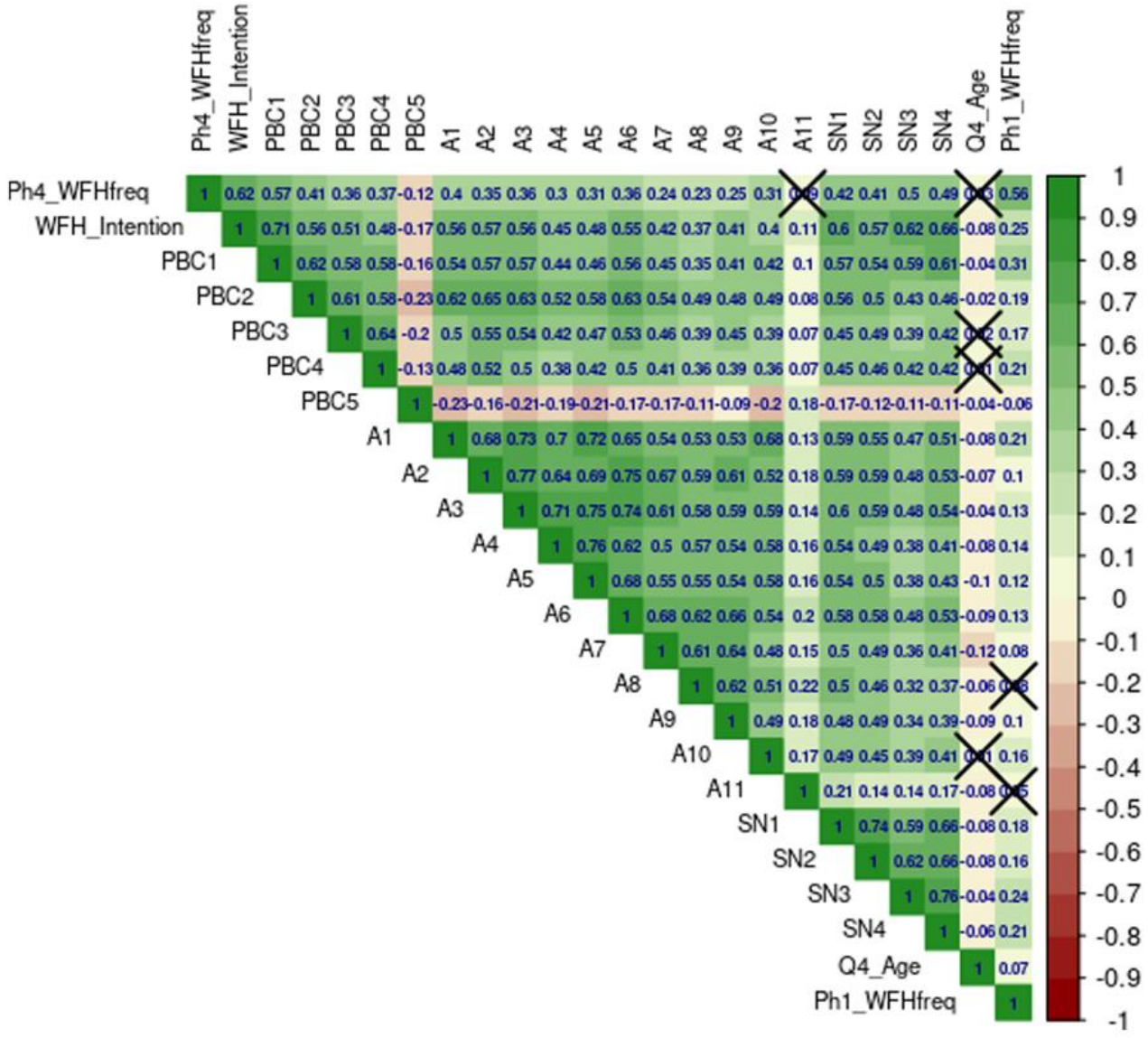
The least squares outcomes are shown in Figure B.4.2. Note how the observed variables hold very strong relationships with the immediately adjoining latent variables (excluding intention), with values typically exceeding 0.8.

> *[G]iven attitude's strong positive covariance with subjective norms and PBC, it did have a positive indirect effect on intention. Perhaps, this indicates that for people with no pre-COVID experience of WFH, an attitude which sees WFH as advantageous cannot alone influence intention to increase WFH, unless WFH is perceived as a viable option (e.g. job type), easy, and supported by one's family and workplace.* (Jain et al., 2022, pp. 61–63)

This method has been effective in:

- developing methods to compare heterogeneous variables by reducing them to rank-order
- using effective cross-correlation method to support a null hypothesis
- executing the null hypothesis with allowance for collinearity to understand direct and indirect effects.

Figure B.4.2 Correlation matrix for all observed variables (X signifies an association that was not statistically significant) (reprinted from Jain et al., 2022, p. 60)

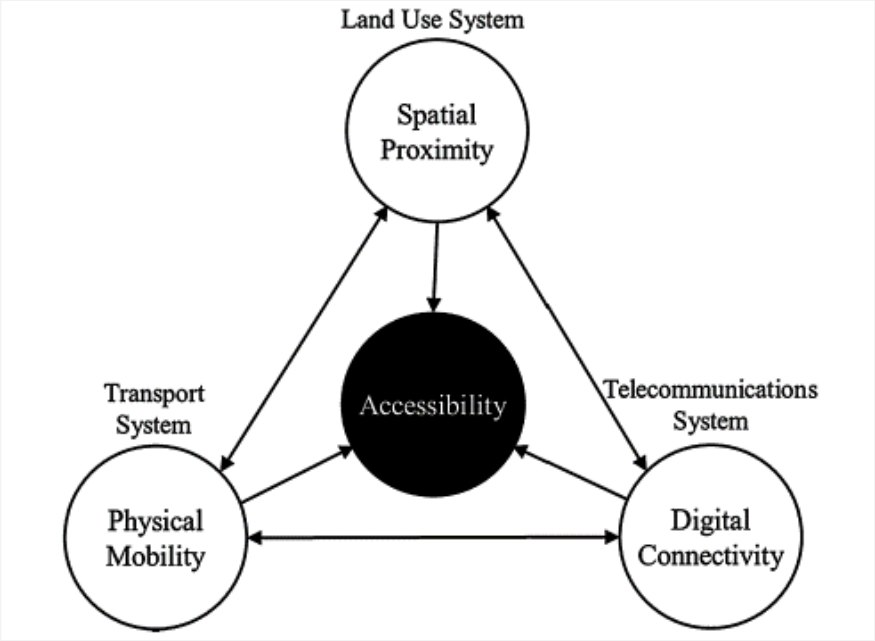


B.5 Approaches to uncertainty management

B.5.1 Triple access and scenario-based planning

The relationship between digital and physical mobilities along with the land-use system (such as densities) is highlighted in Figure B.5.1. The synopsis of Lyons and Davidson's (2016) paper is on simultaneously internalising the role of digital connectivity and the management of risk such as to increase insight into the evolving transport specifically and specifically trends of negative externalities.

Figure B.5.1 Triple access system (reprinted from Lyons & Davidson, 2016, p. 112)



There are a range of modelling methods available, some of which can be quickly discounted as not being supportive of testing interventions designed to influence mode choice. Such a method is the trip end mode split method largely applied in the US. Effectively, this method resequences traditional 4SM, placing model split ahead of distribution. Although there are reasons in support of this method – namely the ability to internalise more behavioural characteristics – the sequencing of the stages reduces the ability to influence mode choice in the model through infrastructure-based interventions (Ortúzar & Willumsen, 2011).

Lyons and Davidson (2016) considered the different applications of modelling towards yielding the most value for society. They have identified two frameworks within which models are applied – demand forecasting and scenario planning.

Demand forecasting

Demand forecasting usually includes the development of a base tool that is validated[6] against a range of observation and extrapolated based on near-term trends. Flyvbjerg et al. (as cited in Lyons & Davidson, 2016) in a study of 210 projects in 14 countries concluded that 'forecasters generally do a poor job of estimating the demand for transportation infrastructure projects' (p. 105).

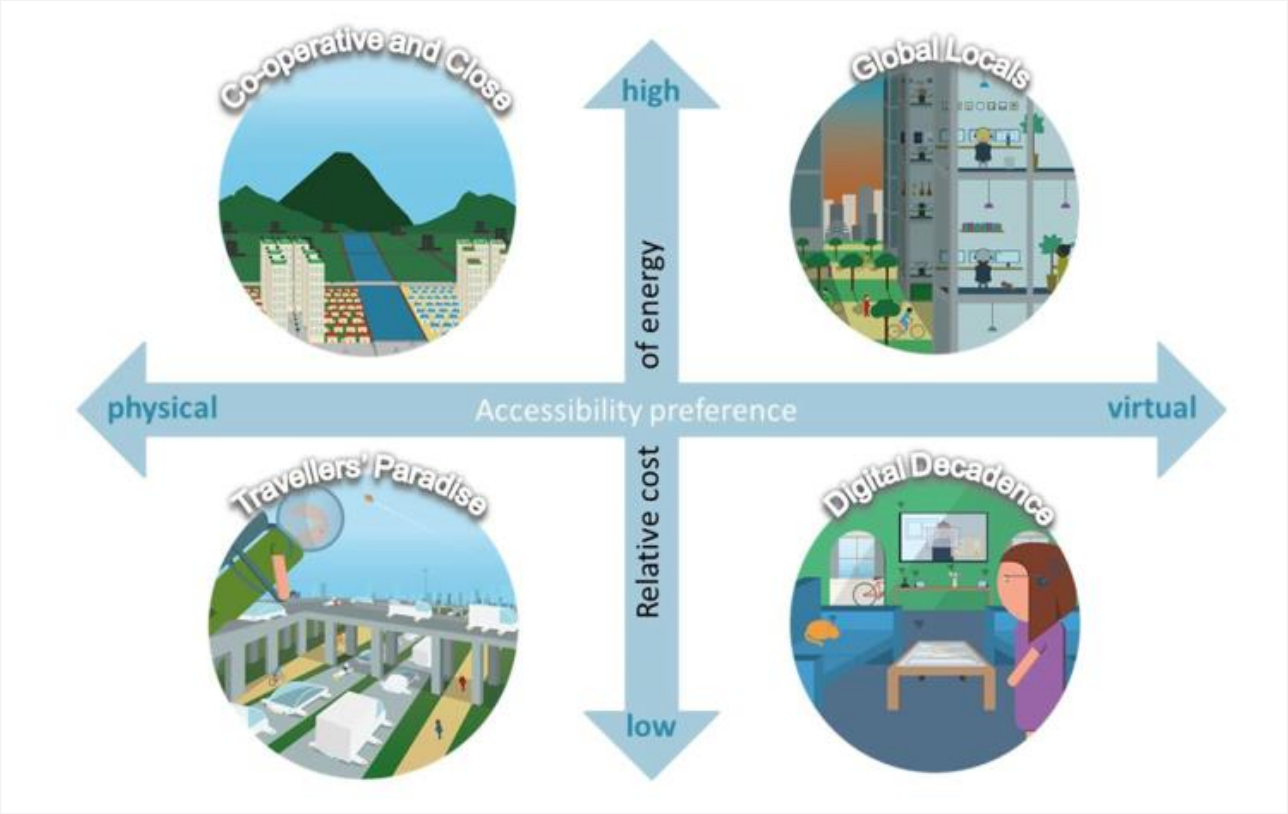
The name of the framework for infrastructure planning including forecasting is known as predict and provide and is widely considered lacking in managing uncertainty to the point that 'any notion of the prediction being 'accurate' is illusory' (Lyons & Davidson, 2016, p. 112). These words were written before the disruption of COVID-19.

Scenario planning

An alternative approach to predict and provide would be to explore, decide and provide. Societal changes – and indeed the prevalence of chaotic disruption – increases the uncertainty and confidence intervals in a forecast. A possible method for managing is to forecast and/or simulate more than one future scenario. This is a method recommended by Lyons & Davidson (2016) summarised in Figure B.5.2.

[6] For example, against the transport model development guidelines (Waka Kotahi NZ Transport Agency, 2019) or the transport analysis guidelines (Department for Transport, 2020).

Figure B.5.2 Example scenario planning parameters (reprinted from Lyons & Davidson, 2016, p. 109)



Lyons and Davidson define their futures by accessibility preference and relative cost of energy. This is a simple and potentially pliable approach, working in with flexible thinking and design practices. Lyons and Davidson (2016, pp. 109–110) describe the flexibility of thinking within the analyst and decision maker. This appears to be an important step in approaching scenario planning and worth setting out:

- **Predicted:** an extrapolated outlook for the future (although grounded in evidence, it is the limitation of this evidence that requires further insight).
- **Presumed:** an outlook based on probability and instinct, but without proof. Disruptive influences such as new technology cannot be easily extrapolated and require inquisitive analysis.
- **Practical:** an outlook that aligns best with immediate interests and imperatives. It is worth nothing that the identify of these interests can change.
- **Plausible:** an outcome that cannot be denied based on current knowledge.
- **Preferred:** an outlook for the future that is desirable.

The framework shown in Figure B.5.2 does appear to accommodate this critical review of thinking, and a key challenge to this research project will be being able to apply a similar framework to modelling, inclusive of WFH. The same framework may be used. However, alternatives will be explored.

Eventually, it would be hoped that they could be useful in a universal modelling context so consideration can be given to the representation of some broader issues. This is also a field that will evolve through interface with the transportation modelling community.

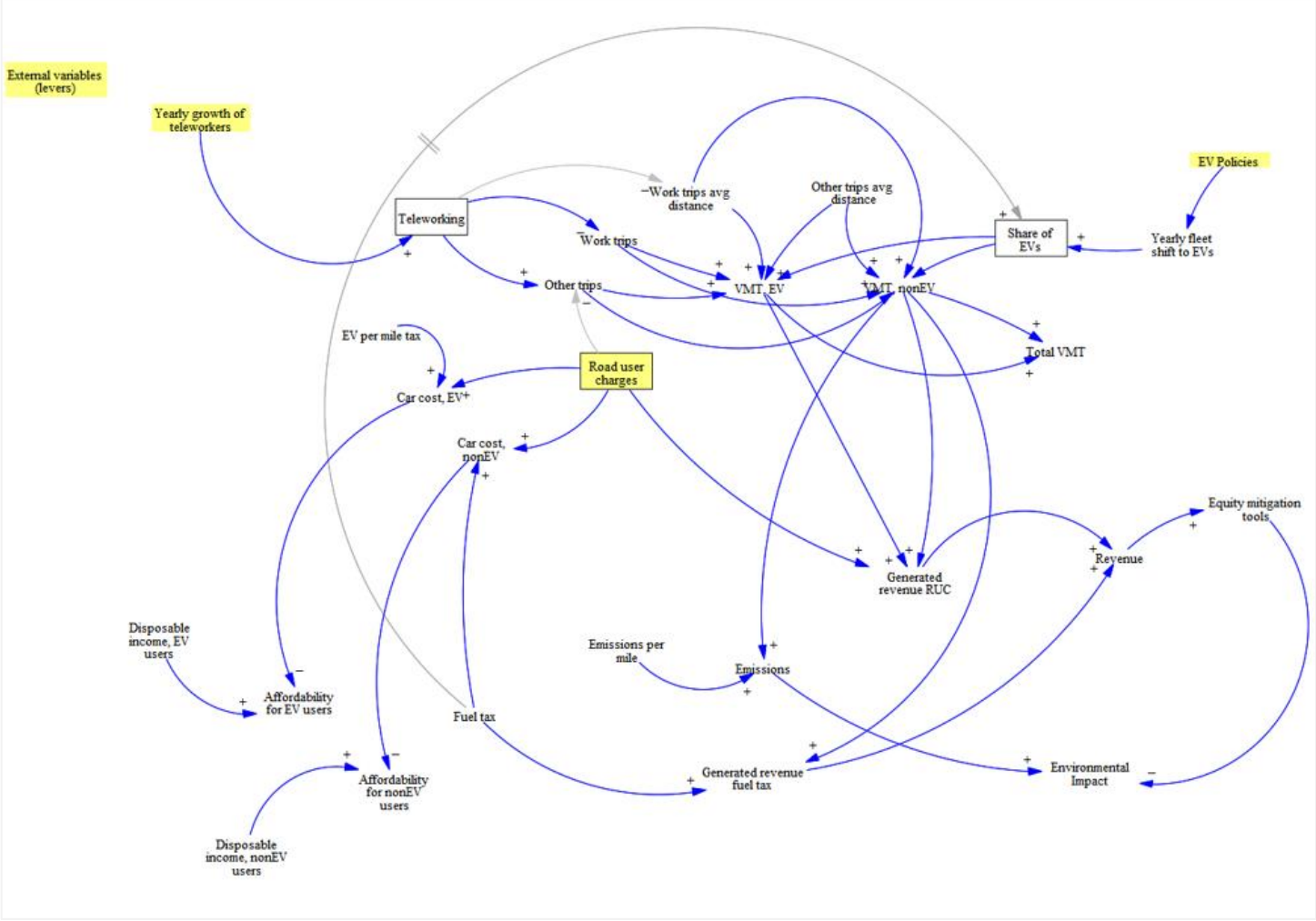
Other benefits of internalising social trends include the ability to develop a rich narrative – a term coined in the Monetised Benefits and Costs Manual (Waka Kotahi NZ Transport Agency, 2023) – and provide an alternative to the definition of energy prices given increasing awareness of inelastic responsiveness to fuel price.

A key next stage of the project will be determining the significant variables, their parameters and measurability and the extent to which they would fit together within a scenario.

B.5.2 System dynamics

System dynamics is a framework to quantify causal relationships. The end product, including a concept of how it is mapped, is given as Figure , including the mapping of levers and influences (shown in yellow such as road user charges) and how they interact with user costs and revenues.

Figure B.5.3 Worked example of causal loops (shared by WSP)



System dynamics is designed to sit alongside travel demand modelling and scenario planning, demonstrated in Figure B.5.4.

Whereas scenario planning can be used to inform modelling of alternatives (and thereby increase the probability of which outcomes of forward planning would realise their benefits), system dynamics is a more visual method of demonstrating consequences of a given intervention under a certain scenario. One of the scenarios demonstrated in Figure is the impact of increasing teleworking – albeit sitting more outside the system than the variable of road user charges. One link that is not established in the above example is the role of road user charges on WFH outcomes. However, this might be further developed.

Therefore, system dynamics is complementary.

The steps to arriving include:

- start with a basic relationship
- add splits – such as considers trip purpose, disaggregates cost type
- add levers and elasticities.

Figure B.5.4 System dynamics process integration

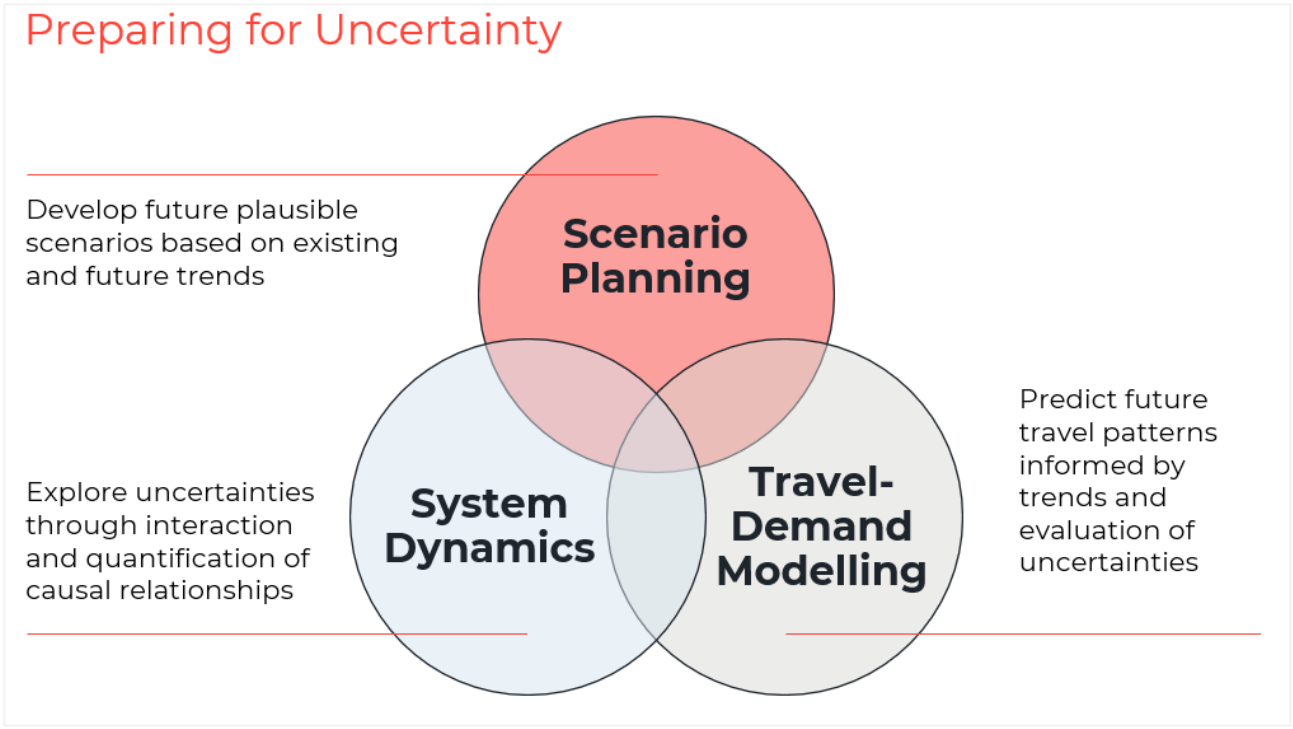
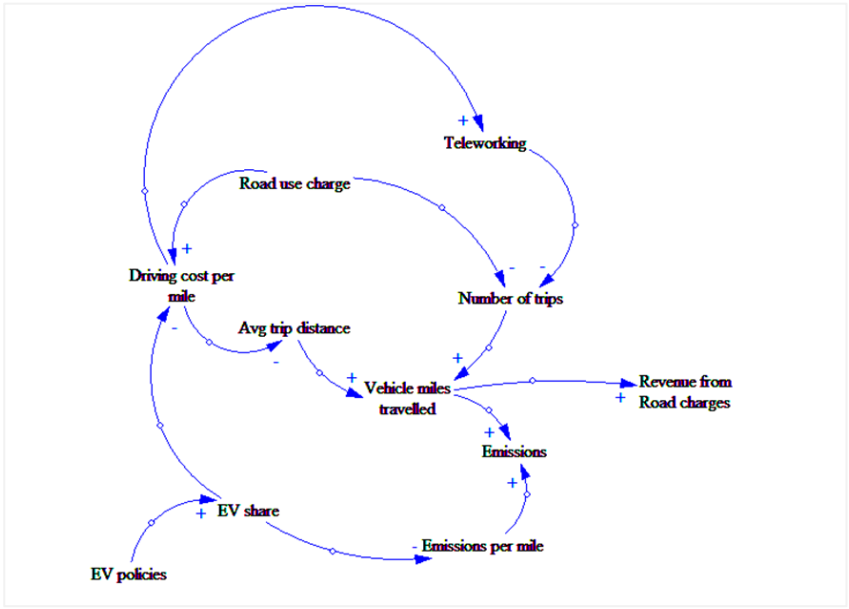


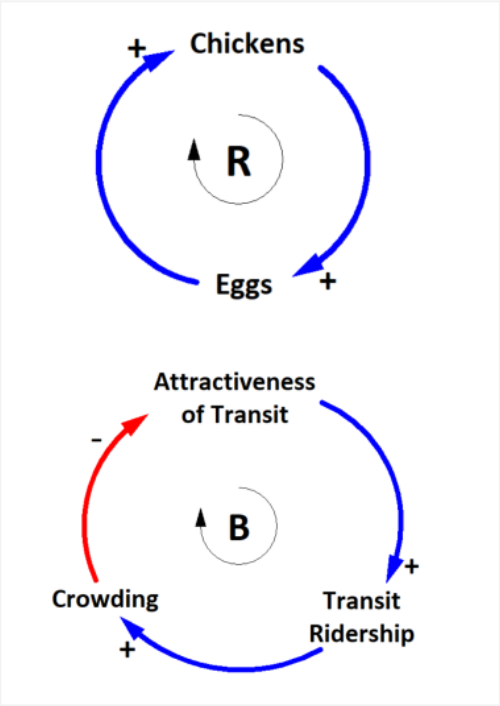
Figure B.5.5 Starting point for system dynamics prior to adding splits and levers



In developing causality mapping, two types of loop may be used (Figure B.5.6):

- **Reinforcing loop:** The example could be a chicken and egg scenario – more chickens reinforce the outcome of more eggs – or the behaviour of a pandemic – more cases reinforces more cases.
- **Balancing loop:** A relationship that reaches equilibrium. The classic example being more ridership, more crowding, an equilibrium in ridership as a choice alternative.

Figure B.5.6 Types of response loop used – reinforcing and balancing loops



System dynamics is a process that can demonstrate, for example, links between road user charges, driver cost and impacts on VKT. However, it is still an extension of a modelling and scenario-based planning.

Appendix C: Managing risk/uncertainty

C.1.1 Synopsis

In summary, developing a risk management framework is a necessary step identified by modelling good-practice guidelines in New Zealand. The need for effective uncertainty management protocol will increase as models look to incorporate more complex variables against a backdrop of greater awareness in the industry of the impacts of disruptive events.

More sophisticated methods, outlined in detail below, demand a carefully managed approach that will require specific resourcing. For these reasons, uncertainty management in the context of modelling WFH should not be considered as an afterthought but potentially as part of a coordinated suite of methods developed on the basis of carefully examining variables and limitations.

However, Byett et al. (2017) identify steps towards minimising uncertainty through gap practice before undertaking more comprehensive scenario planning:

- Accept some variation is natural – there will always be fluctuation in the system.
- Improve measurements – include deployments of stratified and repeated sampling to reduce unexplained variation.
- Improve estimation of model parameters – ensure that the size or scope of the model can accommodate the full extent of what is being measured.
- Improve forecasts – make best use of what is known and explore alternative (extrapolated) futures.
- Sensitivity testing – identify core variables of uncertainty and test sensitivity of the predicted outcomes to fluctuations in these variables.
- Consider different scenarios – this enables greater insight into potential interactions and range of outcomes.

Better practice will not replace but will certainly reduce the need and resourcing of more sophisticated uncertainty management methods. It should also be noted that project-specific uncertainty management measures would be implemented in conjunction with use of the model, which are the main focus of Byett et al. (2017).

C.1.2 Scenario-based planning

The use of scenario planning has potential to increase confidence in forecasting by casting a wider net over possible events. The parameters of the net would be carefully developed, by a steering group and aimed specifically at limiting biases and attracting more universal buy-in. ‘Perhaps one of the greatest challenges in handling uncertainty remains engagement and communication’ (Lyons et al., 2021, p. 9). Forecasting and simulation tools can only be as good as they are trusted.

Scenario planning appears to be more about owning the future and taking more control over uncertainties. The 21st century has witnessed unprecedented disruptions to norms and trends such as the outcomes of COVID-19 on WFH practices. Global modelling expert Luis Willumsen suggests that risk in forecasting has reached a criticality and that modelling practices must change.

The approach of decide and provide developed by Lyons and Davidson (2016) offers a framework to approach scenario planning framed around social preference towards either digital or physical mobility and price of energy. This method also makes allowances for the different types of thinking that exist in the process of transport modelling and appraisal.

For the implicit task of simulating WFH as a mode to be selected, scenarios might be customised around the significant causal variables. One reason above others for this approach would be that demand for driving is inelastic in the face of rising fuel costs (Litman, 2024). There was no literature identified that found or even considered a link between fuel costs and the decision to WFH.

Transport for New South Wales (2021) guides analysts to sensitivity test for:

- reduced population
- increasing WFH
- reduced population and increased WFH
- additional scenarios, including:
  - more local travel
  - freight transport demand shifts
  - avoidance of public transport and associated disease contact
  - ongoing behaviour change from sunk costs made during COVID-19
  - more active travel preferences
  - shifts in cost perception based on not commuting every day
  - higher rates of unemployment in selected industries
  - changes in travel patterns of students.

The need to sensitivity test is specified in New Zealand through the Monetised Benefits and Costs Manual (Waka Kotahi NZ Transport Agency, 2023) and the need for logging uncertainty. However, the parameters of what is to be tested are not specified, although in experience, they tend to be around WFH and population outcomes.

Considerations in choosing to adopt scenario planning (Lyons et al., 2021) include that, like building a model or other analytical tool involved in enabling insight, it requires careful planning and should be developed within a team of diverse future-centric expertise and backgrounds in order to attract more universal buy-in. Finally, it is a process that requires updating:

> *Scenarios have a limited shelf life. As they become familiar, the temptation arises to cling to them – which risks thinking within, rather than looking beyond, the box.* (Wilkinson & Kupers, 2013, as cited in Lyons et al., 2021, p. 5)

In the context of resourcing and effort, strategic transport models are usually updated every few years – a process that would be more costly and resource intensive in comparison. Given that the framing of scenario planning is designed to manage risk (and bias) and be developed such as to attract more universal buy-in, including from decision makers, relatively small costs in developing them may represent a prudent investment.

C.1.3 Difference between sensitivity testing and scenario planning

Sensitivity testing usually involves adjusting a single given parameter in a model, typically population, in order to test the resilience of the performance of an intervention scheme (such as infrastructure) in appraisal. Historically, discount factors have been applied to costed benefits. However, sensitivity tests allow for a more causal appraisal.

In the context of a WFH model, the additional of digital access options adds another dimension, and the role of testing single attribute changes alone would therefore represent a more limited value proposition.

The option of testing for differing of levels of WFH would be moot in a model designed to specifically forecast this outcome. Sensitivity testing some of the derivatives of the selection outcome of WFH would yield more value. Selecting ones to test would require some sort of control.

Scenario planning therefore is a more complex version of sensitivity testing but requires defining and buy-in from all parties connected to modelling and appraisal, including decision making. By nature, some scenarios will be dystopian, which may not play well in a system historically impacted by optimism bias.

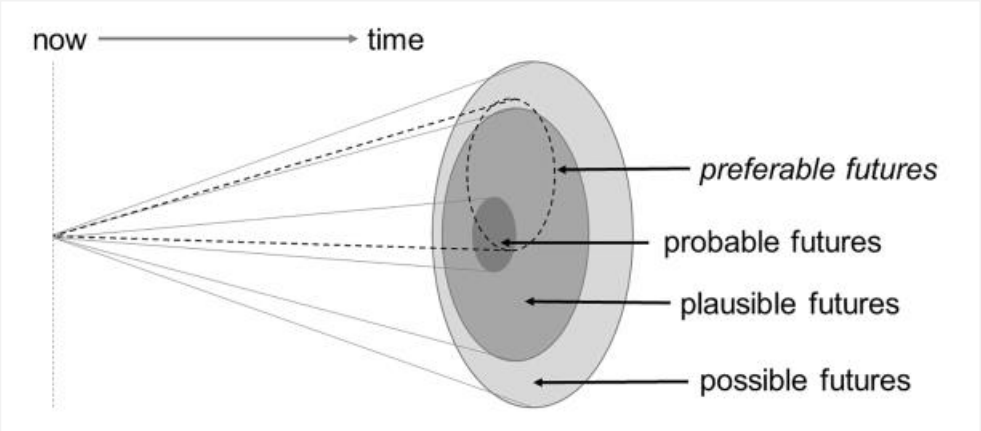
C.1.4 Framing scenarios

The purpose of the scenarios is to capture the likely range of possible outcomes.

> *Creating robust approaches to building multiple types of hypothetical futures has always been a challenge… any representation of the future is a subjective view based on assumptions that determine what we look at and what we see.* (Lyons et al., 2021, p. 2)

A demonstration of the totality of these potential subjective views is offered in the cone of vision (Figure B.5.1) in terms of possible, plausible, probable and preferable futures.

Figure B.5.1 Cone of vision (reprinted from Lyons et al., 2021, p. 3)



Key parameters associated with successful scenario testing include buy-in from stakeholders and diversity within participants of scenario development. In terms of buy-in, the application of the scenarios could be less likely to yield effective decision making if there are conflicts with views or interests held by the decision makers. In terms of diversity, the application of a range of world views and perspectives limits the probability of overlooking plausible options. Furthermore, the 'notion of plausibility limits the range of scenarios to the subjective capability and state of knowledge of the viewer' (Lyons et al., 2021, p. 6). To a great extent, this process of engagement and inclusion is synonymous with broader practice in transport planning and therefore could be readily applied.

In the context of New Zealand, there would be several possible scenarios pertaining to so-called 'black swan' events, including natural disasters – the Canterbury seismic sequences (2011–13), which caused 185 deaths and NZ$32 billion in damage, occurred on previously unmapped fault lines. This does burden the task somewhat. However, acceptance of the possibility of disaster could support a future more poised to respond to it.

Lyons et al. (2021) describe that scenarios may be defined in terms of:

- time, space and system
- within a given spatial region

- describing a future period of 10–50 years
- including a range of three to five different scenarios
- specifically defining a system or sector.

Lyons et al. (2021) identify that framing a scenario in terms of a given future year (such as 2050) is likely to have more impact – a practice already commonly in use by transport modellers.

Another benefit to an engagement-based scenario-development process is the ability to clearly and adequately define the system or sector and its bounds. Clear definition at the start of a project would avoid blow-out later in the project. This forward planning of the process appears synonymous with that of building or interpreting a model where there are many variables of interest, yielding hundreds of possible modelling options (often referred to as scenarios, albeit a different type of scenario). Given that scenario planning may be a relatively new concept to many practitioners, the need to plan for scenario planning in the same way as one might plan a model build is highlighted.

> *Defining the system is a challenge; it often takes time*. (Lyons et al., 2021, p. 5)

Lyons et al. (2021) offer a real example of how the UK Foresight project on Intelligent Infrastructure Systems evolved from a state of the future of mobility to the future of access, which critically evolved (from an already rich and diverse framework) to include digital access. This outcome of evolving the decision focus was derived through intuitive logic developed through workshopping a plausibility-led approach – a process aimed at increasing the likelihood of capturing those probable and preferable futures. Just 15 years (and a pandemic) later, there are calls for the inclusion of digital access in mainstream analysis, including this research paper.

The framing of scenarios would not always require customisation, and in many cases, the axis developed by Lyons & Davidson (2016) of energy cost and societal preference to physical or digital access (Figure B.5.2) could suffice. There is no easy way to validate this assumption given the reliance on the interaction effect between the two axes. However, the slow post-COVID-19 recovery of number of people entering the Auckland CBD during AM peak, being 73% of pre-COVID-19 levels as of March 2023 (Figure 4.5), do suggest some shift in preference for work.

In any case, ‘schemes with higher impacts, greater revenue risk and more uncertain outcomes require more tailoring of scenarios to ensure uncertainty is considered sufficiently’ (Lyons et al., 2021, p. 8). The WFH model format will be applied to strategic regional and national tools, supporting decision making of significant intervention. Therefore, a customised approach would be recommended to support uncertainties around this significant development in the practice of forecasting and simulation.

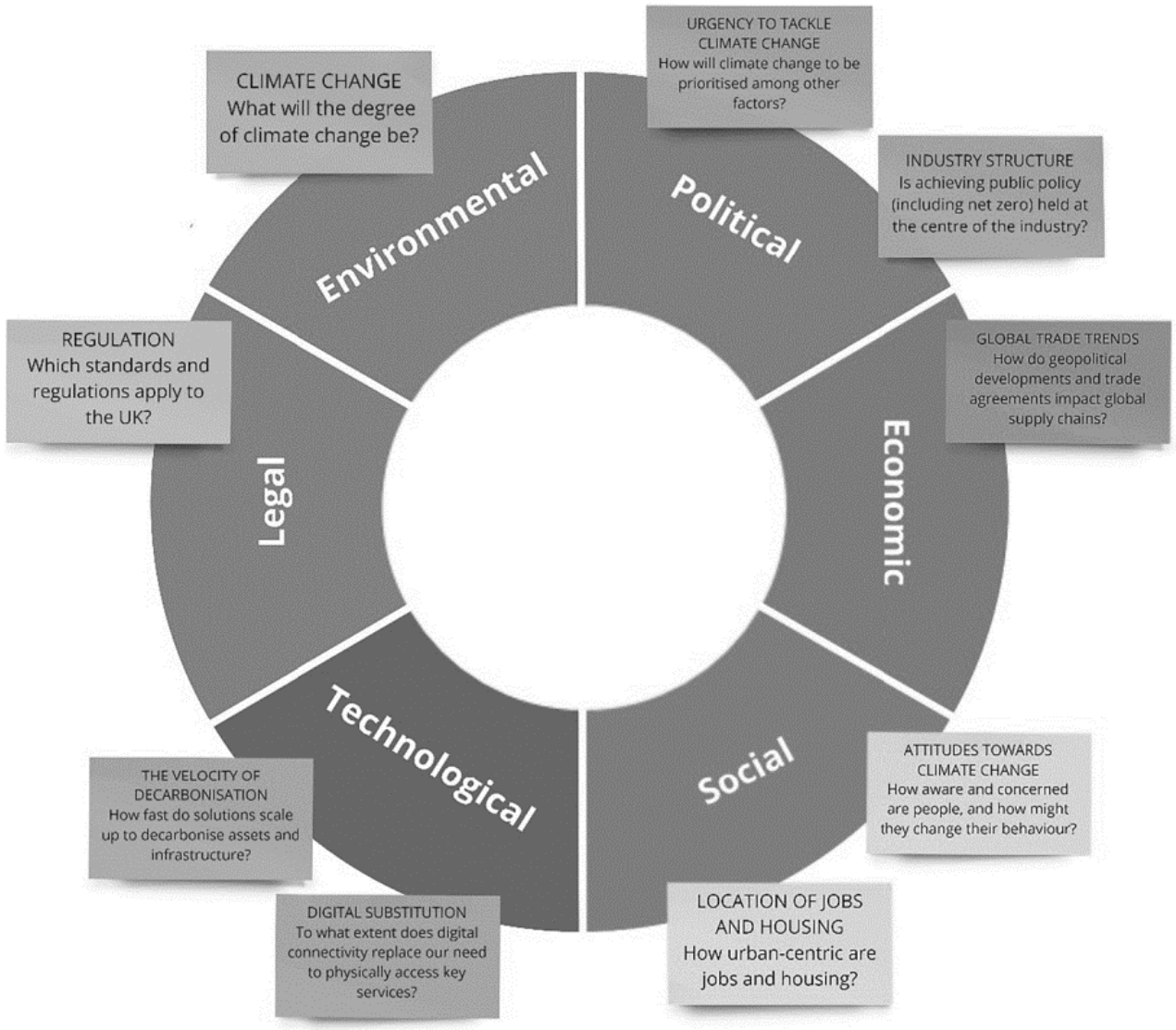
The number of three to five scenarios is estimated as the optimum in terms of limiting cost and cognitive overload and also supporting a more simplified and effective application compared to a larger number.

A starting point for scenario development is the PESTLE or STEEP frameworks. The PESTLE framework is recommended by Lyons et al. (2021) and is also a guiding principle in the development of business cases.[7] PESTLE stands for Political, Economic, Social, Technological, Legal, Environmental.

An example of the application of PESTLE is shown as Figure B.5.2. If developed in 2023, focuses might be influenced by the events of the past three years, including a global pandemic, war and the arrival of a form of artificial intelligence. In a New Zealand context, the rupturing of the Alpine Fault might be considered a priority.

[7] https://www.treasury.govt.nz/information-and-services/state-sector-leadership/investment-management/better-business-cases

Figure B.5.2 Illustrative drivers of change (variables) using the PESTLE framework (reprinted from Lyons et al., 2021, p. 7)



There are various ways of making sense of these plausible outcomes, potentially including some or all of the following steps (Lyons et al., 2021, p. 7):

- **Cross-impact analysis:** This involves developing an influence matrix of the extent to which each variable impacts on another. This can be used to develop a shortlist of the most impactful variables in the system. This would be similar in nature to a covariance matrix, developed as part of developing a discrete choice model.
- **Variable projections:** Each variable will be extrapolated according to at least two possible futures for its state.
- **Consistency analysis:** For a scenario to be credible, the combination of variable projections of which it is to be comprised must be able to reasonably co-exist.
- **Cluster analysis:** Computational processing of a large number of variables into bundles of consistent and similar projections. This process is noted as being less influenced by the habits of the scenario team.

Appendix D: Rationalising variables – detailed tables

Table B.5.1 Variables as detractors or enablers of choosing to WFH

Group/variable		Enabler or detractor of WFH?	Assumption (why is it one or the other?)
Work and employment factors	Industry and employment type	Detractor	Some industries cannot WFH
	Employer policy	Detractor	Some HR policies are restrictive
	Productivity	Both	Depends on the person
	Employer and employee costs	Enabler	Take advantage of cost savings
	Job satisfaction and career prospects	Neither	Expected to be correcting
	Home working environment quality	Enabler	Poorer environment may not detract
	Communication, collaboration	Detractor	In person is a superior experience
Transport and accessibility	Trip characteristics	Both	Depends on distance lived from work
	Car usage and ownership	Detractor	WFH more associated with public transport use
	Reliability of digital access	Enabler	Few if any known instances of detraction
	Quality of access to the transport system	Enabler	Lack of viable travel choice enables WFH
Social and demographic	Psycho-social determinants	Multiple	
	Gender	Neither	Not independent variable
	Age	Neither	Not independent variable
	Income	Enabler	Associated with participating industries
	Family and social influence	Both	Creates distraction, adds value to others
	Education level	Enabler	Associated with participating industries
	Household interactions and conflict	Detractor	Social constraints = primary decision drivers
	Social connectedness and wellbeing	Both	Depends on the person
Environment and land use	Urban characteristics – city size, density	Enabler	Larger cities include more WFH-able positions
	Real estate, rental demands, values	Enabler	Business incentive to reduce costs
	Location, proximity to CBD	Enabler	Higher perceived costs accessing CBD
	Agglomeration effects	Neither	Not independent variable
	Cultural and social attractions	Unknown	Complex, multifaceted
	Property tenure	Neither	Not independent variable

Table B.5.2 Consideration of variables as enablers or detractors – how this might change over time

Group	Variable	Enabler or detractor of WFH?	Assumption (why is it one or the other?)	May hold true if:	May not hold true if:
Work and employment factors	Industry and employment type	Detractor	Some industries cannot WFH	Rise of AI forces more into manual industries	Increased automation of those industries
	Employer policy	Detractor	Some HR policies are restrictive	Continued suspicion of WFH among leaders	Increasing acceptance of WFH among leaders
	Productivity	Both	Depends on the person	Technological advancements, changed attitudes of productivity, past time in the chair	
	Employer and employee costs	Enabler	Take advantage of cost savings	Continued urban sprawl, car-centric growth	More live/work dwellings, mixed-use development
	Job satisfaction and career prospects	Neither	Expected to be correcting	Labour market continues to be competitive	Labour market becomes uncompetitive (AI)
	Home working environment quality	Enabler	Poorer environment may not detract	Permission to WFH is not qualified	HR policies require home environment inspections
	Communication, collaboration	Detractor	In person is a superior experience	In person continues to be superior experience	Tech products can simulate in person
Transport and accessibility	Trip characteristics	Both	Depends on distance lived from work	More compact urban model, stronger local centres, reduced need to travel/increased costs	
	Car usage and ownership	Detractor	WFH more associated with public transport use	Car-centric planning and urban form continues	Increase in car sharing, mobility as a service
	Reliability of digital access	Enabler	Few if any known instances of detraction	Future investment keeps pace with demand	Future demands for capacity outpace investment
	Quality of access to the transport system	Enabler	Lack of viable travel choice enables WFH	Road user charges, mode shift policies	More live/work dwellings, mixed-use development
Social and demographic	Psycho-social determinants	Multiple			
	Gender	Neither	Not independent variable	Decreasing gender-based discrimination	Gender-based discrimination returns
	Age	Neither	Not independent variable	Increasing opportunities across age groups	Age discrimination in the workforce
	Income	Enabler	Associated with participating industries	Increasing scarcity in knowledge-based sectors	Increasing scarcity of on-site skills (trades, etc.)
	Family and social influence	Both	Creates distraction, adds value to others	Changing attitudes to work-life balance, more acceptance of alternative life roles	

Group	Variable	Enabler or detractor of WFH?	Assumption (why is it one or the other?)	May hold true if:	May not hold true if:
	Education level	Enabler	Associated with participating industries	Increasing scarcity in knowledge-based sectors	Increasing scarcity of on-site skills (trades, etc.)
	Household interactions and conflict	Detractor	Social constraints = primary decision drivers	Continuation of family co-habitation	Alternative social-habitation paradigm
	Social connectedness and wellbeing	Both	Depends on the person	Technological advancements in collaboration, increasing acceptance of different personalities	
Environment and land use	Urban characteristics – city size, density	Enabler	Larger cities include more WFH-able positions	Continuation of spatial agglomeration	Development of digital agglomeration
	Real estate, rental demands, values	Enabler	Business incentive to reduce costs	Land-use values run high	Land-use values run low
	Location, proximity to CBD	Enabler	Higher perceived costs accessing CBD	Classic urban models persist, with a CBD	Increased mixed land uses, reduced travel costs
	Agglomeration effects	Neither	Not independent variable	WFH more likely to affect agglomerations than the other way round – rise of digital agglomeration	
	Cultural and social attractions	Unknown	Complex, multifaceted		
	Property tenure	Neither	Not independent variable	Status quo distribution of tenure, access costs	Distribution of tenure according to access cost

Table B.5.3 Table of variables – consideration of significance and independence of variables

Variable	Metric	Indicative significance	Possible interaction effect (test for improved fit)
Industry and employment type	Category (type)	Probably	Communication, collaboration Real estate, rental demands Urban characteristics Proximity to CBD Education level Gender
	Number of employees	Probably	
Employer policy	Number of days permitted to WFH	Probably	Employer and employee costs Productivity
Employer and employee costs	WFH set-up costs ($)	Probably	Employer policy

Variable	Metric	Indicative significance	Possible interaction effect (test for improved fit)
Home working environment quality	Dedicated space (binary)	Probably	
	Comfort (utility)	Probably	
Trip characteristics and quality of access to the transport system	Distance	Probably	
	Time	Probably	
	Cost of trip	Probably	
	Generalised cost	Probably	
	Distance to public transport stop (m)	Probably	
	Public transport headways (time)	Probably	
	Active travel options (relative metric)	Probably	
Communication, collaboration	Perceived utility	Likely	Industry type
Car usage and ownership	Number of cars in household	Likely	
Reliability of digital access	Connection reliability	Likely	
	Connection speed	Likely	
Household interactions and conflict	Number of persons per room (crowding)	Likely	Family influences
Real estate, rental demands, values	Corporate perceived cost	Likely	Industry type, employer policy
Income	Salaried income (NZD)	Likely	Industry type, age
Education level	Highest attained qualification (scaled category)	Likely	Industry type, income
Productivity	Corporate performance	May be	Industry type, employer policy
Family and social influence	Number of dependants	May be	Household interactions and conflict
Social connectedness and wellbeing	Perceived freedom within social construct	May be	Industry type, company size
Urban characteristics – city size, density	Population, density categories	May be	Industry type, policy
Location, proximity to CBD	Distance from CBD central point (m)	May be	Industry type
Cultural and social attractions	Perceived utility	May be	
Agglomeration effects	Density of certain industry types	Probably not	
Property tenure		Probably not	
Job satisfaction and career prospects		Probably not	
Gender		Probably not	Industry type
Age		Probably not	