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Understanding Individuals' Learning and Decision Processes in a Changing Environment by Using Panel Data

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ABSTRACT

When a new element enters individuals' environments such as an introduction of transport service, they may response differently. They need time to learn and familiarize themselves with the new service through experience(s) before they decide whether it is wise to adopt the new service in their daily travel routines. These learning and decision processes are developed over time and thus produce dynamics in individuals' behavioural responses towards the introduction of a transport service. This affects the demand of the new service, including the demand of the existing transport services. Douglas (2003) found that there was a 'ramp-up' factor in the patronage growth of thirteen new or upgraded rail schemes around the world, with 79% in the first year, 95% in the second year and steady state condition after three years of operation. This highlights the importance of understanding the dynamics in individuals' behavioural responses towards the introduction of a new transport service since not all people will try and use the new service within the first year of introduction. On the other hand, these behavioural responses also affect the short- and long-term demand for the new service and the business viability of the service provision. Available studies on individuals' behavioural responses to a new transport intervention are done from microeconomic perspectives that investigate the influence of objective factors on the behavioural responses. Thus, the influence of the theory-based subjective factors on individuals' behavioural responses has not been examined empirically. Understanding these would assist transport and urban planners to design a better marketing strategy to increase the market share of the new service as soon as it opens to the public.

A change in external factors such as seasons (winter, spring, summer and autumn) also affects individuals' activity-travel decisions, thus resulting in dynamics in activity-travel patterns across different seasons of the year. Individuals' constraints, in a form of mandatory activities such as working and studying, are also influencing individuals' decisions to participate in non-mandatory activities (e.g. leisure and maintenance activities) on a daily basis. Moreover, the interdependency between travel demand, time allocation and mode choice, with respect to the interactions between mandatory and non-mandatory activities, in different seasons is less explored. Understanding these would assist transport planners and local transport operators to manage travel demand strategies across different seasons of the year that provide a better transportation systems for all individuals. This may lead to increases in individuals' activity participation, and thus increase their well-being.

This thesis includes five papers, investigating individuals' behavioural responses to the introduction of a new public transport service, including the subjective factors that underlie the decisions to response to the new service that is theory-based. This thesis also examines the effects of seasonal variations on individuals' activity-travel patterns by incorporating individuals' constraints and weather thermal indicators in the model framework. The first paper explores individuals' characteristics of the quick-response and the adopters of the new public transport service after its introduction, and also examines the temporal effects contributed by individuals' adjustments to use and adopt the new service. The second paper investigates the subjective factors that underlie individuals' decisions to use the new public transport service as soon as possible after its introduction by proposing a modified attitude- behaviour model framework. The third and fourth papers analyse the effects of seasonal variations and individuals' constraints on their day-to-day activity-travel decisions and activity travel patterns, including the interactions among different activities engagements, given individuals' unique characteristics, land use and weather attributes. The fifth paper describes the panel survey used in all papers included in this thesis and analyse the attrition and fatigue in the two-week travel diary survey instrument.

Keywords

Behavioural responses, seasons, panel data, travel diary, activity-travel pattern, theory of planned behaviour, space-time constraint, changing environment, tram, Stockholm.

SAMMANFATTNING

När ett nytt element i individers miljöer tillförs, såsom introduktionen av en transporttjänst, reagerar de på olika sätt. De behöver tid till att lära sig om och bekanta sig med den nya tjänsten genom erfarenhet innan de beslutar sig för om det är klokt att använda den nya tjänsten i sina dagliga reserutiner. Dessa lärande- och beslutsmässiga processer utvecklas över tiden och producerar därmed dynamik i individernas beteendemässiga reaktioner av införandet av en transporttjänst. Således påverkas efterfrågan på den nya tjänsten, inklusive efterfrågan på befintliga transporttjänster. Douglas (2003) fann att det fanns en taktökningsfaktor i kundstöd i tillväxten av tretton nya eller uppgraderade järnvägssystem runt om i världen, med 79% under det första året, 95% under det andra året och stabilt tillstånd efter tre års drift. Detta understryker vikten av att förstå dynamiken i individernas beteendemässiga reaktioner vid införandet av en ny transporttjänst eftersom inte alla människor kommer att använda den nya tjänsten inom det första året av introduktionen. Å andra sidan, dessa beteendemässiga reaktioner påverkar också på både kort och lång sikt efterfrågan på den nya tjänsten och även verksamhetens gångbara tillhandahållande av tjänster. Tillgängliga studier på individernas beteendemässiga reaktioner på nya transportingripanden görs från ett mikroperspektiv som undersöker påverkan av *objektiva* faktorer på beteendereaktion. Således, påverkan av teoribaserade *subjektiva* faktorer som ligger till grund för individers beteendemässiga reaktioner har inte undersökts empiriskt. Att förstå dessa skulle hjälpa transport- och stadsplanerare att utforma en bättre marknadsföringsstrategi för att öka marknadsandelen för en ny tjänst så snart den öppnar för allmänheten.

En förändring i yttre faktorer såsom säsonger (vinter, vår, sommar och höst) påverkar också individers aktivitets- och resebeslut, vilket skapar dynamik i aktivitets- och resemönster tvärsöver olika säsonger under ett år. Individernas bivillkor, i form av obligatoriska aktiviteter såsom att arbeta och att studera, påverkar också individers beslut att delta i frivilliga aktiviteter (t ex fritids- och underhållsaktiviteter) på daglig basis. Dessutom: det ömsesidiga beroendet mellan efterfrågan på resor, tidsallokering och transportsätt med avseende på samspelet mellan obligatoriska och frivilliga aktiviteter för olika årstider är mindre utforskade. Att förstå dessa skulle hjälpa transportplanerare och lokala transportföretag att hantera efterfrågan-strategier för resor tvärsöver olika årstider vilket ger ett bättre transportsystem för alla individer. Detta kan leda till ökning i individers aktivitetsdeltagande och därmed öka deras välbefinnande.

Denna avhandling innehåller fem artiklar som undersöker individers beteendemässiga reaktioner vid införandet av en ny kollektivtrafikstjänst, inklusive teoribaserade subjektiva faktorer som ligger bakom de beslut som svar på den nya tjänsten. Denna avhandling undersöker även effekterna av säsongsvariationer på individers aktivitets- och resemönster genom att integrera individers bivillkor och vädertermiska indikatorer inom ramen för modellen. Den första artikeln undersöker vilka egenskaper individer med snabb respons har och egenskaper hos användare av den nya transporttjänsten efter dess införande men undersöker även tidsmässiga verkningar som individers justeringar att använda och anta den nya tjänsten bidragit med. Den andra artikeln undersöker subjektiva faktorer som ligger till grund för individers beslut att använda den nya kollektivtrafikstjänsten så snart som möjligt efter dess införande genom att föreslå ett modifierat attityd-beteendemodellramverk. Den tredje och den fjärde artikeln analyserar effekterna av säsongsvariationer och individernas bivillkor på deras från dag till dag-beslut gällande aktivitetsresor och aktivitetsresemönster, inklusive samspelet mellan olika aktivitetsengagemang, givet individens unika egenskaper, markanvändning och väderattribut. Den femte artikeln beskriver panelundersökningen som används i alla papper som ingår i avhandlingen och analyserar slitningen och trötthetten i en tvåveckorsresedagbok som undersökningsinstrument.

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Nursitihazlin Ahmad Termida
Stockholm, March 2017

LIST OF PAPERS

I. Ahmad Termida, N., Susilo, Y. O., Franklin, J. P. (2016). Observing dynamic behavioural responses due to the extension of a tram line by using panel survey. *Transportation Research Part A,* 86: 78-95. DOI: 10.1016/j.tra.2016.02.005. Presented at the 3rd Symposium of the European Association for Research in Transportation, Leeds, UK, September, 2014.

II. Ahmad Termida, N., Susilo, Y. O., Franklin, J. P. (2016). Subjective factors influencing individual's response to a new public transport service. Revised version submitted to *Transportation*. Presented at the 4th Symposium of the European Association for Research in Transportation, Copenhagen, Denmark, September, 2015.

III. Ahmad Termida, N., Susilo, Y. O., Franklin, J. P. (2016). Examining the effects of out- of-home and in-home constraints on leisure activity participation in different seasons of the year. *Transportation,* 43: 997-1021. DOI 10.1007/s11116-016-9717-3. Presented for poster sessions at the 95th Annual Meeting of Transportation Research Board, Washington, D.C., USA, January, 2016.

IV. Ahmad Termida, N., Susilo, Y. O., Franklin, J. P., Liu, C. (2017). Understanding seasonal variation in individual's activity participation and trip generation by using four consecutive two-week travel diary. Revised version submitted to *Travel Behaviour and Society.* Presented at the 14th World Conference on Transportation Research, Shanghai, China, July, 2016.

V. Ahmad Termida, N., Susilo, Y. O., Franklin, J. P. (2017). Attrition and fatigue in a four waves of two-week travel diary: A case study in Stockholm, Sweden. *To be submitted*.

MY CONTRIBUTION TO THE PAPERS

I. The idea of Paper I was initiated from joint discussion between Professor Yusak Susilo and Nursitihazlin Ahmad Termida. Nursitihazlin prepared the dataset, run the model and wrote the paper. The supervisors helped very much in revising Nursitihazlin's writing, interpreting the results and in responding reviewers' comments until the paper was accepted.

II. The idea of Paper II was initiated from joint discussion between Professor Yusak Susilo and Nursitihazlin Ahmad Termida. Nursitihazlin prepared the dataset, run the model and wrote the paper. The supervisors helped very much in revising Nursitihazlin's writing and interpreting the results.

III. The idea of Paper III was from Nursitihazlin Ahmad Termida. The model structure was adopted from Liu et al. (2015). Nursitihazlin prepared the dataset, run the model and wrote the paper. The supervisors helped very much in revising Nursitihazlin's writing, interpreting the results and in responding reviewers' comments until the paper was accepted.

IV. The idea of Paper IV was initiated from joint discussion between Professor Yusak Susilo, Dr. Chengxi Liu and Nursitihazlin Ahmad Termida. The model structure was adopted from Liu et al. (2014). Nursitihazlin prepared the dataset and wrote the paper. Dr. Chengxi Liu prepared the weather dataset and run the model. The supervisors helped very much in revising Nursitihazlin's writing and interpreting the results.

V. The idea of Paper V was initiated from joint discussion between Professor Yusak Susilo and Nursitihazlin Ahmad Termida. Nursitihazlin prepared the dataset, run the model and wrote the paper. The supervisors helped very much in revising Nursitihazlin's writing and interpreting the results.

RELATED PAPERS, NOT INCLUDED IN THIS THESIS

VI. Zhang, W., Susilo, Y.O., Ahmad Termida, N. (2016). Investigating the interactions between travellers' familiar areas and their multi-day activity locations. *Journal of Transport Geography,* 53: 61-73. DOI: 10.1016/j.jtrangeo.2016.04.012

VII. Liu, C., Susilo, Y. O., Ahmad Termida, N. (2016). Subjective perception towards uncertainty on weather conditions and its impact on out-of-home leisure activity participation decisions. Presented at the 6th International Symposium on Transportation Network Reliability, Nara, Japan. Submitted to *Transportmetrica B.*

VIII. Zhang, W., Ahmad Termida, N., Susilo, Y. O. (2017). What construct one's familiar area? A quantitative and longitudinal study. Presented at the 14th World Conference on Transportation Research, Shanghai, China. Revised-version submitted to *Environment and Planning B: Urban Analytics and City Science.*

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1. INTRODUCTION

1.1 Travel behaviour in a changing environment

Travel behaviour, or how people move in space and time does involve interactions with an environment. Environment is defined as the circumstances, objects, or conditions by which one is surrounded (Merriam-Webster Dictionary, 2017). Thus, environment could be represented by land use and built environment (e.g. density, land use mix, urban sprawl, non- motorized conditions, network connectivity, etc.), external factors (e.g. climate, weather, season, etc.), and social and cultural conditions (e.g. beliefs, customs, practices, behaviour, etc.). Previous studies have found that land use and built environment affect individual travel behaviour such as mode choice, trip generation, trip length, trip chaining, vehicle-miles travelled, and activity space (e.g. Cervero, 1996; Cervero and Kockelman, 1997; Ewing and Cervero, 2001; Cervero, 2002; Frank et al., 2007; Zhang et al., 2012; Dharmowijoyo et al., 2014, etc.). Meanwhile, plenty of studies have found that climate change, day-to-day weather variations, and seasonal variations (e.g. winter, spring, summer, and autumn) affect individual travel behaviour such as mode choice, activity participation, trip chaining, route choice, destination choice, trip distance, and public transport ridership (e.g. Kitamura and Van der Hoorn, 1987; Bhat and Gossen, 2004; Guo et al., 2007; Koetse and Rietveld, 2009; Silm and Ahas, 2010; Sabir, 2011; Tang and Takhuriah, 2012; Connolly, 2013; Cools and Creemers, 2013; Liu et al., 2014, 2015a, 2015b, 2015c, etc.). Many studies have found that socio- cultural conditions (e.g. lifestyle, personal beliefs, and perceptions on transport and environment) affect individual travel behaviour particularly on mode choice and vehicle type based on fuel (e.g. Boarnet and Sarmiento, 1998; Lanzendorf, 2003, 2010; Nutley, 2005; Anable, 2005; Cao et al., 2006; Susilo et al., 2009; Dharmowijoyo et al., 2015, etc.) Since a large body of studies has showed the evidence of the linkage between environment and individual travel behaviour, thus, a change in the environment, may also lead to a change in people's travel behaviour, resulting to the dynamics and variability in their activity-travel patterns.

Focusing on the built environment aspect, when there is a change in the travel environment due to an introduction of a new transport intervention, people will response differently to the change over time, given the constraints and needs to travel. This contributes to a change in the travel demand for the new transport service including the demand for other existing transport services. People's responses to the introduction of a new transport service, therefore, is dynamics. For example, Douglas (2003) confirmed that there was a 'ramp-up' factor (delay in patronage take-up or response during the first months and years of a new service) in the patronage growth of thirteen new or upgraded rail schemes around the world, i.e.: 79% for the first year of operation, 95% for the second year of operation and 100% or a steady-state condition after three years of operation. The need to understand these so-called behavioural responses is crucial for those who concerned with the provision of transport services (e.g. public authorities, transport operators, financing organization, transport and urban planners, etc.) since it would affect short- and long-term demand for the services and the business viability of the service provision. In travel behaviour research, these behavioural responses need to be understood since it is a part of people's learning and decision processes that are dynamics in nature and thus, influence their mode choices and activity-travel patterns over time.

So far, individuals' behavioural responses to the introduction of a new transport service have mainly been investigated from a microeconomic perspective, considering instrumental or objective factors such as travel time, walking time, income, and built environment features (e.g. Hensher, 1997; Chatterjee and Ma, 2006, 2007, 2009; Chatterjee, 2011). This assumes that people choose the service that provides the highest

utility level. This approach can be criticised for decontextualizing choice behaviour since the process of experiencing, intending, attuning and acting that exist in people's ecological setting undeniably influence their behavioural choices (Dijst et al., 2008). Moreover, although previous studies have highlighted the importance of subjective elements in affecting people's choices on travel mode, travel route, tour type, and many more, still a very few studies have examined the influence of subjective factors on individuals' behavioural responses, empirically (e.g. Chatterjee and Ma, 2007, 2009; Yáñez et al., 2010a; 2010b). It is acknowledged that these previous studies have incorporated the concepts from attitudinal research (e.g. perceptions on public transport) into their studies frameworks, however, a full conceptual model drawing upon attitude-behaviour theory is not been examined yet. Therefore, it is important to understand what are the subjective factors, alongside with objective factors, that may influence individuals' behavioural responses to the introduction of a new transport service. This will be done by adopting and modifying the existing attitude-behaviour theory (Theory of Planned Behaviour, TPB (Ajzen, 1991)) so that better insights can be gained from this and the knowledge can be used by transport and urban planners to design a better marketing strategy in order to increase the market share of the new service as soon as it opens to the public, thus affects revenues.

Focusing on external factors such as seasonal variations that contributed by a substantial change in weather attributes (e.g. temperature, humidity, precipitation, wind speed, etc.), people's travel behaviour is also affected by it. Many researchers have argued that seasonal variations play an important role in shaping people's activity-travel patterns (e.g. number of trips, activity participations, public transport ridership, etc.), thus contributing to the dynamics of these patterns across the year. However, only few studies (e.g. Kitamura and Van der Hoorn, 1987; Bhat and Gossen, 2004; Bhat and Srinivasan, 2005; Silm and Ahas, 2010, etc.) have examined the seasonal variations on individuals' activity-travel patterns due to limited panel data available in transport research. Understanding these would assist transport planners and local transport operators to manage travel demand strategies across different seasons of the year that provide a better transportation systems for all individuals. This may lead to increases in individuals' activity participation, and thus increase their well-being.

Both individuals' behavioural responses towards a new transport service and the effects of seasonal variations on individuals' activity-travel patterns should consider the availability of individuals' constraints. Hägerstrand (1970) has introduced the concept of space-time prism that shows individuals' possible behaviour in time and space given their capability constraints, coupling constraints, and authority constraints. Thus, the constraints do not only consider individuals' budgets and time constraints (e.g. capability constraints), but also considered how an individual interacts with other people and materials (e.g. coupling constraints), and complies with any given authorities' rules and regulations (e.g. authority constraints). These constraints would shape individuals' decisions in participating in any activities (both in-home and out-of-home) and travels (Miller, 2007). Therefore, incorporating individuals' space-time constraints and seasonal variations in examining the dynamics in individuals' activity-travel patterns simultaneously would provide better insights on how people make a choice and decision in their daily travels throughout different seasons of the year. To date, this has not been done in the above-mentioned studies on the effects of seasonal variations on individuals' activity-travel patterns.

The majority of travel behaviour analysis has been done using a traditional cross-sectional survey that mostly collects travel data of one day. Given a large number of samples with proper sampling techniques, this type of survey does a decent job in capturing household travel behaviour on average, in a population of interest (Elango et al., 2007). This type of survey, however, has been criticised for not capturing the full range of individuals travel behaviour (Pendyala and Pas, 2000; Cherchi et al., 2017)

and for neglecting the mid- and long-term effects on variability in individuals' activity-travel patterns (Pas and Koppelman, 1987; Kitamura et al., 2006). Due to these reasons, awareness of a need to collect panel data at the disaggregate level has increased, especially multi-day and multi-period data collected on the same individual (longitudinal panel data). Panel data is the only means to better capture theoretical aspects of behavioural dynamics in travel behaviour such as response lags, response leads, habit persistence, etc. (Kitamura, 1990; Goodwin et al., 1990), and also to capture temporal effects due to a change in the travel environment such as shock effects (Cantillo et al., 2007) and inertia effects (Yáñez et al., 2008; Yáñez and Ortúzar, 2009). Moreover, individuals' learning and decision processes in a changing environment can only be captured by panel data. The analysis of day-to-day variability in travel behaviour using panel data would benefit: transport modellers in obtaining a better estimation results; social researchers in gaining better understanding regarding travel behaviour; policy analysts in obtaining better insight about the potential effects of transportation policies (Jones and Clarke, 1988). Panel data, however, have some remaining issues that remain unsolved in terms of the panel survey's design and implementation, especially with longitudinal panel survey.

With these research gaps in mind, this thesis reflects upon investigation of individuals' learning and decision processes in a changing environment on their activity-travel patterns with regard to the introduction of a new public transport service by using longitudinal panel data. In this thesis, this research aim is further decomposed into six main research questions as following:

(1) Who used the new public transport service sooner than others, and adopted the new public transport service as a part of their regular mode choice?
(2) What are the temporal effects generated by the new public transport service?
(3) Using a modified attitude-behaviour theory framework, what are the subjective factors that influence individuals to more quickly use the new public transport service than others?
(4) What are the effects of constraints on individuals' day-to-day leisure activity participations in different seasons of the year?
(5) What are the effects of seasonal variations on individuals' activity participation and travel behaviour considering travel constrains and travel as a derived demand of activity participation?
(6) What attributes contribute to the attrition and fatigue in a two-week travel diary survey?

As this thesis is submitted in the form of PhD Thesis by Publication, most of the content included is in the form of research articles that have already been accepted or submitted for publication. This introductory section provides an overview of those articles and how each research questions listed above have been answered in those articles.

1.2 Research objectives

To answer the research questions, a series of research objectives are discussed and addressed in the articles.

1. To examine individuals' characteristics of quick- and slow-response adopters of a new transport option after its introduction and also who have adopted the new option as a part of their regular mode choice by incorporating the reinforcement learning and individuals' unique socio-demographic attributes in the models.
(Paper I and Paper II)

Paper I aims to investigate which group of travellers have used a new public transport option earlier than others, and integrated the new service as a part of their daily travel patterns. Paper II aims to investigate the behavioural change in terms of attitudes and perceptions on individuals' resources and constraints in using a new or modified public transport service over time after its introduction by using panel data. Understanding these would enable transport and urban planners to design a better marketing strategy to increase the market share of the new service as soon as it introduced to the public.

2. To capture the temporal effects such as shock and inertia effects due to the introduction of a new public transport option in the models. (Paper I)

Paper I aims to capture the temporal effects of shock and inertia that generated by the introduction of a new transport option by analysing the changes in mode shares in all trips, mode migrations for non-discretionary trips, and the elasticity analysis of the number of non- discretionary trips made for each main mode with respect to travel time in each survey period. Understanding these would provide some insights on individuals' learning and decision processes when a new transport intervention is introduced.

3. To investigate the influences of subjective factors on the responses of individuals over time to the introduction of a new or modified public transport service by proposing a theory-based alternative model framework. (Paper II)

Paper II aims to investigate the subjective factors that influence individuals to more quickly use a modified public transport service than others by proposing an alternative model that modifies the TPB model framework. Understanding this could give a valuable insight about individual behavioural change to the opening of a new or modified public transport service, and enable transport and urban planners to design a marketing strategy to increase the market share of the new service as soon as possible after its introduction.

4. To analyse individuals' decision making processes in participating for leisure activities over time in different seasons of the year by incorporating space-time constraints, habit persistence, objective weather indicators and state dependence in the dynamic models. (Paper III)

Paper III aims to examine the effects of out-of-home and in-home constraints on individuals' day-to-day leisure activity participation decisions in four different seasons. Understanding this would assist transport planners and local transport operators to manage travel demand strategies across different seasons of the year.

5. To examine the effects of various work schedule durations (e.g. fixed, shift, partial- and full-flexible) on individuals' leisure activity participation decisions. (Paper III)

Paper III aims to explore the effects of various types of working schedules (fixed, shift, partial- and full-flexible) on individuals' decisions to participate in day-to-day leisure activities. Understanding this enables transport operators to provide efficient transportation systems for all individuals that may lead to increase in individuals' activity participation, especially leisure activities, and thus increase their well-being.

6. To examine the interactions between travel demand, time allocation and mode choice by jointly modelling mandatory and non-mandatory activity-travel engagements over different seasons in the dynamic models.
(Paper IV)

Paper IV aims to investigate seasonal variations by incorporating the interactions between activity demands, the number of trips derived from the demand for activities, travel time generated from the trip and activity demand, and also mode share which generates the travel time across different seasons at individual level. Understanding these would help transport planners to design transport policies that are suitable for different socio-demographic groups in different season conditions.

7. To examine the attrition and fatigue issues in a four waves of two-week travel diary.
(Paper V)

Paper V aims to analyse and capture the attrition and fatigue in one of the survey's instrument (e.g. two-week travel diary) in the models. This understanding would enable transport researchers to understand the possible bias in statistical and econometrical results for studies using this panel data that may affect the conclusions of the studies.

The contributions of each paper with regard to each research objective, study aims, and the involvement of estimation models used in each paper are exhibited in Figure 1.

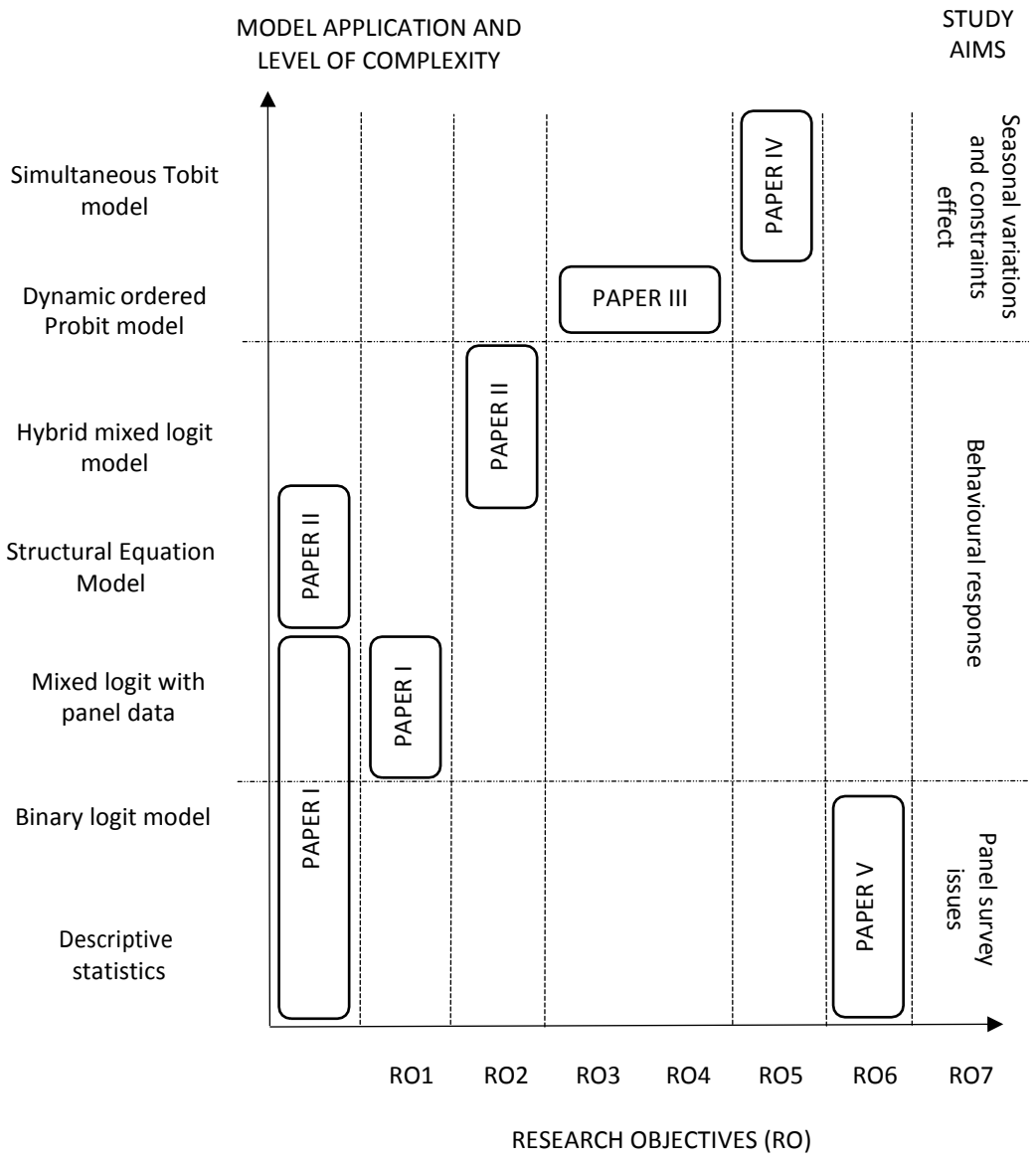

Figure 1 The relationships between research objectives or contributions, models used and study aims in each paper

The thesis utilizes two data sources. First, all the included papers reported in this thesis used the four-wave longitudinal panel data collected in Stockholm, Sweden, in which using only two out of three survey instruments: a two-week travel diary and psychological questionnaire. The third instrument that is not discussed in this thesis is the mental map-related questions, however, the design of the questions was described in Paper I and Paper V. The two-week travel diary is self-reported by pen and pencil approach that was mailed to the respondents, while the psychological questionnaire along with individuals' socio-demographic information was collected using an online approach. The case study used in all papers in this thesis is the tram extension line service *(Tvärbanan)* which connects three main neighbourhood areas, namely Alvik, Solna and Sundbyberg as shown in Figure 2 (see the smaller map on the right-hand side). These areas are considered sub-urban areas in Stockholm County and governed by two different municipalities (e.g. Solna and Sundbyberg municipalities). This tram extension service has been introduced

to the public on 28th October 2013. The first wave of the survey was collected in two weeks before the tram extension was introduced in autumn season (14th – 27th October 2013), the second wave of survey was collected approximately a month after the introduction in winter season (2nd – 15th December 2013), the third and the fourth waves of surveys were collected approximately after five (17th- 30th March 2014) and seven months (26th May – 8th June 2014) of the introduction that collected in spring and summer seasons, respectively. The seven-month period may be enough to cover behavioural responses to emerge and start to diminish (Chatterjee and Ma, 2006). To my humble knowledge, this is the first attempt to use a two-week travel diary in four consecutive waves that covers four different seasons of the year, for the same panel of individuals. However, this panel survey suffers from low sample size, thus contributes to unrepresentative sample of population (see Statistic Sweden (*Statistika Centralbyrån)*, SCB, 2016). It is hope that a total of eight-week (56 days) travel diary can provide a wealth of information for activity-travel pattern analysis and temporal analysis. The focus areas (Solna and Sundbyberg sub-urban areas) have similar land use and built environment characteristics to Stockholm municipality (urban areas) in terms of accessibility to public transport, grocery stores, medical centers, primary schools, job opportunities and provisions of recreational parks (see SCB (2015)). In this study, the respondents were individuals who live within approximately 500 metres from the nearest tram extension's stations and they are treated as the main sample. Meanwhile, 20 percent of the total 102 respondents are the control sample and defined as individuals who live a kilometre away from the nearest tram extension's stations.

Second, two out of five papers (Paper III and Paper IV) utilized the weather data obtained from Swedish Meteorological and Hydrological Institutes (SMHI) (2015), which includes daily air temperature (degree Celsius), hourly relative humidity (%), and hourly wind speed (km/hr). Both hourly recorded relative humidity and wind speed were averaged into daily levels that used the records between 7:00 a.m. and 8:00 p.m. since most of the recorded activities in the two-week travel diary were conducted in daytime. These data are recorded from the nearest weather stations available to the study area with the assumption that the weather data can represent the actual weather in the study area due to the small in size of areas relative to the spatial variation of weather conditions.

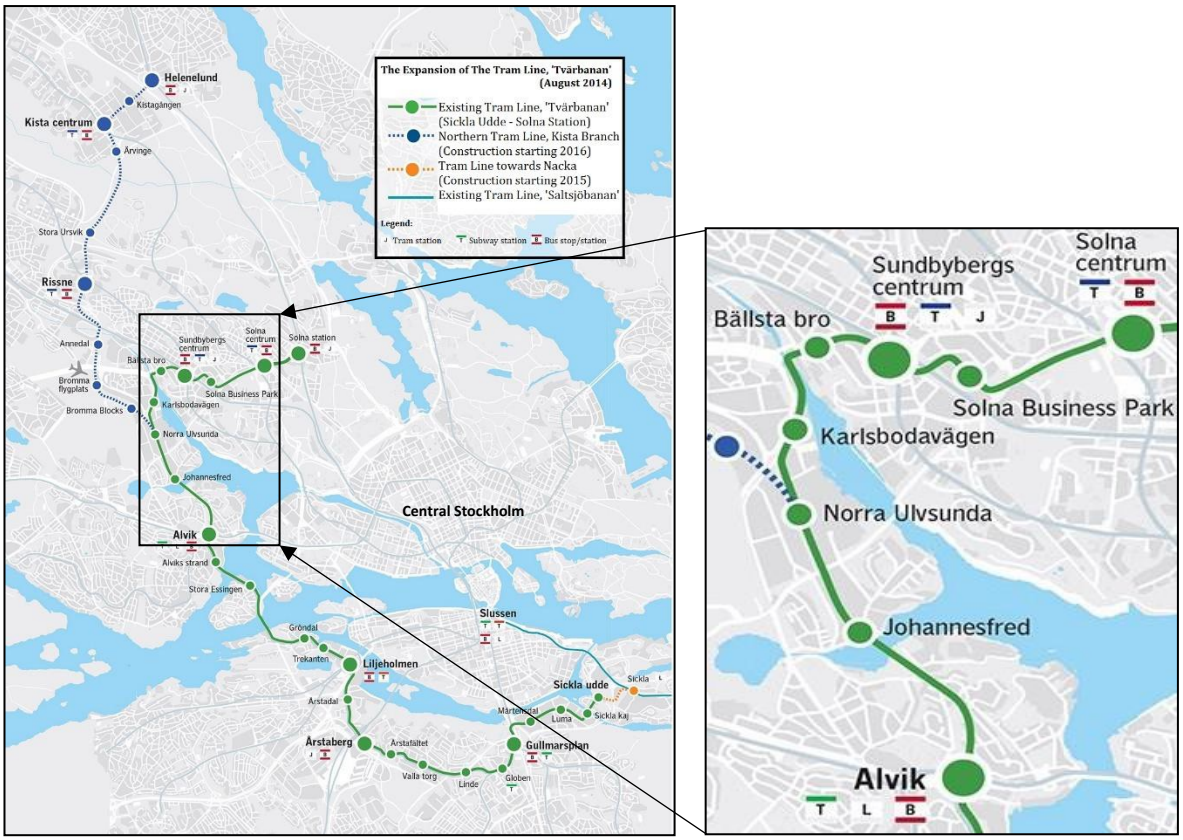

Figure 2 The existing, and the new and planned extension 'Tvärbanan' tram line service (Stockholm County Council, SLL, 2017).

2. THEORETICAL BACKGROUND

2.1 Behavioural responses in travel behaviour studies

Individuals' behavioural responses to the introduction of a new transport intervention are hypothesized to be influenced by objective and subjective factors (e.g. Chatterjee, 2001; Douglas, 2003).

2.1.1 Objective factors influencing behavioural responses

People's adoption to a new transport intervention (in this case is the new tram extension service) on a daily basis is related to their first response or experience with the service. For example, Hensher (1997) examined the factors influencing the time taken for motorists to change from using a free highway to an urban toll road in Sydney, Australia. He found that once a driver began to use the new toll road, they would use it on a regular basis. Chatterjee and Ma (2009) have examined the time taken for residents to adopt a new Route 20 Fastway bus airport service after its introduction in southern England, and they found that residents who never used the new bus service route since its introduced, were increasing unlikely to use it over time. This behavioural response clearly affects travel demand of the new service. Douglas (2003) found that on average, 79% 'ramp-up' factor in patronage growth for thirteen new or upgraded rail schemes around the world estimated within a year of operation. Based on this, apparently, not all people will

respond to the new transport service. Some individuals will respond immediately, quickly, slowly or very slowly in using or adopting a new transport intervention. Perhaps some of them will not use the new service at all. From microeconomic perspective, people choose the option that provides the highest utility level. Thus, the objective reasons for faster adoption are that the new service saves more time and/or money for individuals to travel compared to other services, and provides good access to destinations that individuals have not been able to reach before using the existing services. Study by Chatterjee and Ma (2007) have found that the individuals who gained a reduction in distance from their home to bus services were the ones who give quicker response to the new service.

2.1.2 Subjective factors influencing behavioural responses

By focusing only on the objective factors that influence behavioural responses, the results may be criticised for decontextualizing choice behaviour since it does not capture the individuals' processes of experiencing and acting in using the new service as argued by Dijst et al. (2008). For example, individuals who are aware about the new transport service in advance may influence the faster responses than individuals who are not aware. In addition, the way people feel about, and perceive the value of public transport services, and the opinions of other important people in their life can influence someone's travel decision, and perhaps in this case, someone's decision to use and adopt the new service quickly than others. From individuals' perspectives, Chatterjee (2001) and Douglas (2003) have hypothesized that travel habit, awareness about a change in the travel environment, commitments to current travel behaviour (e.g. possession of season tickets), attitudes, unexpected situations, life stage changes, and learning curve are the subjective factors that influence behavioural response to the new transport service. To date, these hypotheses have not been tested empirically. Moreover, no studies have developed a framework on investigating these subjective factors based on available theory, especially in the psychological field such as TPB (Ajzen 1991). To my knowledge, only one study done by Thorhauge et al. (2016) examined the factors influencing departure time choice using the TPB framework. However, they are focusing on capturing behavioural change, and not behavioural responses.

TPB has a broad application and is considered reliable in predicting intention and behaviour as reported by Armitage and Conner (2001). It includes *attitudes*, defined as an individual's positive and negative feelings about performing the behaviour of interest (e.g. the quickly response to the new transport service), *subjective norms*, defined as an individual's perception of whether important people in his/her life think that behaviour should be performed, *perceived behavioural control*, defined as an individual's perception of his/her ability and constraints that facilitate or inhibit him/her in performing a given behaviour of interest, and *intention*, defined as a cognitive representation of an individual's readiness to perform a given behaviour of interest. On the other hand, Chatterjee (2001) has hypothesized that unexpected situations such as having delay with current transport mode due to road work closure, road congestion, or bad weather, will also affect an individual's decision to response to the new service. Moreover, Ajzen (1991) has noted that some behaviour may not be predicted well using the TPB elements alone due to the fact that behaviour at some degree may depending on non-motivational factors such as the availability of requisite opportunities and resources (e.g. time, money, skill, etc.). Due to these reasons, a modified TPB framework are modelled to investigate the subjective factors influencing behavioural response to a new or modified public transport service.

2.2 Temporal effects and seasonal variations on travel behaviour

2.2.1 The temporal effects on travel behaviour

When a new transport service is introduced, it triggers a change in individuals' travel environment. Over time, these individuals have to make adjustments to use and maybe adopt the new service in their regular travel activities. Thus, dynamics in behavioural responses may arise from these adjustments, associated with perceptions, attitudes, needs, preferences, and decision-making processes of those individuals. This in turns, contribute to several temporal effects such as *response lags* (e.g. where behavioural adjustments are made some time after the events occurred), *response leads* (e.g. where adjustments are made in advance before the events occurred), *habit persistence* (e.g. where individuals showed routine behaviour characterized by repeated decisions of the same choices even after the choice is no longer optimal after the events occurred), *behavioural asymmetry* or *hysteresis* (e.g. where individuals are found to make asymmetric adjustments in behaviour in response to symmetrically opposite events), *state dependence* (e.g. where behaviour in previous state influence the current state of behaviour) *inertia effects* (e.g. the frequent choices that raise the likelihood of individuals to maintain the previous choice) and *shock effects* (e.g. the power of influence generated by the introduction of a new infrastructure that could modify the valuation process of alternatives or increase the probability to change individuals' usual mode choices) (Goodwin, 1977, 1987; Kitamura and Bovy, 1987; Chang and Mahmassani, 1988; Pendyala et al., 1995; Cantillo et al., 2007; Yáñez et al., 2008, 2010a; Yáñez and Ortúzar, 2009; Liu et al., 2016; Ramadurai and Srivinasan, 2006).

On the other hand, different groups of travellers have different needs and different learning processes (e.g. Chatterjee and Ma, 2006; Susilo et al., 2012; Susilo and Cats, 2014), especially when a new transport element is introduced in the travel environment. Moreover, travellers needed to make activity-travel decisions based on their daily experiences with the transport system that results from repeated previous choices (Arentze and Timmermans, 2003). This argument is based on Reinforcement Learning Theory (Sutton and Barto, 1998) applied in machine learning research area in which individuals discover the actions that give them the highest utility by exploring the environment and learning from experience.

2.2.2 The effects of seasonal variations on travel behaviour

In travel behaviour research, few studies have been conducted to analyse the effects of seasonal variations on individuals' activity-travel patterns due to high cost in obtaining a longitudinal panel data that provides the only means to analyse the effects. However, these few studies have proved that seasonal variations do affect people's out-of-home activity participation, particularly in leisure activities, and also affect their mode choices. For example, using the Dutch National Mobility panel survey, Kitamura and Van der Hoorn (1987) have found that there was no seasonal variations effect on individuals' activity participation in the Netherlands, but they maintained the same weekly activity participation in March and September. Using the San Francisco Bay Area Travel Survey (BATS) dataset collected in the year 2000, Bhat and Gossen (2004) found that less participation in out-of- home recreational activity participations during weekends in February and March, while less in pure recreational activity participations in March and October compared to other months of the year. Bhat and Srinivasan (2005) found that in winter season, individuals tend to participate less in recreational and maintenance shopping during weekends. Meanwhile in autumn and spring, adult individuals tend to do pick-up or drop-off activities than others. On the aggregate level, Tang and Takhuriah

(2012) found that bus ridership in Chicago was higher in autumn (September – November) and spring (March – May), and lower in summer and winter months (except for February). In terms of the seasonal variations effect on mode choice, Liu et al. (2015a) found using the Swedish National Transport Survey (NTS) dataset of 13 years that more cycling trips but fewer walking and public transportation trips were made in summer than in winter. They also found that the impact of individuals' perceptions on weather differ in different regions and seasons. For example, cyclists in northern Sweden are more aware of temperature variation than cyclists in central and southern Sweden, especially in spring and summer seasons.

2.3 Space-time constraints in travel behaviour

The tenet of space-time constraints (Hägerstrand, 1970) on travel behaviour has been proved by many previous scholars by using cross-sectional data. However, less has been done using longitudinal panel data (multi-day and multi-period) obtained from travel diary or activity diary that covers four different seasons throughout a year. This is due to high budget constraints and high burden of respondents in keeping all their journeys recorded over several days in multiple period of time (known as survey contacts or *waves*). Thus, resulting in *attrition* (losing respondents in subsequent waves). According to Hägerstrand (1970), individuals must do an activity during a certain time period given a certain time duration. Having a fixed starting time to do certain activities tend to shape individuals to do other activities and allow them to gather all resources to conduct these activities. On the other hand, activities that undertake at certain time for a given certain time duration may influence individuals to visit only certain locations which grant at least minimum conditions of survival. Thus, this theory incorporates individuals condition in terms of availability of resources and constraints in geographical systems, and in turns, influence how individuals travel in space and time dimensions. Hägerstrand have identified three constraints that may influence individuals' activity-travel participation decisions: (1) *capability constraints*, defined as limitations of individuals' ability to perform certain activities, (2) *coupling constraints*, defined as limitations in individuals' choices to conduct certain activities because of the necessity of having to be at the same location in the same time to meet other individuals or materials, (3) *authority constraints*, defined as limitations in time-space dimensions that are imposed by authorities who have power over any given individual. These constraints, therefore, interact with individuals' needs within time and space dimensions (Miller, 2007). Thus, the decisions on participating in non-mandatory activities are believed to be influenced by the scheduled mandatory activities which refer to this space-time constraints (Susilo and Kitamura, 2005; Susilo and Dijst, 2010; Susilo and Axhausen, 2014).

In recent years, with the growing development of information and communication technology (ICT), people have moved into a new world where almost everything can be done online, either to search for information or engage with other people, goods and services, at everywhere and at anytime (Lyons, 2015). This transition may encourage people to work from home or some other place than their workplaces. This is called *teleworking* (Salomon, 2000). From other perspectives, Breedveld (1998) has hypothesized that the traditional workweek (e.g. work from Monday to Friday at 9 a.m. to 6 p.m.) will be replaced by the 'flexibilization' and '24/7 society', with different individuals having different working days of the week and at different times of the day. Thus, based on the space-time constraints, these effects also influence individuals' decision making processes on participating in non- mandatory activities, thus resulting in the dynamics of their activity-travel patterns.

2.4 Panel survey

2.4.1 'Short' survey panel

'Short' survey panel is multi-day data where repeated measurements on the same sample of units are gathered over a continuous period of time (e.g. two day or more successive days), but the survey itself is not repeated in subsequent years (Pendyala and Pas, 2000; Yáñez et al., 2010a). The advantages of this data type are its capability in capturing day-to-day variability of activity-travel patterns, or even week-to-week variability, and low in attrition. However, the infrequent changes in mode choice and low data variability in terms of attributes of each mode and socioeconomic characteristics are causing difficulties in estimating models (Cherchi and Ortúzar, 2008). Moreover, if the data is gathered, let say in five weekdays, it is expected that individuals may repeat exactly the same trips especially for trips made for conducting mandatory activities such as working and studying. Thus, if the data is used for model estimation, bias results may be obtained. The famous examples of available 'short' survey panel are the 1971 Uppsala travel survey in Sweden (Hanson and Hanson, 1981) that covers 35 days of observations, 1973 Reading activity survey in England, U.K. (Shapcott, 1978) that covers seven days of observations, and the 6 week Mobidrive travel and activity diary data in Germany (Axhausen et al., 2002) and Switzerland (Axhausen et al., 2007).

2.4.2 'Long' survey panel

'Long' survey panel or sometime known as *longitudinal panel survey* is a survey done to collect multi-day and multi-period data where repeated measurements (with the same methodology and design) are gathered at separate times, for example once or twice a year during certain number of years, or before-and-after event. The main issue arises from this type of panel survey is attrition between successive survey contacts or waves (e.g. Kitamura, 1990; Alderman et al., 2001; Ruiz et al., 2008). If the same unit of sample is used in this panel survey type (e.g. longitudinal panel survey), then the issue on *fatigue* (respondents' tiredness of keeping detailed records of their journeys after some days) also arises (e.g. Yáñez et al., 2010a; Gerike and Lee-Gosselin, 2015; Comendador and López-Lambas, 2016). Fatigue consists of two types namely, *panel fatigue* (number of under-reporting trips over the days between-waves) and *diary fatigue* (number of under-reporting trips over the days in a wave). Golob and Meurs (1986) have noted that people tend to forgetting or disregarding certain short trips that contribute to the under-reporting trips. Some famous examples of 'long' survey panel are the Dutch National Mobility Panel (Van Wissen and Meurs, 1989), the Puget Sound Transportation Panel (PTSP) in the U.S. (Murakami and Watterson, 1990), the German Mobility Panel (samples are refreshed in each wave, thus known as rotating panel) (Zumkeller and Chlond, 2009), and the Santiago Panel in Chile (focusing on work trips and only for a particular day) (Yáñez et al., 2010a).

3. CONTRIBUTIONS

The contributions of each paper and the involvement of estimation models used are exhibited in Figure 1 previously. Generally, there are five contributions made by all papers reported in this thesis.

3.1 Subjective factors influencing behavioural responses to the introduction of a new transport intervention

Paper II investigates the subjective factors that influence behavioural responses to the new public transport service by proposing a modified TPB model framework that inspired by Chatterjee's hypothesis (2001) on the factors affecting behavioural responses. To my knowledge, no other studies have incorporated a full theory-based framework in modelling individuals' behavioural responses towards a new public transport service, such as in this study. Thus, this is one of the main contribution made in the paper. A hybrid mixed logit model, that incorporates structural equation model (SEM) estimation into mixed logit model was estimated. The results of SEM revealed that being aware about a new public transport service in advance is important to encourage people to response quickly to the new service after its introduction, as argued by previous researchers. The hybrid mixed logit model revealed that individuals act on quick-response to a new public transport service are according to their intentions, which in-line with the argument of TPB framework (Ajzen, 1991). The panel analysis highlights that accessibility (e.g. walking distance) in using a new public transport service plays an important role in attracting individuals to frequently use the new service just after its introduction, and individuals do adjust their perceptions on accessibility when using the new service, based on their past experiences within five months of the introduction. The results also indicate that individuals' learning processes in terms of being aware about the new service are still ongoing within seven months after the introduction. Thus, suggesting that proper marketing strategies should be implemented within this period.

3.2 The temporal effects due to the introduction of a new transport intervention

Paper I examines individuals' learning and decision processes in using a new public transport service. This is done by capturing the temporal effects such as reinforcement learning based on past experiences, shock effects, and inertia effects. A mixed logit model with panel data is estimated and the results revealed that after the introduction of a new service, reinforcement learning occurred only in the short-run period (a month after), but did not continue to the medium- (five months after) and long-run (seven months after) periods. This implies the travellers in this study did not maintain their previous choice of using the new service in their current use of the new service. Therefore, they may stick to habits, where inertia characterizes their behaviour on mode choice. Analysis of mode migrations on non- discretionary trips revealed that shock effects generated by the new service are not detected for such trips.

Paper III examines the effects of space-time constraints that underlie individuals' decisions to participate in day-to-day leisure activities in different seasons by incorporating the thermal indicator in the model estimations. Several dynamic ordered Probit models are estimated to capture the effects in different seasons. The model structure is similar to Liu et al. (2016) study, however, the difference between their paper and Paper III is that in this paper, the space-time constraints are considered, in which out-of-home mandatory activities are influencing in-home and out-of-home non-mandatory activity participation decisions. The results highlight that individuals in this study exhibit routine behaviour characterized by repeated decisions in participating in leisure activities that can last up to 14 days, regardless of the seasons. The previous day's effect or state dependence exhibited in the summer season only, indicating that individuals in this study continue to participating in leisure activities on a daily basis in this season. This may be due to warmer weather condition compared to other seasons. The positive coefficient of habit persistence in number of studying days' period is found in

spring, suggesting that a long study period (e.g. 14 days) in this season contributes to the accumulation of needs of leisure activity participation that triggers the leisure activity participation. In contrast, the significant negative coefficient of habit persistence in number of studying days' period is found in winter season, suggesting that a long study period in this season contributes to less leisure activity participation in this season.

3.3 The effects of seasonal variations on activity-travel patterns

Paper III incorporates weather attributes of thermal indicator in the model framework that estimate the effects of space-time constraints on individuals' day-to-day leisure activity participation decisions. The results revealed that the thermal indicator is only significant in the autumn season, indicating that individuals in this study are sensitive to the increase/decrease in temperature during this season, thus affecting their leisure activity participation.

Paper IV explores the interactions between travel demand (e.g. number of trip), time allocation (e.g. activity durations) and mode choice (e.g. mode share) in different seasons by jointly modelling the work and/or study, routine and leisure activity-travel engagements. Several simultaneous Tobit models are estimated for this purpose by considering individuals' unique characteristics and endogeneity in those activity-travel engagements between different seasons. The endogeneity relationships proposed in Paper IV are similar to Liu et al. (2014) study. However, the differences are: (1) the sample in this paper include all individuals (commuters and non-commuters) while they used non-commuters sample only, and (2) this paper includes mandatory activity-travel indicators in the proposed endogeneity relationships while they include only routine and leisure activity-travel indicators in their proposed endogeneity relationships. The results revealed that trade-offs between work and/or study trips towards routine and leisure trips are larger in winter and spring respectively, than in other seasons. Moreover, seasonal variations play important roles especially on total travel time spent for participating in mandatory and non-mandatory activities. For example, the travel time spent on work and/or study trips by any modes (e.g. car, public transport and slow modes) during spring season is longer than in other seasons. Meanwhile, the travel time spent on leisure trips by public transport and slow modes is longer in summer season than in other seasons.

3.4 The effects of space-time constraints on activity-travel patterns

Paper III examines the effects of in-home maintenance and mandatory constraints, and out- of-home mandatory constraints on individuals' leisure activity participation decisions on a daily basis by estimating dynamic ordered Probit models. The results showed that in-home maintenance and mandatory constraints have insignificant effects on individuals' day-to-day leisure activity participation decisions, but significantly affected by out-of-home mandatory constraints, regardless of the seasons. Moreover, by using only two waves' data obtained in autumn and winter seasons, the study revealed that individuals who have shift working duration types have the most constraints in participating in leisure activities in both seasons.

Based on the space-time constraints, Paper IV examines the endogeneity effects between mandatory, routine and leisure activity-travel engagements in different seasons of the year by estimating several simultaneous Tobit models. The results highlight clear trade-offs between mandatory activities (work and/or study) and non-mandatory activities (routine and leisure), regardless of the seasons, particularly in number of trips. Indicating that the more number of trips made by individuals for conducting mandatory activities, the less likely it is for the individuals to make more trips for conducting non-mandatory activities in all four seasons of the year.

3.5 The longitudinal panel data

Paper V describes a comprehensive longitudinal panel data collection at individual level that includes the design of each travel behaviour variable based on the existing theory and literatures in travel behaviour and attitudinal research. The design of each instrument is intended to capture multidisciplinary factors that underlie individuals' decisions and activity- travel patterns in a changing environment. It is noted in the paper that the unique aspects that offered by the survey's instruments in this study are the overall 56-day travel diary in four consecutive waves that covered all four seasons in the year, as well as, an attempt to collect an abstract representation of individual's mental map in a standardized way. In this paper, the analysis of attrition and fatigue was done on a two-week travel diary survey instrument only. The analysis of attrition using binary logit model shows that there are no systematic tendencies of the dropouts' characteristics between-waves, indicating that attrition is purely random. However, individuals with low income are more likely to leave the panel in waves 3 and 4. Meanwhile, the analysis of fatigue (captured by the number of missing trip per day variable) using also binary logit model revealed that the number of missing trips per day is not significantly affected by the number of successive weeks implemented, which in this case is two weeks. Meanwhile, the effects of waves are significantly decreasing over successive waves, indicating that waves 2 to 4 travel diaries are less likely to include missing trips than in the Wave 1 travel diary. Moreover, there is no correlation between immobile days and missing trips per day are to be found between-waves. Thus, no indication of fatigue appears. However, personal attributes (e.g. gender, own dependent children in the household, age, income, marital status) and travel characteristics (e.g. home-based trip, trip purpose, travel distance and number of inter-modal transfers) significantly affect the number of missing trips per day.

4. DISCUSSIONS

This thesis, represented by five papers, has focused on investigating individuals' learning and decision processes in a changing environment, which in this case is a change in the travel environment due to the introduction of a new public transport service. The case study used in all papers is the 'Tvärbanan' tram extension line which was introduced on 28th October 2013 and covers two sub-urban areas in Stockholm county, namely Solna and Sundbyberg municipalities (see Figure 2). The papers in this thesis have utilized two different data sources. First, the longitudinal panel data of four waves which consists of self-reported two- week travel diary (using pen and pencil approach) and psychological questionnaire (using online approach). The first wave was collected in two weeks before the tram extension was introduced in autumn season (14th – 27th October 2013), the second wave was collected approximately a month after the introduction in winter season (2nd – 15th December 2013), the third and the fourth waves were collected approximately after five (17th – 30th March 2014) and seven months (26th May – 8th June 2014) of the introduction that collected in spring and summer seasons, respectively. Second, Paper III and Paper IV have utilized the weather data obtained from SMHI (2015) that includes daily air temperature (degree Celsius), hourly relative humidity (%), and hourly wind speed (km/hr). Both hourly recorded relative humidity and wind speed were averaged into daily levels that used the records between 7:00 a.m. and 8:00 p.m. because majority of the recorded activities in the diary were conducted in daytime.

In Paper I, the analysis on mode migrations on non-discretionary trips (e.g. working and studying) revealed that 13.5% of the total 2,108 non-discretionary trips, which were made by 49.3% of the total 67 respondents, have migrated modes between Waves 1 to 4, suggesting that few individuals change mode for this trip type, especially changing to the

tram mode. Thus, shock effects (Yáñez et al., 2008; Yáñez and Ortúzar, 2009) generated by the tram extension are not detected for the trips. However, based on the mode share analysis on all trips, shock effects may be detected for a while, at least a month after the introduction of a tram extension service. It is also noted that the highest peak of tram extension mode was found in Wave 2, indicating that the respondents may be driven by curiosity in trying the new service. Individuals in this study have applied the reinforcement learning (Sutton and Barto, 1998; Arentze and Timmermans, 2003) based on past experiences, only in the short-run period (a month after the introduction). Indicating that travellers in this study did not maintain their previous choice of using the tram extension service in their current use. Thus, they may stick to their habits where inertia characterizes their behaviour. It is found that individuals who have a car in their households are the one who more quickly used the new tram. This implies that having a car, which in theory would facilitate the choice of car transport over other modes (e.g. Bresson et al., 2004) did not prevent individuals from trying the new service quickly than others. This results is a good news for marketing strategies since it may show that it could be much easier to persuade car users, at least in Stockholm, to use a new public transport option in the future.

It is found that the tram extension service is unpopular for commuters, but more suitable to serve discretionary trips (e.g. leisure trips) and as a feeder (a transit point on the way home) (Paper I). Therefore, there might be some other reasons that make the tram extension an uncompetitive mode compared to other existing modes such as subway and bus. Thus, subjective factors that underlie individuals' decisions to response to the tram extension service and also a change in individuals' awareness towards the new service as well as a change in individuals' perceptions of the ease or difficulty in using the new service (*perceived behavioural control*) (e.g. perceived walking distance, individual's physical constraint, etc.) are examined in Paper II. It is found that being aware about the new service in advance significantly affects the intention of quick-response in using the new service, and individuals act according to their intentions in terms of delivering a quick-response to the new service. Furthermore, panel analysis revealed that accessibility plays an important role in attracting individuals to use the tram extension frequently within a month after its introduction. Then, there is evidence showing that individuals do adjust their perceived walking distance in using the tram extension service based on their past experiences in using the service within five months after the introduction. Thus, from a policy perspective, it is crucial that a new public transport service should be built within reasonable walking distance radius in order to attract people to use the service consistently. Awareness items (e.g. aware about the timetable of the new service and aware about where to gain information regarding the new service) were relatively unstable within seven months period after the introduction, indicating that the learning process is still ongoing within this period. This suggests that a proper marketing strategy should be implemented before and after the introduction of a new public transport service, at least within seven months period or even longer.

Based on space-time constraints (Hägerstrand, 1970), both Paper III and Paper IV consider the effect of mandatory activities (e.g. work and/or study) on non-mandatory activities (e.g. leisure and/or maintenance). In Paper III, it is found that an individual's leisure activity participation decision is significantly influenced by out-of-home work durations, but not influenced by in-home constraints, regardless of the seasons. It is also found that individuals in this study exhibit routine behaviour characterized by repeated decisions in participating in leisure activities that can last up to 14 days, regardless of the seasons. State dependence effects (e.g. previous day's effect) exhibited in the summer season only. This may be due to warmer weather condition in this season compared to other seasons. Using the data of two waves collected in spring and summer, it is found that individuals with shift working duration types have the most constraints in participating in leisure activities in both seasons. However, no concrete conclusion can be

made on this since no data is available in the other two seasons (autumn and winter). To see the clear effects of mandatory activities on non-mandatory activities that include not only leisure, but maintenance or routine activities as well, the interactions between travel demand, time allocation and mode choice in different seasons are examined in Paper IV. Again, the results indicate that leisure and routine activities are influenced by mandatory activities, regardless of the season, especially on the number of trips. This supports the findings found in Paper III and also Hägerstrand's theory of space-time constraints. A positive mutual endogeneity relationship between number of trips and activity duration within the same activity type is also found.

The common problems in a longitudinal panel data are attrition and fatigue that consists of panel fatigue and diary fatigue. Thus, these both issues are analysed in Paper V, focusing only on the two-week travel diary survey instrument. It is found that the attrition rate was 34.3% out of the 102 participants in the survey on general, and 26.4% out of the 91 participations in the travel diary survey, which is much larger than the 6-week Mobidrive panel survey (Axhausen et al., 2002). While, the attrition rates between consecutive waves are around 7% to 10%, much smaller than the Dutch National Mobility panel survey (Kitamura, 1990) and the Puget Sound panel survey (Murakami and Watterson, 1992), but larger than the Santiago panel survey (Yáñez et al., 2010a). Although this panel survey is hard to compare with regard to the sample size and survey's data collection approach (e.g. interview), but the similarity in response burden may be comparable with those panel surveys due to the number of instruments used and the length of travel diary survey period. Based on the binary logit model of the dropouts, however, attrition was found to be purely random in which no systematic tendencies of the dropouts' characteristics are found between waves. In the analysis of fatigue, it is found that both panel and diary fatigue seems not appeared in this panel survey since no decreasing patterns of the trend line of number of missing trips per day per persons (with missing trips) are detected across 14 days of observations. Moreover, the significant negative coefficients of 'waves' dummy variables and the insignificant dummy variable of the 'week' in the binary logit models are also detected. Indicating that number of missing trips per day is unlikely to be affected by number of successive waves (waves 2 to 4 since Wave 1 is a base-wave). It is found that mode choice has no significant effects on missing trips per day, but travel distance has positively significant effects in which longer distance is likely to include missing trips. This result contradicts to the Dutch National Mobility Panel survey (Golob and Meurs, 1989) in which under-reporting trips were highly contributed by walking trips and certain short trips. Individuals' unique characteristics (e.g. gender, age, marital status, etc.) are also significantly affect the number of missing trips per day. There is no correlation between number of immobile days and number of missing trips per day was found. Indicating that the respondents in this panel survey who have high immobile days are not necessary contribute to the high in missing trips per day. However, the missing trips in this panel survey can be contributed by other factors such as the number of waves deployed, the interval period between successive waves and the number of instruments used and questions asked in each wave (e.g. Halpern-Manners and Warren, 2012; Gerike and Lee-Gosselin, 2015).

5. CONCLUSIONS

As a conclusion, it is found that middle-income travellers and travellers who owned car(s) used the new or modified public transport service (e.g. tram extension line) earlier than others. It is also found that travellers who hold public transport season tickets and travellers who applied reinforcement learning within a month after the introduction of a tram extension line were more likely than other travellers to adopt the tram extension as a part of their regular mode choice (*research question 1*). As for the temporal effects

(*research question 2*), shock effects, generated by the tram extension are not detected for non-discretionary trips (e.g. home-based work and school/education trips). In all trips, however, shock effects may be detected for at least a month after the introduction of a tram extension line based on the mode share analysis, particularly on the changes in public transport mode shares. The reinforcement learning based on past experiences occurred only in the short-run (a month after the introduction) period, but did not continue to the medium- (five months after) and long-run (seven months after) periods. It is also found that the travellers in this study may stick to their habits, where inertia characterizes their behaviour. Note that the shock effects are defined as the power of influence generated by the introduction of a new infrastructure that could modify the valuation process of alternatives or increase the probability to change the usual mode choice (Yáñez et al., 2008; Yáñez and Ortúzar, 2009). The inertia effects are defined as the frequent choices that raise the likelihood of an individual to maintain the previous choice (Cantillo et al., 2007; Yáñez et al., 2010a). Reinforcement learning is defined as the actions discovered by individuals that give them the highest utility by exploring the environment and learning from experience (Sutton and Barto, 1998), which in this case is the experience in using the tram extension service on a daily basis. In examining the subjective factors influencing individuals' behavioural responses to the introduction of a tram extension service (*research question 3*), a modified TPB framework is adopted and it is found that intention influences an individual's quick-response choice. The intention, however, is significantly affected by the awareness construct (e.g. being aware about the new service in advance with regard to total travel time, destinations served, and timetable) and an individual's perceived ability to obtain information about the new public transport service through internet sources.

In terms of the effects of constraints on individuals' day-to-day leisure activity participation decisions in different seasons of the year (*research question 4*), it is found that out-of-home work duration is significantly affect individuals' leisure activity participation on a daily basis. Indicating that the longer the time spent for work, the less the leisure activity participation conducted by individuals, regardless of the seasons. Out-of-home study duration is also significantly affects individuals' day-to-day leisure activity participation in autumn and spring seasons, indicating that the longer the time spent for study, the less the leisure activity participation conducted by individuals in these seasons. Moreover, it is also found that a long study period contributes to the accumulation of needs of leisure activity participation that triggers the leisure activity participation in spring season. In terms of the effects of working duration types on individuals' day-to-day leisure activity participation, it is found that individuals who have shift working duration types have the most constraints in participating in such activities, based on the two waves' data collected in spring and summer seasons. Focusing on the effects of seasonal variations on individuals' activity participation and travel behaviour considering travel constraints and travel as a derived demand of activity participation (*research question 5*), it is found that there are clear trade-offs between work and/or study trips towards routine and leisure trips which are larger in winter and spring respectively, than in other seasons. Moreover, total travel time spent on work and/or study trips by all modes (e.g. car, public transport and slow modes) during spring season is longer than in other seasons. Whilst, the travel time spent on leisure trips by public transport and slow modes is longer in summer season than in other seasons.

The panel survey in this study has made the first attempt to collect a two-week travel diary and a set of mental map-related questions in four consecutive waves via pen and pencil approach longitudinally. In terms of attrition and fatigue issues in panel survey (*research question 6*), the total attrition rate on a two-week travel diary was considered high with 34.3% out of a total participation in the survey (102 participants) and 26.4% out of a total participation in the travel diary only (91 participants). The attrition rates between consecutive waves are found around 7% to 10% which is considered low. It is

found that attrition is purely random with no systematic tendencies of the dropouts' characteristics are to be found. However, middle income individuals are tend to leave the panel in waves 3 and 4. Meanwhile, no indication of both panel and diary fatigue appeared in this panel survey based on the analysis of number of missing trips per day. Personal attributes (e.g. gender, age, marital status, own child and income), temporal factors (e.g. weekdays and waves) and travel characteristics (e.g. home-based trip, trip purpose, long travel distance and high number of inter-modal transfers) significantly affect the number of missing trips per day.

6. LIMITATIONS AND FUTURE WORKS

The papers included in this thesis have explored the individuals' learning and decision processes due to the introduction of a new public transport service (e.g. tram extension line). Specifically, the subjective factors that influence individuals' behavioural responses to the new service and the changes in individuals' awareness and perceptions in using the new service over time are explored. Moreover, learning process such as reinforcement learning, and temporal effects such as shock effects, inertia effects, state dependence, and habit persistence are captured through several dynamic models implemented in the papers. On the other hand, the effects of seasons are also examined on individuals' activity-travel patterns. Furthermore, the decision processes on day-to-day activity participations are explored by incorporating seasonal variations, space-time constraints, travel demand and mode share in the same model framework. The issues of attrition and fatigue in the panel survey of two- week travel diary are also discussed. Despite of these contributions, however, a lot of limitations are still to be found in those papers, thus open more opportunities for future research. It is worth noting that the main limitation in this study is low sample size for the two-week travel diary in four waves, thus, cautions are needed to infer any conclusions based on the analysis made using this panel data.

In Paper I, mode migration analysis has only been done for non-discretionary trips (e.g. work and study trips). It is more realistic to assume that individuals need to travel for conducting mandatory activities that generate non-discretionary trips, regardless of the seasons, compared to discretionary trips (e.g. leisure trips). It is because discretionary trips may be affected by seasonal variations and mandatory activities made on a daily basis. However, it could be interesting to see how individuals migrate mode regardless of types of trip purposes so that overall changes in mode choice can be obtained. By doing this, a temporal effect of behavioural asymmetry, or hysteresis (Goodwin, 1977) where people are found to make asymmetric adjustments in behaviour in response to symmetrically opposite events, can be captured. Understanding these would give more insights on how a new public transport service would affect people's choice processes over time, particularly in mode choice.

Previous studies (e.g. Hensher, 1997; Chatterjee and Ma, 2006, 2009) have found that objective factors such as travel time and travel cost influencing individuals' behavioural responses to new transport interventions. However, in the case of this tram extension service, objective factors have not been investigated yet. Paper II has examined the subjective factors, alongside with personal and land use attributes, influencing individuals' behavioural responses to the introduction of a public transport service based on a modified TPB. Therefore, it would give much better insights of why people response to the new public transport service quickly than others if both subjective and objective factors are examined simultaneously in the same model system. With the advanced statistical tools and econometric models that are available today, this is possible to be done although the level of complexity may be arise depending on the number of exogenous and endogenous variables included in the model system. Understanding these would enable transport planners to design a better planning for a new transport

intervention that is attractive to travellers especially individuals who mainly used private cars to travel. Meanwhile, it also assists local transport operators to design a better marketing strategy to attract more people to use their new transport service as soon as the new service is introduced that affects the demand and viability of the service. On the other hand, the relationship between the first response in using the new service and habit in using the service is remain unclear. This could be another area for future research.

The effects of in-home and out-of-home constraints on individuals' day-to-day leisure activity participation are examined in Paper III by taking into accounts seasonal variations and weather thermal indicators. Creemers et al. (2015) have argued that thermal conditions that make people consider physiological factors such as heat resistance of clothing and also human activities (e.g. Physiologically Equivalent Temperature, PET) may influence individuals' leisure activity participation decisions in different seasons, and this is worth researching in the future. Furthermore, since the effects of individuals' working duration types on individuals' daily leisure activity participation decisions are analysed using only two waves' data (Wave 3 and Wave 4), thus the effects of four different seasons are not captured in Paper III, resulting in no concrete conclusion is made for this effect. The detailed on working schedule types such as day and night shifts are worth investigating in the future by using more comprehensive dataset than in this panel data. These are important to be explored so that all types of workers can participate in leisure activities equally, thus will minimise the social exclusion that may have led to growing isolation and depression which affected well-being. Understanding these would assist transport planners and local transport operators to manage travel demand strategies across different seasons of the year and to provide efficient transportation systems for all types of people that may affect their well-being in a longer-term perspective.

Individuals' daily activities are often interacted with other household members' activities. Everyone in the household play different roles and they may negotiate or share the household chores together, thus affecting how they decide to conduct out-of-home activities that trigger trip demand for the activities. These interactions are not captured by explanatory variables used in Paper IV. Thus, for future studies, it is recommended to explore the interactions and how it could affect an individual's activity participation decision on a daily basis, and in different seasons of the year.

Detailed descriptions of panel survey design were mainly discussed in Paper V. Multivariate analysis that considers the effect of individuals' characteristics on attrition and fatigue in the two week-travel diary shows that attrition is purely random and both panel and diary fatigues are not detected. Thus, besides socio-demographic factors, in-depth study has to be done to examine what are the underlying factors that made individuals in this study have decided to not participate in the subsequent waves and what contributes to the high in missing trips and immobile days. Understanding these would enable researchers to design a better panel survey in future so that attrition and under-reporting trips could be minimised, thus minimising bias in statistical analysis and econometric models results using the panel dataset. This is important since the results will affect study's conclusions.

Finally, the papers presented in this thesis focus on individuals' travel behaviour by utilizing the data obtained in two survey's instruments only, which are the travel diary and psychological questionnaire. However, the third survey's instrument which is the mental map-related questions, is not being explored yet except for a study done by Zhang et al. (2016), stated in the related publication that is not included in this thesis. Thus, the data of individuals' stated preferences on mental map-related questions, that have been collected via pen and pencil approach in four consecutive waves, can be used to explore the complex relationships between individuals' mental maps and their activity spaces that have been hypothesized as having a mutual relationship. Lynch (1960) and Weston and Handy (2004) have argued that an image of a space in individual's mind is

the result of a two-way process between the observer and his or her environment. For example, by travelling, people learn about the environment and add this new information in their mental maps. Then, when planning for travel, people may make decisions based on the existing and new information stored in their mental maps. To date, however, these relationships are still ambiguous and remain unclear (Mondschein et al., 2010) due to the difficulty in combining an abstract concept of space representation in human mind (mental map) and human actual activity-travel patterns on space (activity space), which is dynamics in nature. Exploring the mutual relationships between individuals' mental maps and activity spaces by applying spatial analysis and modelling techniques are worth for future research. On the other hand, individuals' mental maps evolve with their ages as they stored more environment information from their travel experiences over time. Thus, exploring how individuals' mental maps evolve over time could be another interesting topic in travel behaviour research in the future. If the new transport service is introduced, which in this case is the tram extension line, the impact of this new service on individuals' mental maps is also worth researching for in the future.

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