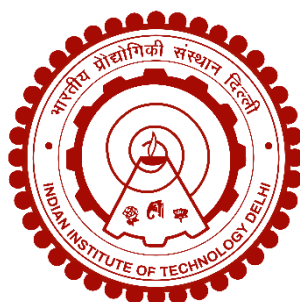


AN ASSESSMENT OF THE IMPACTS OF INTRA- HOUSEHOLD INTERACTIONS ON HOUSEHOLD ACTIVITY-TRAVEL BEHAVIOR

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by

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Department of Civil Engineering

Submitted

In fulfillment of the requirements of the degree of Doctor of Philosophy

to the



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This thesis is dedicated to all my teachers.

Certificate

This is to certify that the thesis entitled “***An Assessment of The Impacts of Intra-Household Interactions on Household Activity-Travel Behavior***” is being submitted by **Mr. Punyabeet Sarangi** to the Indian Institute of Technology, Delhi, India, for the award of the degree of **Doctor of Philosophy**. This is a record of the original bonafide research work carried out by him under my guidance and supervision. To the best of my knowledge, the thesis has reached the requisite standard. The doctoral research work presented in this thesis has not been submitted, in part or in full, to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Travel behavior models have traditionally treated individuals as the decision-making unit, even though the behaviour of individuals is contingent on interactions among household members. Literature suggests that interactions at the household-level are observed not just in long-term decisions such as vehicle ownership and residential location choices but also in day-to-day activity-travel patterns. Therefore, the thesis aims to investigate the impacts of intra-household interactions on household members' activity-travel behavior within the framework of modelling short-term mobility decisions. Among the short-term decisions, this particular work focuses on decisions related to out-of-home activity participation, time allocation, travel party composition, mode choice, and destination choice decisions. The contributions of the thesis to international literature are as follows. *First*, the thesis accounts for the joint activity-travel patterns of all adults (age > 18 years) household members. In contrast, previous studies considered the interaction between spouses/household heads or parents and children. This adds a new 'layer of interactions' to the existing activity-based travel demand models. *Second*, the interactions among household members are treated as context-dependent, i.e., it is influenced by socio-demographic attributes, built-environment factors, attitudes and perceptions of household members, and choice situations. This approach of embedding context and situation effects while analyzing intra-household interactions reflects the realistic nature of day-to-day activity-travel patterns. *Third*, in contrast to the current literature on joint travel, which mainly focuses on direct family members, the present thesis incorporates social utility by considering extended family members and members from social circles and their influence on household utility. This is achieved by developing a typology of joint household tour patterns embedding activity types, joint travel arrangements in the presence of direct, extended, and social members, and mode choice, thereby accounting for the heterogeneity in activity-travel patterns. *Fourth*, the thesis accounts for repetitive visits to multiple activity destinations and adds a time budget dimension to the discrete choice set by examining the aggregated time spent at multiple activity locations during a particular time interval of a day. This accounts for the heterogeneity in activity participation and time allocation behavior.

This thesis utilizes the primary household activity-travel survey data collected in Bhubaneswar city, India, in three phases across April-May 2019, September-October 2019, and February-March 2020, to capture the heterogeneity in the interactions among household members across – i) activity participation and time-allocation decisions, ii) activity task allocation and travel party composition, iii) mode choice decisions, and iv) activity destination choice. The dependent variables associated with these choice decisions are either discrete/ordinal in nature or have a continuous dimension with upper and lower limits or a combination of discrete and continuous variables. Consequently, multivariate methods such as censored regression techniques, integrated choice latent variable (ICLV) and multiple discrete-continuous (MDC) models were applied in the research. From a methodological standpoint, the work expands the existing modelling practices by i) estimating multivariate frameworks allowing for correlations across alternatives and households to examine the nature of inter- and intra-household interactions, ii) the application of composite marginal likelihood (CML) method compared to traditional maximum simulated likelihood (MSL) while optimizing multivariate models, iii) defining a two-level nested framework of tour typologies in terms of activity type, travel partners and mode choice, and iv) introducing a flexible time budget constraint defined at the household-level for an MDC framework.

The thesis finds that the nature of the interaction between spouses while participating in out-of-home non-work activities is more pronounced as compared to time allocation decisions. The inter-person variation for activity participation and time allocation decisions of spouses was reported to be substitutive in nature. In contrast, the intra-person variation for these decisions is gender dependent. Regarding task allocation and touring party composition, the error correlation matrix suggests significant inter-group substitution effects across the four accompaniment types (traveling alone, with immediate family members, extended family, or social members) for different non-work activities. The intra-group effects are complementary in the case of joint pursuits highlighting the likelihood of adult household members adhering to the same accompanying group. The model coefficients suggest that the effect of individual characteristics, household socio-demographics, and seasonal and temporal characteristics are more impactful than vehicle ownership and built environment features. The tour typologies concerning mode choice decisions reveal that the nature of intra-household interaction in a developing country is more pronounced (as 64% of

total tours in the sample are joint) compared to a developed region (e.g., Sydney household travel survey data had 52% joint tours). The results from the structural model of the ICLV framework indicate that household head characteristics and built environment variables significantly influence the attitudes and perceptions of adult household members. By including the latent factors in the nested ICLV model estimation, a substantial part of the intrinsic taste (or distaste) variability associated with mode choice decision was captured that was previously ascribed to alternative specific constants. Additionally, the thesis contributed to the literature by deriving distinct values of travel time savings for public and personal modes for different tour typologies, as there would be different trade-off preferences across activity types and accompanying person arrangements. The heterogeneity in activity destination choice decisions across three-time intervals on a weekday is measured through a temporal repetition index (TRI). It revealed that recreational activity locations have the highest median TRI value in a day, whereas shopping trips have the lowest. The former indicates minimal variation in departure time to recreational destinations, whereas the latter reveals a higher variation in departure time in case of shopping locations. The variance-covariance matrix of the mixed MDCEV model suggested the need to incorporate inter-household variations while modeling the frequency of visits to activity locations. Among the explanatory variables, household socio-demographic and trip attributes are significant determinants of repeated trips to multiple activity destinations. The thesis also discusses the broad policy implications of selected control variables across these short-term decisions.

Keywords: Intra-household interaction, activity-travel behavior, short-term decisions, social utility, India

सार

यात्रा व्यवहार मॉडल ने परंपरागत रूप से व्यक्तियों को निर्णय लेने वाली इकाई के रूप में माना है, हालांकि व्यक्तियों का व्यवहार घरेलू सदस्यों के बीच बातचीत पर निर्भर करता है। साहित्य से पता चलता है कि घरेलू स्तर पर बातचीत न केवल लंबी अवधि के निर्णयों जैसे कि वाहन के स्वामित्व और आवासीय स्थान के विकल्प में देखी जाती है, बल्कि दिन-प्रतिदिन की गतिविधि-यात्रा के पैटर्न में भी देखी जाती है। इसलिए, थीसिस का उद्देश्य अल्पकालिक गतिशीलता निर्णयों के मॉडलिंग के ढांचे के भीतर घर के सदस्यों की गतिविधि-यात्रा व्यवहार पर अंतर-घरेलू बातचीत के प्रभावों की जांच करना है। अल्पकालिक निर्णयों के बीच, यह विशेष कार्य घर से बाहर गतिविधि भागीदारी, समय आवंटन, यात्रा दल संरचना, मोड विकल्प और गंतव्य पसंद निर्णयों से संबंधित निर्णयों पर केंद्रित है। अंतर्राष्ट्रीय साहित्य में थीसिस का योगदान इस प्रकार है। सबसे पहले, थीसिस में सभी वयस्कों (उम्र > 18 वर्ष) के परिवार के सदस्यों की संयुक्त गतिविधि-यात्रा के पैटर्न के बारे में बताया गया है। इसके विपरीत, पिछले अध्ययनों ने पति-पत्नी / घर के मुखिया या माता-पिता और बच्चों के बीच बातचीत पर विचार किया। यह मौजूदा गतिविधि-आधारित यात्रा मांग मॉडल में एक नई 'बातचीत की परत' जोड़ता है। दूसरा, घर के सदस्यों के बीच बातचीत को संदर्भ-निर्भर के रूप में माना जाता है, यानी यह सामाजिक-जनसांख्यिकीय विशेषताओं, निर्मित-पर्यावरणीय कारकों, घरेलू सदस्यों के दृष्टिकोण और धारणाओं और पसंद की स्थितियों से प्रभावित होता है। अंतर-घरेलू बातचीत का विश्लेषण करते समय संदर्भ और स्थिति प्रभावों को एम्बेड करने का यह दृष्टिकोण दिन-प्रतिदिन की गतिविधि-यात्रा पैटर्न की यथार्थवादी प्रकृति को दर्शाता है। तीसरा, संयुक्त यात्रा पर वर्तमान साहित्य के विपरीत, जो मुख्य रूप से प्रत्यक्ष परिवार के सदस्यों पर केंद्रित है, वर्तमान थीसिस विस्तारित परिवार के सदस्यों और सामाजिक दायरे के सदस्यों और घरेलू उपयोगिता पर उनके प्रभाव पर विचार करके सामाजिक उपयोगिता को शामिल करती है। यह गतिविधि के प्रकारों को एम्बेड करने, प्रत्यक्ष, विस्तारित, और सामाजिक सदस्यों की उपस्थिति में संयुक्त यात्रा व्यवस्था, और मोड पसंद की संयुक्त घरेलू यात्रा पैटर्न की एक टाइपोलॉजी विकसित करके हासिल की जाती है, जिससे गतिविधि-यात्रा पैटर्न में विविधता के लिए लेखांकन होता है। चौथा, थीसिस कई गतिविधि स्थलों पर बार-बार जाने के लिए खाता है और एक दिन के एक विशेष समय अंतराल के दौरान कई गतिविधि स्थानों पर बिताए गए कुल

समय की जांच करके असतत विकल्प सेट में एक समय बजट आयाम जोड़ता है। यह गतिविधि भागीदारी और समय आवंटन व्यवहार में विषमता के लिए खाता है।

यह थीसिस भारत के भुवनेश्वर शहर में अप्रैल-मई २०१९, सितंबर-अक्टूबर २०१९ और फरवरी-मार्च २०२० में तीन चरणों में एकत्र किए गए प्राथमिक घरेलू गतिविधि-यात्रा सर्वेक्षण डेटा का उपयोग करती है, ताकि घर के सदस्यों के बीच बातचीत में विषमता को पकड़ा जा सके - १) गतिविधि भागीदारी और समय-आवंटन निर्णय, २) गतिविधि कार्य आवंटन और यात्रा पार्टि संरचना, ३) मोड पसंद निर्णय, और ४) गतिविधि गंतव्य विकल्प। इन पसंद निर्णयों से जुड़े आश्रित चर या तो असतत / क्रमसूचक होते हैं या ऊपरी और निचली सीमाओं के साथ एक निरंतर आयाम या असतत और निरंतर चर के संयोजन होते हैं। नतीजतन, सेंसर किए गए प्रतिगमन तकनीकों, एकीकृत विकल्प अव्यक्त चर (ICLV) और कई असतत-निरंतर (MDC) मॉडल जैसे बहुभिन्नरूपी तरीकों को अनुसंधान में लागू किया गया था। एक पद्धतिगत दृष्टिकोण से, काम मौजूदा मॉडलिंग प्रथाओं का विस्तार करता है १) अंतर और इंटर-घरेलू बातचीत की प्रकृति की जांच करने के लिए विकल्पों और घरों में सहसंबंधों की अनुमति देने वाले बहुभिन्नरूपी ढांचे का अनुमान लगाना, २) समग्र सीमांत संभावना (CML) विधि का अनुप्रयोग बहुभिन्नरूपी मॉडल का अनुकूलन करते समय पारंपरिक अधिकतम सिम्युलेटेड संभावना (MSL) की तुलना में, ३) गतिविधि प्रकार, यात्रा भागीदारों और मोड पसंद के संदर्भ में टूर टाइपोलॉजी के दो-स्तरीय नेस्टेड ढांचे को परिभाषित करना, और ४) एक लचीले समय बजट की कमी को परिभाषित करना MDC फ्रेमवर्क के लिए घरेलू स्तर पर।

थीसिस में पाया गया है कि समय आवंटन निर्णयों की तुलना में घर से बाहर गैर-कार्य गतिविधियों में भाग लेने के दौरान पति-पत्नी के बीच बातचीत की प्रकृति अधिक स्पष्ट होती है। गतिविधि भागीदारी के लिए अंतर-व्यक्ति भिन्नता और पति-पत्नी के समय आवंटन निर्णयों को प्रकृति में स्थानापन्न होने की सूचना दी गई थी। इसके विपरीत, इन निर्णयों के लिए अंतर-व्यक्ति भिन्नता लिंग पर निर्भर है। कार्य आवंटन और दौरे की पार्टि संरचना के संबंध में, त्रुटि सहसंबंध मैट्रिक्स विभिन्न गैर-कार्य गतिविधियों के लिए चार संगत प्रकारों (अकेले यात्रा, तत्काल परिवार के सदस्यों, विस्तारित परिवार या सामाजिक सदस्यों के साथ) में महत्वपूर्ण अंतर-समूह प्रतिस्थापन प्रभाव का सुझाव देता है। संयुक्त गतिविधियों के मामले में इंटर-ग्रुप प्रभाव पूरक होते हैं, जो वयस्क घरेलू सदस्यों के समान समूह का पालन करने की संभावना को उजागर करते हैं। मॉडल गुणांक सुझाव देते हैं कि व्यक्तिगत विशेषताओं, घरेलू सामाजिक-जनसांख्यिकीय, और मौसमी और लौकिक

विशेषताओं का प्रभाव वाहन स्वामित्व और निर्मित पर्यावरण सुविधाओं की तुलना में अधिक प्रभावशाली है। मोड पसंद निर्णयों से संबंधित टूर टाइपोलॉजी से पता चलता है कि एक विकसित क्षेत्र (उदाहरण के लिए, सिडनी घरेलू यात्रा सर्वेक्षण नमूने में ५२% संयुक्त पर्यटन है) की तुलना में एक विकासशील देश में इंटर-घरेलू बातचीत की प्रकृति अधिक स्पष्ट है (हमारे नमूने में कुल पर्यटन का ६४% संयुक्त है)। आईसीएलवी ढांचे के संरचनात्मक मॉडल के नतीजे बताते हैं कि घरेलू मुखिया की विशेषताएं और निर्मित पर्यावरण चर वयस्क घरेलू सदस्यों के दृष्टिकोण और धारणाओं को महत्वपूर्ण रूप से प्रभावित करते हैं। नेस्टेड आईसीएलवी मॉडल अनुमान में अव्यक्त कारकों को शामिल करके, मोड पसंद निर्णय से जुड़े आंतरिक स्वाद (या अरुचि) परिवर्तनशीलता का एक बड़ा हिस्सा कब्जा कर लिया गया था जिसे पहले वैकल्पिक विशिष्ट स्थिरांक के लिए निर्दिष्ट किया गया था। इसके अतिरिक्त, थीसिस ने अलग-अलग टूर टाइपोलॉजी के लिए सार्वजनिक और व्यक्तिगत मोड के लिए यात्रा समय बचत के अलग-अलग मूल्यों को प्राप्त करके साहित्य में योगदान दिया, क्योंकि गतिविधि प्रकारों और व्यक्ति की व्यवस्था के साथ अलग-अलग ट्रेड-ऑफ प्राथमिकताएं होंगी। एक सप्ताह के दिन तीन बार के अंतराल में गतिविधि गंतव्य पसंद निर्णयों में विषमता को एक अस्थायी पुनरावृत्ति सूचकांक (TRI) के माध्यम से मापा जाता है। यह पता चला है कि मनोरंजक गतिविधि के स्थानों में एक दिन में उच्चतम औसत टीआरआई मूल्य होता है, जबकि खरीदारी यात्राएं सबसे कम होती हैं। पहला मनोरंजक स्थलों के लिए प्रस्थान समय में न्यूनतम भिन्नता दर्शाता है, जबकि बाद वाला शॉपिंग स्थानों के मामले में प्रस्थान समय में उच्च भिन्नता दर्शाता है। मिश्रित एमडीसीईवी मॉडल के प्रसरण-सहप्रसरण मैट्रिक्स ने गतिविधि स्थानों पर यात्राओं की आवृत्ति को मॉडलिंग करते समय अंतर-घरेलू विविधताओं को शामिल करने की आवश्यकता का सुझाव दिया। व्याख्यात्मक चर के बीच, घरेलू सामाजिक-जनसांख्यिकीय और यात्रा विशेषताएँ कई गतिविधि स्थलों के लिए बार-बार यात्रा के महत्वपूर्ण निर्धारक हैं। थीसिस इन अल्पकालिक निर्णयों में चयनित नियंत्रण चर के व्यापक नीतिगत निहितार्थों पर भी चर्चा करती है।

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List of Acronyms

AE	Aggregate Elasticity
ALBATROSS	A Learning Based Transportation Oriented Simulation System
ASC	Alternative Specific Constants
ASE	Aggregate Semi-Elasticity
BIC	Bayesian Information Criterion
BMC	Bhubaneswar Municipal Corporation
BPTS	Bhubaneswar-Puri Transport Services
BSCL	Bhubaneswar Smart City Limited
CAIC	Constrained Akaike Information Criterion
CEMDAP	Comprehensive Econometric Micro-simulator for Daily Activity-Travel Patterns
CFA	Confirmatory Factor Analysis
CHASE	Computerized Household Activity Scheduling Elicitor
CL	Confidence Level
CLRT	Composite Likelihood Ratio Test
CML	Composite Marginal Likelihood
CMP	Comprehensive Mobility Plan
CRUT	Capital Region Urban Transport
DCM	Discrete Choice Model
DMMP	Dutch Mobile Mobility Panel
EFA	Exploratory Factor Analysis
FA	Factor Analysis
GHK	Geweke-Hajivassiliou-Keane
ICLV	Integrated Choice and Latent Variable
IIA	Independence of Irrelevant Alternatives
IID	Independent and Identically Distributed
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
LL	Log-Likelihood
LRT	Likelihood Ratio Test
MIMIC	Multiple Indicator Multiple Cause
MMDCEV	Mixed Multiple Discrete-Continuous Extreme Value
MNL	Multinomial Logit
MoHUA	Ministry of Housing and Urban Affairs
MORP	Multivariate Ordered Probit
MoSPI	Ministry of Statistics and Program Implementation
MSL	Maximum Simulated Likelihood
MTW	Motorized Two-Wheeler
NL	Nested Logit
NSO	National Statistical Office
PCA	Principal Component Analysis

PLFS	Periodic Labor Force Survey
PSTP	Puget Sound Transportation Panel
RUM	Random Utility Maximization
SEM	Structural Equation Model
SRI	Spatial Repetition Index
TASHA	Travel Activity Scheduler for Household Agents
TP	Tour Pattern
TRI	Temporal Repetition Index
TTAPS	Toronto Travel-Activity Panel Survey
TTF	Travel Time Frontier
UHTS	Uppsala Household Travel Survey
VTTS	Value of Travel Time Savings