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Abstract (Doctor)

Title of Thesis	Integrated Evaluation of Real and Virtual Networks for Air-front Smart Cities
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Approx. 800 words

The Air-front Smart City is an emerging urban development concept that seeks to integrate airport functions and Digital Transformation (DX) technologies with development not only within the city but also in hinterland regions. The air-front smart cities focus on the enhancement of quality of life (QOL), economic competitiveness, and environmental sustainability by utilizing DX technologies and improving airport functions, while considering the strength and uniqueness of the city. The expansion of digital technologies has already enabled the substitution or complementarity of physical activities with digital alternatives. Understanding of how these transformations reshape service access, social behavior, and urban spatial dynamics has become critical for designing future sustainable cities and air-front smart cities. This thesis addresses these challenges by developing an integrated evaluation methodology for air-front smart cities to consider the substitutability and complementarity of physical service access findings using a social dynamics simulation model. The developed integrated evaluation model in this thesis is expanded to evaluate urban living and business environments within the air-front smart cities.

Chapter 1 introduces the research background, the growing importance of DX, and the necessity of integrating real and virtual interactions into urban planning. The chapter clarifies the research problem: despite rapid digitalization, existing urban evaluation frameworks cannot jointly assess real and virtual networks, social dynamics, and policy impacts. The research objectives, significance, and structure of the thesis are presented accordingly.

Chapter 2 reviews the literature on the Air-front Smart City concept, real and virtual network theory, social dynamic simulation, and QOL evaluation. The chapter positions this study within existing research and highlights its novelty: (1) integrating behavioral substitutability and complementarity into urban simulation, (2) developing a multi-layer network model that represents real and virtual interactions simultaneously, and (3) constructing a comprehensive evaluation system linking the integrated accessibility index to QOL and quality of business (QOB) for policy analysis.

Chapter 3 investigates the substitutability and complementarity between physical and digital services using a web-based survey. The chapter provides a systematic analysis of behavioral substitution ratios across 5 activity categories, revealing variations by age, gender, mobility resources, residential location, and social relationship types. The results disclose that younger individuals show higher substitution tendencies, while older individuals rely more on physical networks.

Cluster analysis identifies seven social relationship groups, demonstrating that online-oriented individuals adopt more digital alternatives, whereas community-oriented individuals maintain strong physical activity patterns. The chapter further examines residential relocation choices and shows that digital accessibility influences location choice primarily in urban areas. These findings offer fundamental behavioral insights necessary for understanding how real and virtual networks interact within Air-front Smart Cities.

Chapter 4 develops a multi-layer social dynamics simulation model that represents urban space through interconnected real and virtual layers. The model incorporates real and virtual accessibility, land price, household generation, life events, residential location choice, and the service choice model. Additionally, the chapter incorporates a social network layer to life event models to assess its impact on service choice. A virtual city is constructed to verify the model's ability to replicate population distribution, service usage, and network interactions. This chapter demonstrates how integrated accessibility and social interactions affect service choice and residential location choice, providing a tool for projecting future urban developments.

Chapter 5 presents the total concept and methodological foundation of this thesis by constructing an integrated accessibility-based evaluation framework for both QOL and QOB. Based on insights from Chapters 3 and 4, the chapter develops accessibility indices that incorporate physical and virtual service accessibility. The QOL and QOB models are enabled to evaluate urban living and business environments for different stakeholders of business within the air-front smart city context. The chapter showcases indicator definitions and scenario settings (Aichi startups, Baguio agriculture, and Phuket tourism), which illustrate how the framework can be applied to diverse contexts. This chapter establishes the core evaluation methodology for air-front smart cities.

Chapter 6 applies this methodology to an air-front smart city policy evaluation case study in Aichi, Japan. Using survey data, open access regional data, parameter estimation, and integrated accessibility calculations, the chapter evaluates how policy interventions affect startups' QOB, business partners' QOL, residents' QOL, and overall urban performance. Furthermore, the chapter applies the methodology to Singapore and Munich using the parameters estimated in Aichi and compares startup ecosystems within these three regions.

Finally, Chapter 7 summarizes the major findings and discusses future research opportunities. The results show that sustainable air-front smart city development requires a balanced approach where digital services complement, rather than replace, physical accessibility. Policies that integrate DX, human mobility, social interactions, and spatial planning are essential for ensuring resilience, inclusivity, and environmental sustainability.

Overall, this thesis provides a comprehensive empirical and methodological foundation for evaluating air-front smart cities. By integrating substitutability and complementarity analysis, social dynamics simulation, and QOL–QOB accessibility evaluation, the study offers practical guidance for policymakers aiming to create adaptive and human-centered urban environments in the digital era.