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THE SMART HUB CONCEPT: DEVELOPING THE RELATIONSHIP BETWEEN HUMAN MOBILITY AND ENERGY CONSUMPTION IN TOKYO

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ABSTRACT

Technologies are changing in both the mobility sector, with electric, autonomous, and demand-responsive service mobility vehicles, and the energy sector, with increasing usage of alternative energy sources, battery efficiency, and microgrids. In such a crucial time to achieve sustainable practices to ward off major climate change impacts, these changes across different systems need to be integrated globally. The objective of the study of mobility services and microgrids in the Sumida Ward of Tokyo, Japan is to find the optimal placement for an integrated space, referred to as Smart Hubs, for both vehicular charging and energy storage using MATSim simulation and EnergyPlus modeling methods. The findings could enlighten planners and public officials of the optimal placement of these new community spaces for both time and energy optimization of new mobility services and to change the way urban energy systems are managed and utilized.

Keywords: Electric Vehicles, Autonomous Vehicles, Energy Storage, Batteries, Smart Hub, Demand-Responsive Mobility

NONMENCLATURE

Abbreviations	
AV/EVs	Autonomous & Electric Vehicles
DRS	Demand-Responsive Service
DRT	Demand-Responsive Transit
MOEs	Measures of Effectiveness
EUI	Energy Use Intensity
Symbols	
E_{un}	Energy Usage of Vehicle n
EC	Energy Capacity of Vehicle
EE	Energy Efficiency of Vehicle
d_i	Distance from Smart Hub to Initial
Δd_j	Change in Distance from Initial to j
E_U	Total Vehicular Energy Usage
E_G	Total Energy Generated
E_b	Total Building Energy Usage

1. INTRODUCTION

Transportation networks around the globe will undergo substantial changes in how they operate, function, and are integrated in the next several decades as electric, autonomous, and demand-responsive mobility vehicles are released [1]. Studies have shown that there will be many economic, social, environmental, and energy-related consequences due to these incoming disruptive technologies.

Automotive companies are now reimagining themselves into mobility companies, in reaction to recent changes to transportation options such as ridesharing. In the past two years, there have been several high-profile autonomous vehicle concepts released that could act as either demand-responsive mobility and transit vehicles, parcel delivery vehicles, or even food or shopping delivery vehicles. Toyota has released the concept called e-Palette which is an automated, electric, flexible vehicle that can adapt to various needs and services, and with the release have announced partnerships with Amazon, DiDi, Mazda, Pizza Hut, and Uber [2], potentially under their new Monet Technologies joint-venture with SoftBank [3]. Ford, in partnership with Gnewt, has begun implementing a similar “Warehouse On Wheels” concept, with testing happening already in London, and plans to grow itself into a mobility and services company [4]. Similarly, Mercedes-Benz Vision Urbanetic concept and Renault's EZ-PRO vehicles are seeking to change the way we use our urban transportation networks and achieve optimal logistics [5]. Together, these vehicles will increase the demand for localized electric charging stations and warehousing for parcel and service delivery.

The economic consequences relate to whether certain automotive companies will be able to keep pace with automation and technology improvements, if brick-and-mortar stores will still be necessary and desirable, and the equitability of these new technologies and whether or not they are released as single-ownership vehicles like today or fleet vehicles held under mobility company ownership. The social consequences are related to how humans will interact with the built environment around them and if they will overuse convenient services from home; however, there is still a desire of humans to seek out social interaction. The desire for social interaction could actually instead be the driving force of success for mobility on-demand service platforms [6]. There is clear data that has shown that the social interaction desire is going to change the retail environment, but not eliminate it, an example being the recent comeback of farmers' markets [7].

The potential energy consequences are less clear, especially due to the uncertainty of how and when EV/AVs will be released. Electric vehicles have the potential of taking the road transport system to near zero emissions [8]; however, infrastructure improvements will be necessary to ensure that national power grids can keep up with the energy demand to power all of the electric vehicles that may be on the network [9], especially as our mobility networks become heavily used by demand-responsive services. Batteries have long been improving in order to handle the need for individual electric single-occupancy, and even electric intraurban aircraft vehicles [10]; however, this battery technology must also improve to safely handle the necessary loads for storage in areas that carry a net-positive energy load. This storage could become influential in preparing the infrastructure needed in individual areas, in the form of Smart Hubs, as presented in sections 2 and 3.

As vehicles require additional energy demands from vehicles, urban and community planning should also consider strategies for integrating energy infrastructure [1]. Energy infrastructure must balance energy supply and demands [11], manage dynamics in multi-scales [12], control hourly or half-hourly demands for peak responses [13], and leverage existing methodologies [14]. As an emerging technology, microgrid systems have been investigated as the concept of containing small energy generations, while acting as local distributions systems [15]. The small scale energy production can be better and faster to adapt demands' fluctuations [15], [16]. The distribution systems can be operated as stand-alone or grid-connected [15]. Microgrids may act in tandem and be incorporated with future mobility distributions systems that also require a storage "hub", the basis of the research presented.

2. SMART HUBS

The Smart Hubs concept was developed by the core team of researchers from the National Institute of Environmental Studies Japan aiding graduate students in the Georgia Institute of Technology's annual Smart City International Design Studio in Japan. The Smart Hubs concept began as a reaction to the development of autonomous, electric, and demand-responsive mobility vehicle technology over the coming years and decades, but also addresses many of the other challenges facing communities around the world. While automakers and technology companies are investing in the design of the vehicles themselves, less effort has been placed in the design of the urban environments where these new technologies will operate. Infrastructure must be designed in anticipation of these technologies, while also prioritizing human experience and minimizing environmental impact. Innovations in technology present an opportunity to redesign the public realm.

2.1 The Concept

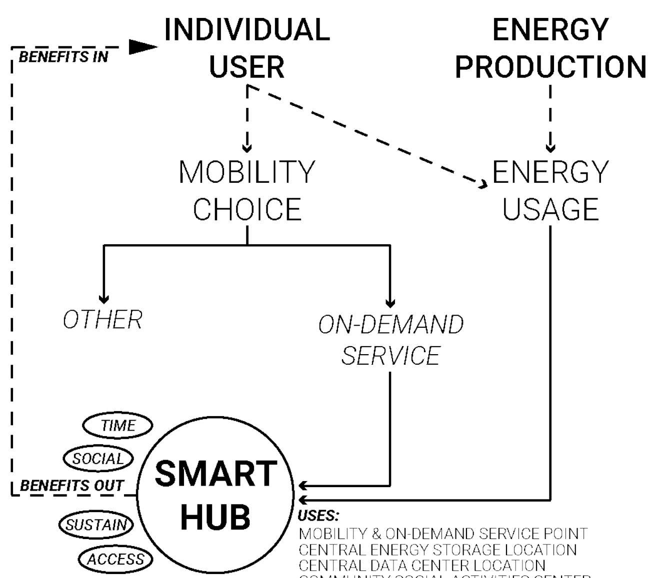

Fig 1 Smart Hub Functional Diagram

The Smart Hub concept addresses an overlooked aspect of future mobility vehicle design: where to store, charge and service the vehicles. A network of distributed service/charging stations which integrate seamlessly with the urban environment are proposed. These stations are designed to be located underground, allowing functional services to be hidden and unlocking new opportunities for public space above. Furthermore, a distributed system better meets local needs by providing rapid access to services and emergency response to the adjacent neighborhoods. This distributed network of service "hubs" would take on the additional roles of being the local mobility and demand-responsive service point, the central energy and data location, and the integrated community activities center or other social space. The functionalities of Smart Hubs are shown in Fig 1.

2.2 The Needs and Benefits

There are concerns about the emerging mobility and energy technologies that are addressed by Smart Hubs, such as the potential of DRS's causing less social interaction if general shopping and food services are provided door-to-door and the lack of a method to determine the right location for local energy and data storage. The benefits come in four specific forms: Time, Social, Sustainability, and Access.

The time-savings that Smart Hubs bring are similar to those that proposed DRS vehicles bring, which is that services outside of a neighborhood could become more locally available and accessible. While door-to-door service would cause the most time-savings among users, Smart Hubs will also bring these services to a neighborhood with a potential social experience.

The social benefits stem directly from the ability of the Smart Hubs to bring DRS and DRT vehicles to a neighborhood and bring residents out to a public space. It also provides the public space to host other events.

The sustainability benefits come both from the mobility and energy sectors. New AV/EVs will diminish the need for many transportation trips of an individual and will ultimately lower energy usage and emissions from current standards. The energy sector will benefit from a central location to hold excess energy that is generated by buildings, while also providing a location for vehicles to charge directly from the microgrid. This will lower the EUI on the larger electric grid.

The access benefits are generated by more services being provided at a local level by DRSs, which especially benefit aging citizens. Additionally, a central location to store local data could provide citizens the opportunity to understand what data is collected, and how they are interacting with their own built environment.

3. METHODS AND ANALYSIS

3.1 Initial Analysis in Sumida Ward, Tokyo

The initial analyses of Smarts Hubs were completed for the northern Sumida Ward area in Tokyo, Japan. The existing conditions of the transportation network and building energy usage were first observed. The roadway network was coded in GIS into typologies and a 'superblock' road network was considered. All other roads within the superblocks would only be utilized by DRS and DRT vehicles. The locations for the vehicular charging and warehouse locations (later referred to as Smart Hubs), were not chosen initially based on any scientific method. Fig 2 shows the analysis area.

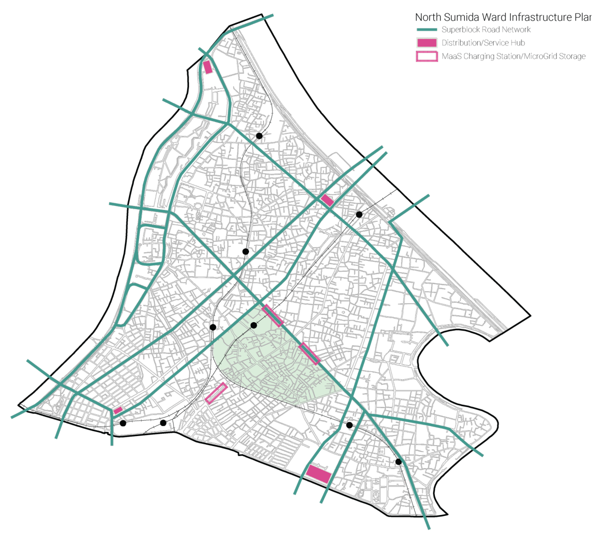

Fig 2 North Sumida Ward DRS Vehicle Depot Proposal

<u>3.1.1 Mobility Analysis</u>

Using the base MATSim model that was developed by ETH Singapore, TU Berlin, and National Institute for Environmental Studies Japan researchers, the demand was updated to reflect a change of all agents' trips, outside of home-work trips, to signify usage of a DRS. The first scenario simulated the DSR vehicle going door-to-door to complete a service. The services were categorized into 100 different types, which is each considered separately and with a particular time of completion (or time spent at the agent's door). The optimizer within the model attempts to use the fewest number of vehicles, while each vehicle arrives at the agent's door during the period of the 'other' trip that has now placed the agent back home. The initial scenario generated showed one vehicle serving about four or five time slots, but only represents a 10% sample of the actual population of northern Sumida Ward. There would likely be more fluctuation in the MOEs if the time slots became dynamic. With further effort placed into the demand generation, the amount of social interaction per agent could be evaluated. The initial scenario demand generation brings the question of why people go to particular locations for their ‘other’ trips and how would a DRS change those interactions with the built environment. The initial scenario simulation is highlighted in Fig 3.

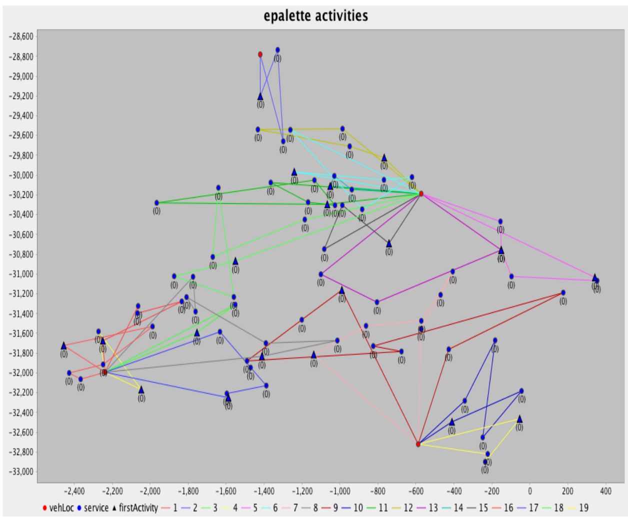

Fig 3 DRS Vehicle MATSim Sumida Ward Scenario Model

3.1.2 Energy Analysis

Microgrid systems can control real-time energy balance and optimize power generations and storage [15]. To design system boundaries for the microgrid, this research detects potential decentralization of energy generation empowered by solar radiation and energy demands at the block-level. Building energy models simulated annual energy use intensity (EUI; kWh/m^2) for each building, and the energy demands of individual buildings were aggregated at the block-level. Also, solar irradiance on vertical façades and roofs were assessed using a parametric modeling [17]. Average solar irradiance was identified during a period from June 1st to August 31st. Kyojima 1 in northern Sumida was tested to evaluate the energy balance. Fig 4 shows the annual EUI and solar irradiance at the block-level.

Building energy demand savings of 45-65% are possible using strategies including improvements of lighting equipment, optimized operations, or natural ventilations, etc. [18], [19]. To optimize the boundary of microgrid systems, the self-sufficiencies are presented according to the future energy-saving scenario in Fig 5. This research defined energy sufficiency as how much energy required can be delivered by solar potentials. Fig 5 compares the current energy sufficiency of each block and the future energy sufficiency when 45% of energy is saved. The analysis results provide spatial information for setting microgrid boundaries as well as optimizing the Smart Hub locations.

Based on the energy sufficiency, the microgrid systems can empower Smart Hubs to operate and respond to users’ demands in a flexible way by communicating and optimizing energy surpluses or shortages.

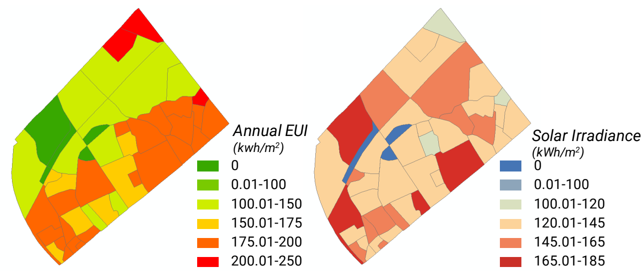

Fig 4 Annual EUI and solar irradiance in blocks in Kyojima 1

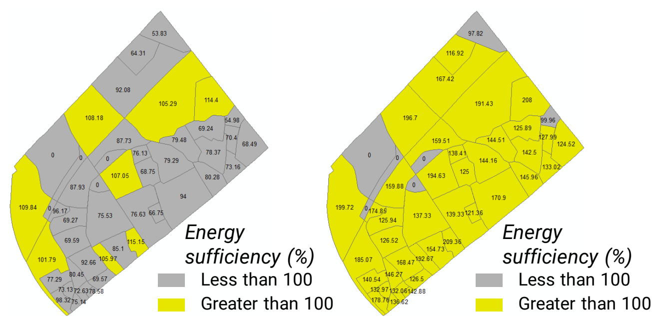

Fig 5 Energy sufficiency (%): current state (left) and future energy-saving scenario (right)

3.2 Future Analysis

The future analysis integrates the methods in 3.1 to achieve the optimal location for Smart Hubs, as the original locations in northern Sumida Ward were not chosen through a methodical, mathematical, or optimized method. The planned mobility analysis results in 3.2.1 inform the microgrid analysis described in 3.2.2.

3.2.1 Enhanced Mobility Analysis

Mobility service providers will benefit from optimized vehicular locations, Smart Hubs, by decreasing the amount of time and distance to recharge and allowing for more localized warehousing space. The decrease in time and distance will increase profitability. The localized alternative energy sources will result in the efficient and sustainable use of the electric grid to keep mobility services running. The optimization of Smart Hub locations within a particular boundary for mobility services will come from running the agent-based MATSim simulation model until there are generalized convergence points of where DRS and DRT vehicles would be at zero energy capacity. The ideal locations can then be identified both for full-scale Smart Hub locations, and for small-scale vehicular charging locations. This optimization is described in Fig 4.

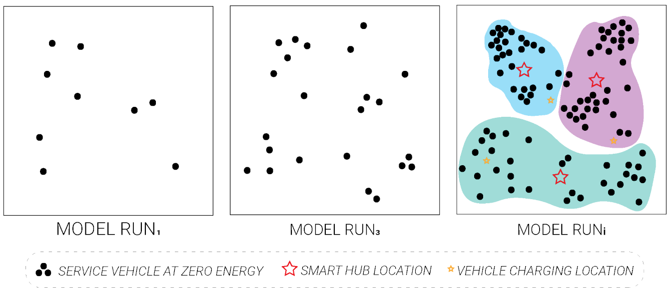

Fig 4 Future Mobility Analysis Model Convergence Concept

The following mathematical equations describe the calculations that would be taking place in the code before a particular data point is noted. Each vehicle running on the network would complete simulated trips until the available energy in the vehicle approaches zero. In theory, the vehicle could have an infinite number of zero energy usage trips, as the limit describes. The total energy usage for each service vehicle is then summed.

$$E_{un} = EE(d_i + \sum_{k=1}^{n} \Delta d_{jk})$$

$$\lim_{n \to \infty} EC_n - E_{un} = 0$$

$$E_u = \sum_{k=1}^{x} E_{un,k}$$

The total energy usage for all service vehicles for a specific time period is then compared to the available energy that is generated, and available, by local alternative energy sources. The building energy usage is subtracted from the energy generated within a boundary area. This equation is necessary to understand if a particular area can generate enough energy to service all buildings and mobility needs within a particular area, which is the desired scenario when using Smart Hubs.

$$E_u \leq (E_G - E_b)$$

One potential issue in this planned analysis is that future development and a change in particular human behavior and usage patterns could impact whether an optimal location remains optimal in the future. This analysis utilizes existing data, which does not include a plethora of information about whether or not particular demographics and socio-economic groups will be attracted to DRS or DRT. Without data about these unproven services, the optimization also goes unproven if human behavior and development patterns change.

3.2.2 Enhanced Energy Analysis

The energy analysis awaits the results of the mobility analysis and Smart Hub location placement. With this specific battery storage location identified, the energy analysis can then be completed to develop a network of microgrids to understand the building energy usage at the neighborhood and block-level, while fulfilling the desire for net zero energy usage for both building usage and mobility usage. The energy analysis is then completed in the same way that it was in the initial study discussed in section 3.1. Like in 3.2.1, it is important to recognize that a change in development patterns and human behavior could impact optimal locations.

4. CONCLUSION

Smart Hubs have the ability to integrate future mobility technologies and urban energy sectors, both benefiting from this innovation. DRS and DRT vehicle fleets will be able to utilize localized energy sources and minimize the amount of time and distance required to recharge their AV/EV vehicles. At the same time, microgrids and alternative energy storage will be possible at optimal locations throughout a particular boundary area at multiple scales. The other benefits come directly to the community by providing a new public space and a central location to utilize demand-responsive services in a more social and interactive environment. The community may also have the opportunity of understanding and utilizing their own community data—creating a greater trust between community and data companies. Bringing all of these functions together could attract multiple international functions into one location; a place where Toyota and Ford could utilize the same space as Amazon, Google, Starbucks, Pizza Hut, and energy companies, while also benefiting the community at-large. In order to fully implement the Smart Hub concept, there remains further studies to address location optimization for mobility services and urban energy sources.

REFERENCE

[1] E. Hannon, C. McKerracher, I. Orlandi, and S. Ramkumar, “An integrated perspective on the future of mobility,” *McKinsey Co.*, no. October, p. 68, 2016.

[2] N. Banks, “CES 2018: Meet Toyota’s Flexible, Electric, Automated E-Palette,” *Forbes*, New York City, Jan-2018.

[3] S. Pham, “SoftBank and Toyota want driverless cars to change the world,” *CNN Business*, Atlanta, 04-Oct-2018.

[4] A. Kreetzer, “Ford’s ‘Warehouse On Wheels’ to Speed-Up Deliveries, Ease Congestion and Improve Air Quality,” *Auto Futures*, 2019. [Online]. Available: https://www.autofutures.tv/2019/02/18/fords-warehouse-on-wheels-to-speed-up-deliveries-ease-congestion-and-improve-air-quality/. [Accessed: 30-May-2019].

[5] S. Dent, “Renault’s EZ-PRO is a workspace, coffee truck and rolling post office,” *Endgadget*, 2018. [Online]. Available: https://www.engadget.com/2018/09/19/renault-ez-pro-autonomous-delivery-ev/. [Accessed: 30-May-2019].

[6] A. Polacco and K. Backes, “The Amazon Go Concept: Implications, Applications, and Sustainability,” *Backes / J. Bus. Manag.*, vol. 24, no. 1, pp. 80–93, 2018.

[7] P. Merholz, “The Future of Retail? Look To Its Past.,” *HBR*, 2011. [Online]. Available: https://hbr.org/2011/12/the-future-of-retail-look-to-i.

[8] R. Smit, J. Whitehead, and S. Washington, “Where Are We Heading With Electric Vehicles?,” *Air Qual. Clim. Chang.*, vol. 52, no. 3, pp. 18–27, 2018.

[9] F. T. Davidson, D. Tuttle, J. D. Rhodes, and K. Nagasawa, “Is America’s Power Grid Ready for Electric Cars?,” *CityLab (republished from The Conversation)*, 2018. [Online]. Available: https://www.citylab.com/transportation/2018/12/americas-power-grid-isnt-ready-electric-cars/577507/. [Accessed: 30-May-2019].

[10] R. B. Binder, L. A. Garrow, B. J. German, P. L. Mokhtarian, M. J. Daskilewicz, and T. H. Douthat, “If you fly it, will commuters come? Predicting demand for evtol urban air trips,” in *2018 Aviation Technology, Integration, and Operations Conference*, 2018.

[11] J. Keirstead, M. Jennings, and A. Sivakumar, “A review of urban energy system models: Approaches, challenges and opportunities,” *Renew. Sustain. Energy Rev.*, vol. 16, no. 6, pp. 3847–3866, Aug. 2012.

[12] M. Jaccard, *Sustainable fossil fuels: the unusual suspect in the quest for clean and enduring energy*. Cambridge University Press, New York, 2005.

[13] A. Hawkes and M. Leach, “Impacts of temporal precision in optimisation modelling of micro-Combined Heat and Power,” *Energy*, vol. 30, no. 10, pp. 1759–1779, Jul. 2005.

[14] R. E. Best, F. Flager, and M. D. Lepech, “Modeling and optimization of building mix and energy supply technology for urban districts,” *Appl. Energy*, vol. 159, pp. 161–177, Dec. 2015.

[15] M. Manfren, P. Caputo, and G. Costa, “Paradigm shift in urban energy systems through distributed generation: Methods and models,” *Appl. Energy*, vol. 88, no. 4, pp. 1032–1048, Apr. 2011.

[16] R. Kamphuis, P. Carlsson, C. Warmer, J. Kester, and K. Kok, “Distributed intelligence for supply/demand matching to improve embedding of distributed renewable energy sources,” in *Securing Critical Infrastructures*, 2004.

[17] S. Chang, N. Saha, D. Castro-Lacouture, and P. P.-J. Yang, “Multivariate relationships between campus design parameters and energy performance using reinforcement learning and parametric modeling,” *Appl. Energy*, vol. 249, pp. 253–264, Sep. 2019.

[18] M.-C. Dubois and Å. Blomsterberg, “Energy saving potential and strategies for electric lighting in future North European, low energy office buildings: A literature review,” *Energy Build.*, vol. 43, no. 10, pp. 2572–2582, Oct. 2011.

[19] M.-H. Kim, J.-S. Park, and J.-W. Jeong, “Energy saving potential of liquid desiccant in evaporative-cooling-assisted 100% outdoor air system,” *Energy*, vol. 59, pp. 726–736, Sep. 2013.