Development of an electric discharge machining system

Sociotechnical evaluation of urban development plans intended to reduce automobile dependency of American cities

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Traditional machining techniques (typically using a spinning bit to remove material) are inappropriate in certain applications because the heat produced by the machining process alters the material properties of the part (for example, some metals become brittle as a result of work-hardening). In aerospace applications, for instance, where any loss of nominal material properties could result in a part failing, a different type of machining process proves helpful (Dixit & Jose Matthew, 2022).

Electric discharge machining is a manufacturing process that uses small, repeated electrical sparks to slowly remove material to produce a part. Little of the spark energy goes to heating the bulk material, so that the bulk material properties of the part remain unchanged. Each spark represents a delicate balance between delivering enough energy to remove material and delivering so much energy that the tool and workpiece weld together, ruining the part (Dixit & Jose Matthew, 2022). For this reason, specialized electronics are required to control and monitor the electric discharge machining process for optimal, safe operation. My capstone group and I aim to design and construct a model electric discharge machining setup. This project encompasses electrodynamics, thermophysics, electronic design, control theory, and embedded systems program; as such it is an excellent way to synthesize knowledge from fields across electrical engineering to construct a fairly complex device.

My sociotechnical research addresses a topic I care about that is not directly tied to my technical capstone. American cities rely on their transportation infrastructure to thrive, but my opinion, backed by a wide body of research, is that automobile-centered patterns of development have begun to strangle their growth (Newman & Kenworthy, 1999). Automobile-centered mobility infrastructure is unsustainable technically (roads can be widened only so far),

environmentally (every man-hour in traffic means more atmospheric carbon), and economically, socially (every man-hour in traffic is time not spent enjoying life or creating value) (Gehl, 2010).

My sociotechnical research will study the proposed solutions to these problems. I will use a multifaceted approach (described later on and involving both interviews and a sociotechnical analysis) to evaluate these proposed plans for urban development on the basis of their effectiveness at reducing automobile dependency and improving quality of life for residents.

Although solutions to automobile-centered development may appear unrelated to electrical engineering at first glance, there are actually two key ways in which my sociotechnical research ties in to my technical field. First, electrical engineers are instrumental in the development of transportation technologies of the future: electric cars, trains, buses, bicycles, and trams. They also contribute to the telecommunications technologies which tie the transportation system together (a smart city might gather data to inform future development), or even render it irrelevant (remote work software). Second, and more importantly, the problem of urban mobility bears key resemblances to technical problems which appear in electrical engineering. The routing problems which arise in high-density integrated circuits is analogous to the difficulty of finding space for roads. Another example: the same mathematics used for electrical network analysis can be applied to transportation networks to predict patterns of usage.

Electric discharge machining system

In the Introduction, I stated that electrical discharge machining is superior to traditional machining processes when cutting parts out of aerospace alloys. My capstone project team is building an electric discharge machining system with a particular aerospace application in mind: we aim to form the regenerative cooling passages of a jet or rocket engine into a block of metal to demonstrate our system. The heat produced by these engines is so great that circulating

coolant would quickly boil; instead, the fuel itself serves as coolant, flowing through passages built into the engine walls before combustion (Huzel & Huang). The traditional manufacturing process for these passages involves milling canyons into the oustide of the engine walls, then electrochemically plating metal over the canyons to seal them off. Multiple steps are involved, and, because the inner engine wall must be milled, superior alloys not compatible with milling must be ruled out (Huzel & Huang). Electrical discharge machining presents a simple alternative: cut regenerative cooling holes directly down the engine walls, regardless of the alloy.

Electric discharge machining is a manufacturing process that uses small, repeated electrical sparks to slowly remove material to produce a part (Dixit & Jose Mathew, 2022). Little of the spark energy goes to heating the bulk material, so that the bulk material properties of the part remain unchanged (Dixit & Jose Mathew, 2022). A high voltage is applied to the narrow gap between the "workpiece" (a metal block to be cut into) and the "tool" (a metal extrusion of the same shape as the intended hole), and, when the electric field becomes strong enough, electrons are torn off atoms in the gap to form a conductive state of matter known as plasma. A great electric current flows through this plasma, with electrons leaving the negatively charged tool to strike the positively charged workpiece with great energy, enough to vaporize a small amount of workpiece metal (Raza & Nirala, 2021). A continuous flow of water carries the metal vapor away so that it does not recondense (Dixit & Jose Mathew, 2022). By means of many such sparks each second, material can be slowly removed from the part.

Developing an EDM system presents several significant technical challenges. The main challenge is that the physics of the breakdown process is poorly understood, so that we cannot predict in advance how the sparks will behave and have to design our device with a large envelope (Raza & Nirala, 2021). A high-speed, high-current electronic switch must be designed

to control the duration of the sparks without risk of failure. A reliable method of detecting the onset of a spark must be devised and applied to interrupt the spark current after the appropriate amount of energy has been delivered: too much energy, and the workpiece and tool will weld together; too little energy and material removal will occur very slowly. Because the electrical energy must be immediately available to supply the spark, an appropriate capacitor must be found to store the energy near the spark gap which will not be damaged by fast discharge. The presence of high voltages in the system presents difficulties as well. The device must be designed for remote operation, so that the user does not have to approach the high-voltage components.

Evaluation of urban development plans

A century of automobile-centered urban development has brought American cities up against a scalability asymptote in terms of the economic, environmental, and social costs of further growth along these same lines, and it is long past time to search for new development paths to follow in the future (Newman & Kenworthy, 1999). Several development proposals exist, including the compact city, multimodal development, the natural city, the village city, and transit-oriented development, among others (Le Clercq & Bertolini, 2003). These proposals are not mutually exclusive, and the optimal solution may well lie with some combination of them. My sociotechnical research aims to evaluate the effectiveness of each development plan for reducing automobile dependence and enhancing the quality of life for residents.

My sociotechnical research effort will consist of three main phases: a literature review, an interview campaign, and an analysis using sociotechnical frameworks to draw conclusions. The literature review will survey the proposals for urban development that aim to address the problems of car-dependent cities. I will not yet attempt to evaluate each development plan for

effectiveness; I will simply enumerate the major existing proposals and try to understand their essential characteristics in order to support the subsequent phases.

After the literature review, I will conduct an interview campaign, speaking to a few dozen people living in major cities of the United States and Europe. I plan to begin each interview by asking how the mobility options in the subject's city affect his daily life. I'll transition into open-ended questions about how often (and in what circumstances) the subject becomes aware of how his city was planned, and how he might like to see it improved. In order to gather data on how each subject views the various urban development plans, I plan to present him with a series of images generated by modifying a photograph of a public place in his city according to each proposal I discover in the literature review. I will then ask the subject to explain which development plans he would prefer to see in his city, and why he holds that view. My methodology follows closely the semi-structured interview approach of Nello-Deakin & Nikolaeva (2021), coupled to the geographically comparative approach of Pelzer (2010). The modified-photograph technique is inspired by the work of Gehl (2010).

The sociotechnical analysis will employ the theory of actor networks to synthesize the data I gather in the previous two phases (the literature review and interview campaign) and allow me to evaluate the various urban development plans on the basis of their effectiveness at enhancing the quality of life for residents of American cities. I plan to construct an actor network consisting of at least (more elements will occur to me as I research): the mobility infrastructures (roads, railways, cycle lanes, etc.), mobility technologies (automobiles, trains, bicycles, etc.), spatial distributions of activities (e.g. the locations of homes, offices, and shops), development administration, and resident population. This last I will model using the results of the interview campaign.

The reason I choose to include the resident population is that the ideology of residents surrounding their city's development path can have an outsize impact on how effective each development proposal ultimately is (Nello-Deakin & Nikolaeva, 2021). My research thus far suggests that residents participate in the network not only in a technical sense, as consumers of mobility who make economically rational decisions about how and where to travel, but also in a social sense, as transportation activists. According to some theorists, city dwellers with a strong ideology around urban development can make decisions about mobility that are economically irrational (Dieleman & Wegener, 2004; Le Clercq & Bertolini, 2003). Thus a common sentiment among residents about how a city should develop can serve as a kind of "social momentum" to amplify policies and enact change.

Conclusion

My technical capstone will be complete when my group has realized our own electrical discharge machining system with at least the minimal features set out in our project proposal: the device should be able under remote operation to cut a hole in a block of aluminum. My group will also produce a detailed technical report documenting our design decisions and how these might be improved in hindsight. The technical report in particular will prove valuable to other electrical engineering students interested in learning about this important but complex manufacturing process, and, if the system works, I hope this inspires future students to pursue ambitious capstone projects.

The question of how cities should be developed in the future to ameliorate the problems of car dependence is a pressing one because we are running up against the scalability limits of the current system at present. My sociotechnical research will be complete when I have pursued all three phases of research and produced a summary of my findings. I will conduct a literature

review to understand the proposed solution to car-dependence, interview people in cities across the U.S. about how they would like to see the transportation infrastructure of their cities change in a comparative study, and examine these findings through the lens of actor-network theory to finally evaluate the effectiveness of each development plan identified in the literature review. I expect to find that a combination of several of the proposals would be most effective.

References

Boyce, C. (2010). Walkability, Social Inclusion and Social Isolation and Street Redesign. *Built Environment (1978-)*, *36*(4), 461–473.

Boyce uses two walkability enhancement projects in Geelong, Victoria as case studies to evaluate how effective physical infrastructure and public policy are in influencing the social factors which contribute to walkability. The paper posits a positive feedback loop: low walkability of a city leads to fewer public encounters, causing social isolation and criminal behavior, which in turn discourages walking and removes any public support for walkability projects. The solution suggested is a bottom-up approach to urban planning, whereby citizens are expected to participate in the infrastructure design of their neighborhoods. The article reviews studies of the physical and mental health benefits of walking in detail; I will use this as a tertiary source in my background section recommending a transition away from car dependence in cities.

Bozovic, T. (2021). *Non-walkability in the Car-Centric City* [Auckland University of Technology]. https://hdl.handle.net/10292/14729

Bozovic's thesis aims to understand how the user experience of people in the walking environment their city provides influences their decision to walk rather than driving. He makes an extensive literature review of walkability theory, which I will reference to provide background for my own paper, but also uses a survey of several thousand residents of Auckland, New Zealand, to evaluate the correctness of these theories. Based on the strength of correlations between survey responses, Bozovic found that people were most likely to walk as part of a journey also incorporating public transit. This suggests a hierarchical transport system (walk to activities within a neighborhood, take a bus or train

to adjacent neighborhoods, and drive to other cities) could work well. Bozovic also used interviews to learn what Auckland residents wanted to make their city more walkable; I will draw on these results in my writing.

Buehler, R., & Pucher, J. (2010). Cycling to sustainability in Amsterdam. *Sustain: A Journal of Environmental and Sustainability Issues*, *21*, 36–40.

Dekker, H.-J. (2021). *Cycling Pathways: The Politics and Governance of Dutch Cycling Infrastructure, 1920-2020*. Amsterdam University Press. https://doi.org/10.5117/9789463728478.

Dieleman, F., & Wegener, M. (2004). Compact City and Urban Sprawl. *Built Environment (1978-)*, *30*(4), 308–323.

The authors propose a bidirectional interaction between urban land use and transportation use: historically, transportation has been viewed as a need determined by the layout of homes and workplaces in a city, but to some extent land use can result from the arrangement of transportation infrastructure itself. They suggest a positive feedback loop operating to increase car-dependence as road networks allow businesses to be more distantly located from consumers. Several theories are brought in to explain this positive feedback loop, including the gravity theory of human interaction, the economic cost-minimization theory, and the social ecology activity-maximization theory. This article takes Portland, Oregon and Randstad, the Netherlands as case studies for the implementation of compact city and multifunctional land use policies aimed to reduce car dependency, and finds that these policies are both theoretically and empirically sound. I will use this reference to enumerate the various urban development paradigms and explain why each could help to reduce car dependence.

Gehl, J. (2010). *Cities for People*. Island Press.

Jan Gehl is a Danish architect dedicated to redesigning cities for pedestrians and cyclists. This book represents the accumulated knowledge from that life's work and includes photographs of infrastructure that steers residents away from active or public transit and towards car dependence. These photographs come accompanied by discussion and architectural drawings of remedies. Gehl also shares how he has seen the specific projects he has built in Copenhagen and around the world have contributed to making cities more livable for their inhabitants.

Le Clercq, F., & Bertolini, L. (2003). Achieving Sustainable Accessibility: An Evaluation of Policy Measures in the Amsterdam Area. *Built Environment (1978-)*, *29*(1), 36–47.

This article evaluates the effectiveness of three different approaches to implementing sustainable mobility systems in cities: the transportation planner's approach, the transport economist's approach, and the urban planner's approach. The authors argue that it is not mobility - the transportation network - itself which ought to be made sustainable, but rather accessibility, defined as the number of easily accessible activities, goods, and services for a person living in the city. Thus policies should advocate multimodal development and concentration of activities near public transit nodes as well as encouraging a reduction in personal automobile usage. The city of Amsterdam is taken as a case study, and the authors find that the development policies there have been excellent at implementing their type of sustainable accessibility paradigm. In particular, they laud the ABC zoning policy, which helped to optimize layout for public transit. I will present the views of these authors as typical concretizations of the "compact city" paradigm that have worked well for reducing car dependency.

Nello-Deakin, S., & Nikolaeva, A. (2021). The human infrastructure of a cycling city: Amsterdam through the eyes of international newcomers. *Urban Geography*, *42*(3), 289–311. https://doi.org/10.1080/02723638.2019.1709757

This article examines the reasons for the widespread adoption of bicycles among Amsterdammers, driven by a sense that physical ("hard") factors are insufficient explanation. The authors consider bicycle transportation in Amsterdam as a sociotechnical system and search for both social and technical factors in cycling adoption. They employ an ethnographic approach, interviewing thirty people who had recently moved to Amsterdam from abroad and who had not used bicycles to travel around in the country where they had lived before. Participants were asked what influenced them to take up cycling, what obstacles they had faced in doing so, and similar questions. The researchers found that cycling adoption was driven by factors either directly or indirectly resulting from the city having a large population of avid cyclists. The findings suggested that cyclists represent "human infrastructure" as crucial as physical infrastructure like bicycle lanes to bicycles taking transportation share from automobiles. I will use this reference to inform how I use actor-network theory framework to evaluate how cities can better implement transportation, as well as to inform my methodology when I conduct my own interviews.

Newman, P., & Kenworthy, J. (1999). *Sustainability and Cities: Overcoming Automobile Dependence*. Island Press.

Pelzer, P. (2010). *Bicycling as a Way of Life: A Comparative Case Study of Bicycle Culture in Portland, OR and Amsterdam*.

This reference complements the ethnography work of Nello-Deakin and Nikolaeva, again analyzing the ways in which both social and material factors contribute to the adoption of cycling in urban environments. Pelzer conducts dozens of semi-structured interviews with cyclists living in Portland and in Amsterdam in order to learn about what leads people to bike rather than drive, and what obstacles they face within that. He concludes that both physical and social factors play a role in both cities, but that a cycling culture is not sufficient in Portland to overcome the infrastructural barriers to cycling (such as long distances and narrow cycle lanes). The authors argue that a certain amount of cultural momentum is needed in order to enact change, and that the same cultural momentum helps to perpetuate a cycle-friendly mobility infrastructure once it is there. I plan to use this reference mainly to frame (and inform the methodology of) my own comparative interviews of residents of cities designated as walkable and as unwalkable in both the US and Europe.

Register, R. (2006). *Ecocities: Rebuilding Cities in Balance with Nature*. New Society Publishers.

Register's book looks at cities as ecosystems or organisms, and takes the radical stance that today's cities are diseased and dysfunctional, with car-dependence being just one symptom of that issue. The book's expansive and optimistic vision of the cities of the future offers a number of solutions to today's problems which, unlike the policy-based proposals of my other references, are more distant destinations toward which we could aim than directions we could take. Register advocates a compactification and diversification of cities, a return of wilderness to the center of cities, and adoption of varied methods of travel including walking, cycling, electric-scootering, public transit,

and ridesharing. The book serves as an inspiration of what is possible for cities of the future, and can thus guide my analysis of policy recommendations. It explains what the global optima are for cities, so that I can avoid policies that move in the direction of local optima.

Schuetz, J., Giuliano, G., & Shin, E. J. (2018). Can a Car-Centric City Become Transit Oriented? Evidence From Los Angeles. *Cityscape*, *20*(1), 167–190.

This article examines the variation of employment density and type over time in the vicinity of public transit nodes in Los Angeles and finds that public transit has been largely ineffective in reducing urban sprawl and car dependence. The empirical data does, however, provide two key lessons to the designers of urban public transit: transit nodes should be placed to encourage high-density multifunctional land use in undeveloped airs, rather than attempting to serve medium-density activity centers distributed according to previous development patterns. If care is not taken, public transit simply becomes a mode of transit parallel to and inferior to cars. I aim to use this article to provide background information on the development path of Los Angeles, California, one of the most car-dependent cities in America. It will also serve as a counterpoint to Clerq and Bertolini's proposal that transportation and land use mutually influence each other, an idea extracted from analysis of two cities which have worked hard to become less car-dependent.

Vale, D. S., Saraiva, M., & Pereira, M. (2016). Active accessibility: A review of operational measures of walking and cycling accessibility. *Journal of Transport and Land Use*, *9*(1), 209–235.

This review describes a number of useful measures of accessibility in cities and evaluates their respectives strengths, shortcomings, and ambiguities. The authors argue that

ultimately, no one of these measures is infallible, so that planners should rely on several complementary measures as figures of merit in city design. The general conclusion of the work is that graph-theoretic measures of accessibility work best: briefly, construct a graph where weighted edges represent transportation links and vertices represent points of interest. I intend to reference this review as I study plans for reducing car dependence in cities - I can use the various measures to evaluate how well these plans accommodate pedestrians and cyclists.

Dixit, B. K., Jose Mathew, Uday (Ed.). (2022). *Electric Discharge Hybrid-Machining Processes: Fundamentals and Applications*. CRC Press. https://doi.org/10.1201/9781003202301

Li, Z., Li, H., Lin, F., Chen, Y., Liu, D., Wang, B., Li, H., & Zhang, Q. (2013). Lifetime investigation and prediction of metallized polypropylene film capacitors. *Microelectronics Reliability*, *53*(12), 1962–1967. https://doi.org/10.1016/j.microrel.2013.06.005

Raza, S., & Nirala, C. K. (2021). Multiphysics simulation of plasma channel formation during micro-electrical discharge machining. *AIP Advances*, *11*(2), 025138. https://doi.org/10.1063/5.0028665

Huzel, D., & Huang, D. (n.d.). *Modern Engineering for Design of Liquid-Propellant Rocket Engines*. American Institute of Aeronautics and Astronautics.