Automating Ports: Technology Frontier and Industry Application by Heidi Wyle and Prof. Daniela Rus, 02/21/25

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Part I. Literature (for further reading about generative ai for autonomous driving)

Xu, Minrui, Dusit Niyato, Junlong Chen, Hongliang Zhang, Jiawen Kang, Zehui Xiong, Shiwen Mao, and Zhu Han. "Generative AI-empowered simulation for autonomous driving in vehicular mixed reality metaverses." *IEEE Journal of Selected Topics in Signal Processing* 17, no. 5 (2023): 1064-1079.

Andreoni, Martin, Willian T. Lunardi, George Lawton, and Shreekant Thakkar. "Enhancing autonomous system security and resilience with generative AI: A comprehensive survey." *IEEE Access* (2024).

Aasi, Erfan, Phat Nguyen, Shiva Sreeram, Guy Rosman, Sertac Karaman, and Daniela Rus. "Generating Out-Of-Distribution Scenarios Using Language Models." *arXiv preprint arXiv:2411.16554* (2024).

Arnelid, Henrik, Edvin Listo Zec, and Nasser Mohammadiha. "Recurrent conditional generative adversarial networks for autonomous driving sensor modelling." In *2019 IEEE Intelligent transportation systems conference (ITSC)*, pp. 1613-1618. IEEE, 2019.

Part II. Recent News

United States Government Accountability Office. (2024). *Port infrastructure: U.S. ports have adopted some automation technologies and report varied effects* (GAO-24-106498). https://www.gao.gov/products/gao-24-106498

EasyMile. (2023, July 5). *Port industry transformation: Embracing autonomy for stability, efficiency, and growth*. EasyMile. https://easymile.com/ez-experts/port-industry-transformation-embracing-autonomy-stability-efficiency-and-growth

Fox Business. (2024, October 4). *'Shark Tank' star says there's 'zero evidence' that automation at ports 'hurts wages at all'*. New York Post. https://nypost.com/2024/10/04/business/kevin-oleary-slams-port-workers-automation-argument/

Part III.

Jinhua questions

Q1: Regarding the transition from research to real-world business, how did you and Daniela restart the collaboration, and what was the ambition behind it?

A1: The idea originated from informal discussions, particularly at Heidi's dining table. Initially, there was interest in a different technology, but after seeing Daniela's autonomy research in action,

the focus shifted to practical implementation. The goal was to make a meaningful impact, leading to Venti's focus on goods movement as a more feasible entry point compared to urban mobility.

Q2: When do you expect full autonomous operations on the wharf side of the port?

A2: Operations have already begun, with full deployment expected by the end of 2025, potentially earlier in Q4.

Q3: How does the system handle extreme weather conditions like heavy rain and frequent lightning in Singapore?

A3: The system is designed to mathematically remove light scattering effects from raindrops, allowing operations even in heavy monsoons. As for lightning, no issues have been reported so far.

Q4: When will we see your autonomous trucks operating in the United States?

A4: Agreements with U.S. railroads are being finalized, with deployment expected by mid-2025.

Audience Questions:

Q1: What level of effort is required to operationalize this technology in a new port? How long would it take to recover the investment compared to human-driven trucks?

A1: The initial development was highly resource-intensive, but transferring the system to a new port requires only about 5% of the original effort. Feature space mapping is automated and quickly refined through annotation. Scaling tools further accelerate deployment in ports with standardized layouts.

Q2: Is real-time connectivity required for autonomous operations, or can the system function independently?

A2: The core autonomy is a closed system with no dependence on cellular or satellite networks. However, communication with remote operators requires proprietary local networks.

Q3: What are the potential employment impacts of automation? How are current port workers being affected?

A3: Some drivers are retrained as remote operators, offering them new job opportunities. Additionally, automation is a gradual process—ports operate hundreds of vehicles, and transitioning to an autonomous fleet takes years, mitigating immediate labor disruptions.

Q4: How does Venti’s system compare to the older Frog Automation system and MIT startup ISEE.ai?

A4: Frog Automation uses embedded infrastructure for guidance rather than full autonomy, making it a different approach. ISEE.ai operates in a similar domain but with fewer operational complexities compared to Venti’s fully developed, large-scale deployments.

Q5: In a disaster scenario, how quickly can the system be stopped, and have there been any major incidents?

A5: The system is designed for immediate "safe stop" upon detecting anomalies, prioritizing safety over continued operation. Over years of real-world use, only one incident occurred that could have been problematic, but the fail-safe mechanisms worked as intended.

Part IV. Summary of Memos.

Themes from Other Memos

1. **Challenges in Achieving True Autonomy:** The complexity of real-world conditions remains a major hurdle for AV development. Heidi Wyle highlighted unexpected challenges like accounting for puddle reflections during Singapore's monsoon season, showing the gap between simulations and real-world performance. The discussion reinforced that controlled environments like ports offer a more feasible near-term application for AVs than urban streets. (Erin, Marina)
2. **Labor and Workforce Implications of Automation:** A recurring theme was the impact of AVs on employment. Venti Technologies' approach—transitioning truck drivers to remote operators—was seen as a model for mitigating job displacement, at least in Singapore. However, concerns persist in other regions, particularly where union regulations resist automation. The discussion raised questions about whether automation can truly maintain or improve labor conditions over the long term. (Ziyan, Donghang, Yuhan, Magdalena)
3. **AI and Self-Driving Systems – Technical Advancements and Safety Considerations:** Daniela Rus described how multimodal AI and innovations like text-to-drive could enable AVs to generalize knowledge beyond their training data. The concept of "BarrierNet" was introduced as a way to mathematically constrain AI decisions to ensure safety, which could be a game-changer for AV trust and reliability. The use of reinforcement learning to optimize driving policies and reduce computational costs was also discussed. (Hanyang, Yuhan, Marina)
4. **Societal and Policy Challenges in AV Adoption:** A contrast emerged between Singapore's rapid AV adoption, where operational agencies are eager to innovate, and the U.S., where government hesitation and lengthy certification processes slow down implementation. The discussion suggested that governments' openness to technology plays a crucial role in determining how quickly AVs will be integrated into mobility systems. (Hanyang)
5. **The Future of Transportation – Efficiency vs. Broader Goals:** AV technology was framed as both a challenge and an opportunity for public transit. On one hand, automation promises efficiency and cost savings. On the other, it disrupts traditional arguments for public transport investments, particularly the idea that transit jobs provide stable, local employment. Some questioned whether transportation should prioritize efficiency over other values such as equity, stability, and social cohesion. (Magdalena)

My Reflection

I am deeply impressed by the work being done by Dr. Heidi Wyle and Prof. Daniela Rus in advancing the operationalization of autonomous vehicle (AV) technology, particularly within structured environments such as ports. Venti Technology's ability to successfully deploy and scale an autonomous fleet in real-world logistics applications is a testament to the rigorous research and

engineering that underpins this field. The discussion highlighted not only the technical milestones achieved but also the practical challenges of integrating AVs into industrial operations.

A key takeaway from the conversation was the structured approach to system deployment, particularly the efficiency of their feature space mapping and adaptation process. The ability to transfer AV systems from one port to another with only a fraction of the original effort (approximately 5%) is an impressive achievement. It underscores the scalability of their AI-driven control systems and the potential for widespread adoption across global supply chains. The strategic use of real-time annotation, automated mapping, and modular autonomy layers is a model for how AI applications can be made adaptable and transferable across different environments.

Another particularly insightful point raised was the consideration of labor market effects and the transition of human workers into new roles as AV technology advances. Rather than outright replacement, retraining programs for drivers to become remote operators demonstrate a sustainable model for technological integration. The broader perspective provided by Prof. Rus also resonated—technological progress has always redefined the nature of work, and the emphasis on collaborative human-machine systems rather than full displacement reflects a more balanced approach to automation.

Additionally, the discussion on AV safety and fail-safe mechanisms provided a nuanced perspective on risk management in autonomous systems. The philosophy of "safe stop" as a default behavior for AVs, ensuring immediate halting upon uncertainty, is a crucial safeguard. This reminded me of past discussions in AV research emphasizing not only learning from failure but also learning from near-miss events. The implementation of robust safety layers, such as the barrier net approach described by Prof. Rus, further strengthens confidence in AV technology by ensuring mathematically provable safety guarantees.

Finally, I found the broader implications of AV-driven infrastructure transformation particularly thought-provoking. The vision of a “dark port” in the coming decades, where fully automated cranes, trucks, and logistics systems operate without human intervention, is a striking illustration of how deeply automation can reshape industries. This discussion reinforced the importance of thoughtful deployment strategies—balancing efficiency gains with social and economic considerations to ensure that technological advancements create value across multiple dimensions.

This exchange provided valuable insights into the intersection of AI, automation, and real-world deployment challenges. It is encouraging to see how research transitions into impactful, scalable solutions, and the discussion serves as an excellent case study of how AI-driven autonomy can be responsibly and effectively implemented in industrial settings.

Part V. Other Information

Other questions: How does the AV industry currently define and categorize "edge cases" in safety-critical scenarios, and is there a structured way to ensure AVs generalize well across rare but dangerous situations? How feasible is the idea of a "dark port" or a fully autonomous supply chain, and what are the major technological, regulatory, and economic hurdles to achieving this vision?