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Developing a Vertically Integrated Project Course to Connect Undergraduates to Graduate Research Projects on Smart Cities Transportation Technology

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Abstract

This academic practice paper describes the design of a new Vertically Integrated Projects course on smart cities at New York University Tandon School of Engineering. It provides an overview of smart cities topics and related project-based design curriculum. The goal of this paper is to make this type of course transferable to other universities. Vertically Integrated Projects, a program based at Georgia Institute of Technology, has expanded to a consortium of 24 universities. The goal of this program is to provide long-term research projects to undergraduate students. Typically, five to thirty students from all grade levels and disciplines work under a faculty advisor on a team project. Sophomore to senior students receive one credit hour per semester and must enroll for at least three consecutive semesters. Requiring multiple semesters helps students to advance the project's complexity and move through ranks of leadership. Teams recruit students at the sophomore level and can have leaders through the graduate level. This research paper documents the preparation of a Vertically Integrated Projects course focused on creating innovative technology for smart cities initiatives. Four sub-teams will be working on different aspects of smart cities: including quantified cities, autonomous vehicles, connected infrastructure, and shared mobility.

Introduction

A new project-based course will form research teams that design and prototype technological innovations to address the needs of smart cities. This technology will be designed with respect to the need for data collection and processing essential to the operation of connected cities. This Vertically Integrated Projects (VIP) course at NYU Tandon School of Engineering will coordinate with the Civil and Urban Engineering (CUE) department and the Center for Urban Science and Progress (CUSP) faculty research projects. The team will research the needs of smart cities related to the technical issues outlined in the Report to the President "Technology and the Future of Cities." New York University was recently awarded the lead role on the University Transportation Center (UTC): Connected Cities for Smart Mobility and Resilient Transportation (C^2SMART). UTCs, as designated by the United States Department of Transportation (USDOT), are supported by a multimillion dollar grant for a five year period. Due to the development of the new UTC, the VIP will have an emphasis on transportation including: cities, vehicles, infrastructure, and transportation users.

The goal of this new course is aligned with the mission of the VIP consortium – to promote innovation through real world projects that connect student to faculty research.[1] The goal of the VIP program at NYU Tandon School of Engineering is to add project-based curriculum throughout the four year undergraduate degree. Increasingly, engineering educators are identifying this project-based curriculum sequence as the cornerstone to capstone courses – first-year intro to engineering and capstone design curriculum. Vertically Integrated Projects allow students to continue developing skills from the first-year engineering design projects: entrepreneurship, innovation, design, teamwork, and leadership. In addition to these professional skills, these Vertically Integrated Project teams will develop hardware, software, data analysis, planning and applications, and project management of their problem definition. The VIP curriculum allows students to develop a well-rounded skill set to take into their careers beyond undergraduate education.[2]

The Vertically Integrated Projects course will consist of four different sub-teams. Each sub-team - cities, vehicles, infrastructure, and transportation users - will design and prototype sensors and technological innovations that address the needs of smart cities. Students will coordinate with the NYU Tandon School of Engineering MakerSpace, incubators – NYU Urban Future Lab, research centers, and several departments. These departments include civil engineering, urban planning, electrical and computer engineering, computer science, and urban informatics. However, student enrollment was not limited to only these majors. Students will determine the most appropriate needs for the university stakeholders and will research, design, and implement internet of things and connected devices technology.

Instruction on technology will include informal workshops on Arduino, Raspberry Pi, sensors, big data, intelligent transportation systems, and quantified cities. The research teams will consult with graduate students and professors with funded research working on urban problems. These products and services will be implemented in the real world through these ongoing projects. Students will also learn about and address several National Academy of Engineering Grand Challenges including a focus on the challenge *to Restore and Improve Urban Infrastructure*. The structure and organization of this course are documented in this paper for other instructors to replicate the best practices for creating this type of curriculum.

Literature Review

New York University was recently added to the Vertically Integrated Projects consortium initiated at Georgia Tech. Vertically Integrated Projects (VIP) are 1 credit hour team research project-based courses that undergraduate students can take for 3 (a minimum requirement) to 6 consecutive semesters. VIP focus on multidisciplinary and multiyear learning that supports long term team building to promote leadership and innovation. VIP are intended to focus on large scale design and discovery projects that support research at the hosting university – smart cities is the perfect fit for NYU because of the number of ongoing projects in urban engineering and informatics fields. The smart cities technology VIP will provide an opportunity to connect and funnel the most talented students into ongoing research and entrepreneurial projects.[3]

Pedagogically, the movement for project-based hands-on coursework in engineering education has been shown to increase student engagement, interest, and creativity.[3,4] A course like this allows students to explore their creativity and apply technical knowledge in a way that traditional coursework cannot. This course will adapt inductive learning techniques by proposing a problem, then providing support for teamwork and cooperative learning through the engineering design process.

Some barriers and concerns include how to fairly treat responsibilities for students at different levels of experience. Previous research found that creating a scaffolding model for students at different years can be a successful approach. [5] This scaffolding model would provide tiered levels of expectations and responsibilities to prepare younger students for more challenging work in the future. Further research found that the lower division students can be seen as a burden to the older students.[6] The best approach to handling these problems is to have a critical mass of upper division students who can evenly distribute the responsibilities of mentoring the lower division students.

Other logistical issues with the creation of VIP teams include enrollment and course credit. Due to the exclusivity of VIP courses there can be concern for too many students to be interested.[7] However, this can be useful to the creation of a productive VIP team, since it is critical to select a core group of talented students on each team that are passionate about the project.[8] These students tend to take the leadership roles on the teams. Course credit for degrees is a common coordination issue because different departments react differently to the incorporation of VIP project-based courses.[8] The VIP program at NYU is currently exploring opportunities for all departments to accept VIP credit for their degree programs.

Outcomes of project-based courses and VIP programs have shown positive improvements in the areas of multiple ABET accreditation requirement and engineering education goals. The primary objectives addressed by VIP curriculum are multidisciplinary teamwork skills, an ability to apply technical knowledge to problem solving, a connection between societal and consumer needs for engineering, tools for effective communication to a variety of audiences, and an understanding of the design process from start to finish.[7,9]

Methods

Recruitment for the course included posting flyers, an info session, and university marketing emails and Twitter posts. A total of 47 students applied and 33 students will be participating. 20 of the 33 participating students are enrolled for course credit – those that have sophomore through senior status. First-year students do not receive credit, but can voluntarily participate in the course so that they may enroll in the sophomore year. Although, they are not directly responsible for completing assignments they can demonstrate their motivation to be part of the course by completing the same tasks as enrolled students. The graduate students do not receive credit, but instead receive the benefit of having undergraduate students who can support their research projects. Georgia Tech recommends that a maximum of 30 students enroll, but since this is a new course, the enrollment was capped at 20. However, the course is open for expansion. The 20 students include an equal distribution of relevant majors and years. Table 1 shows the breakdown of majors and Table 2 shows the breakdown of years.

Table 1: VIP Smart Cities Technology Participation by Major

Major	Number of Students
Business and Technology Management	1
Chemical and Biomolecular Engineering	3
Civil and Urban Engineering	6
Computer Engineering	3
Computer Science	6
Urban Informatics	3
Electrical Engineering	4
Mechanical and Aerospace Engineering	3
Physics and Mathematics	1
Sustainable Urban Environments	3
Total	**33**

Table 2: VIP Smart Cities Technology Participation by Year

Year	Number of Students
First-Year	7
Sophomore	6
Junior	10
Senior	4
Master's	2
PhD	4
Total	**33**

The resources available for this project include the research groups at the NYU Tandon School of Engineering working on smart cities related projects. These resources include experts, facilities, research groups, funded projects, and curriculum. This VIP will be housed in the Civil and Urban Engineering department. Professors in transportation, environmental, and urban infrastructure engineering will provide expert seminars on smart cities topics. In addition to the civil department, several other disciplines that have a stake in smart cities will be asked to lecture for the course, including: computer engineering, computer science, electrical engineering, and chemical engineering. This collaboration across disciplines will provide a variety of perspectives on the research projects like cybersecurity and big data principles.

Several other non-engineering entities will play a role in shaping the smart cities VIP course. The NYU Center for Urban Science and Progress will play a large role in connecting graduate research with undergraduate research in the VIP. Some students enrolled in the VIP Smart Cities Technology course are teaching assistants for the NYU K-12 summer STEM program on the

Science of Smart Cities. Incubators on campus that work with several companies on smart cities related topics will be connected to the VIP teams. A new MakerSpace at NYU will provide the equipment and resources necessary to carry out the research projects for the course. Each of these groups will support the progress of the sub-teams in the smart cities VIP, and the VIP will help to coordinate efforts and connect students to these programs.

The topics listed in Table 3 outline the smart cities subjects that will be covered in the course through instruction, guest speakers, and individualized research. In addition to these proposed topics, industry experts will be invited to share their experience and perspective on the projects.

Table 3: Instruction and Expert Speakers Planned Smart Cities Topics

Universal Topics	*Sub-team Specific Topics*
Smart Cities Initiatives	Quantified Communities
Big Data	Intelligent Transportation Systems
Making and the Internet of Things	Connected Infrastructure
Cybersecurity for Smart Cities	Connected Mobility
Smart Cities Innovation	Sustainable Environments

The course meeting times are based on the schedules of the students participating in each sub-team. An initial kick-off meeting was used to introduce each student to the different sub-teams. They were then asked to select their top two choices, which were used to generate the sub-team rosters. Consideration was made for an equal distribution of years as well as major specific to the sub-team's needs. Google Drive and Google Docs was used for maintaining a VIP notebook, which was a documentation of their individual work that was used to assess their progress. In addition to the VIP notebook, a final report, final presentation, peer-evaluations, and self-evaluations make up student's grades for the course. The Slack team communication platform was used for communications with the VIP team and sub-teams. Slack has a channel feature that allows for a communication thread on specific sub-teams that supports the structure of the VIP sub-teams.

Sub-Team Projects

The current research focuses have been selected based on sub-teams interests and ongoing research efforts and include: 1) quantified communities, 2) autonomous vehicles, 3) connected infrastructure, and 4) shared mobility.

1. Constantine Kontokosta, an urban informatics professor who is a co-advisor for the VIP course, has a long term quantified communities research project using Arduino based electronics for environmental sensing and data collection. This team is working on recreating the devices that have already been deployed in the city and reverse engineering

the hardware and software to improve the device. In particular, the team will investigate the air pollution sensor currently used in the device.

2. A new project in the University Transportation Center lead by Kaan Ozbay, a transportation engineering professor who is also a co-advisor for the VIP course, is testing the feasibility of adding connected, autonomous features to vehicles in the New York and New Jersey Port Authority bus system. Devices on the buses and surrounding vehicles will improve data collection and the efficiency of public transportation services.
3. Another new project by Joseph Chow, another transportation engineering professor in the UTC and the third co-advisor for the VIP course, is investigating electric vehicle infrastructure and testing smart, connected devices for electric vehicles charging stations for potential use in a car-share network for Brooklyn. This VIP sub-team will research methods for making the rapidly growing electric vehicle infrastructure more intelligent and user-friendly.
4. Joseph Chow is also establishing a connection between NYU and one of the United States Department of Transportation (USDOT) approved autonomous vehicles test sites. This test site is looking into the best method for using shared autonomous vehicles to improve first and last mile transit trips on an overcrowded commuter rail line. The project will focus on user interaction with the mobile application based system and the algorithm used for ride-share applications.

The inspiration for these topics came from a presentation by Regina Hopper, the CEO of the Intelligent Transportation Society of America, at the 2017 Transportation Research Board Annual Meeting. She outlined the three primary areas of smart cities innovation being: vehicles, infrastructure, and transportation users. In addition to these three transportation focused areas the fourth area of cities was included to maintain a broader view of the smart cities initiative. Since the USDOT initiated the smart cities competition, much of the funding and focus has been on transportation. However, areas including food access, water quality, building information modeling, and energy usage may still be incorporated into the course.

The sub-team titles: cities, vehicles, infrastructure, and transportation users, bolded in the titles below, are intentionally broad so that the sub-teams can adapt to new aspects of the projects and specific problems in each semester. The VIP Smart Cities Technologies sub-teams can evolve and become more complex over time as the project needs change.

Quantified ***Cities***

Urbanization has been the impetus behind the investment and focus on smart cities developments. Figure 1, taken from Beyond Traffic[10] – a USDOT research report summarizing transportation trends and needs through 2045, reveals the increase in urban populations in the United States. In particular, it is essential that engineers and scientists monitor the impact of growing urban populations on the environment. This means quantifying and analyzing air pollution, light pollution, noise pollution, and heat island effects. An ongoing project that investigates these environmental issues at four different neighborhoods in New York City is deploying devices that collects data to understand what differences exist between communities.

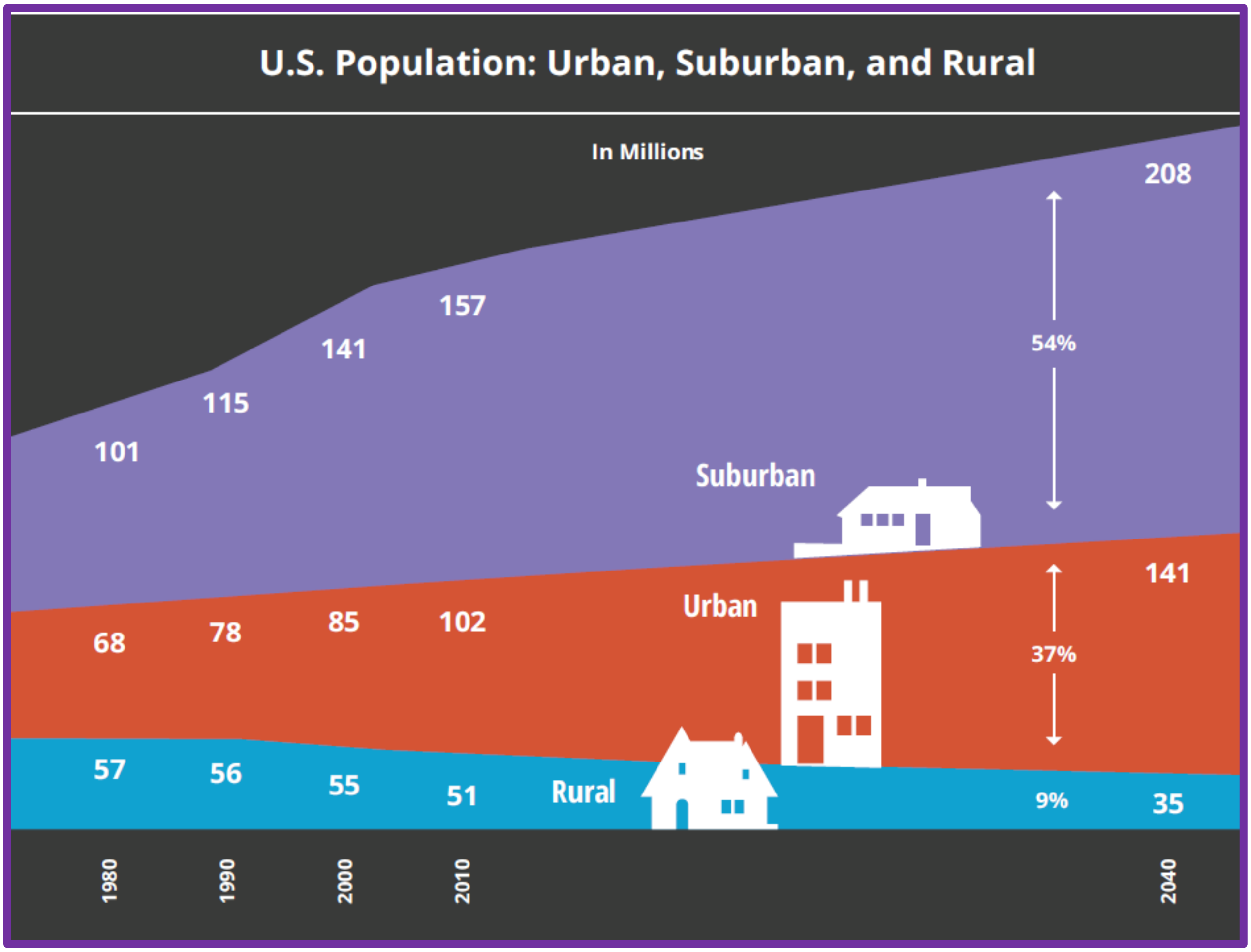

Figure 1: Growth in Urbanization Needs Research Into Environmental Impacts[10]

Students on the quantified cities sub-team will work on testing, analyzing, building, and innovating the rapid prototyping electronics and sensors used for this project. The goal of the sub-team is to provide technical support for the graduate researchers and deliver feedback on how to improve the devices being used. The sub-team will also investigate data analysis techniques and applications of the information derived from the study.

*Autonomous **Vehicles***

The connected vehicles project stems from the USDOT pilot program deployed in three different cities. Transportation agencies at all levels across the countries are incorporating lessons learned from the connected vehicles pilot program into new projects with the goal of improving the efficiency of moving goods and people through urban areas. Figure 2 represents the three initial locations supported by the USDOT.

Figure 2: The First Three USDOT Connected Vehicles Pilot Projects[11]

The local port authority is interested in developing connected, autonomous technologies on their bus system to improve operations without the need for expensive infrastructure projects. This VIP sub-team will look into the design of connected and autonomous vehicles, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication technologies, data analysis, and planning applications.

Connected ***Infrastructure***

Experts predict that autonomous vehicle fleets will be predominately electrically powered.[10] The expansion of electric vehicle charging infrastructure has already begun. As this infrastructure continues to grow, the connectivity and intelligence of charging station networks will be essential to vehicle owners and autonomous fleet operators.

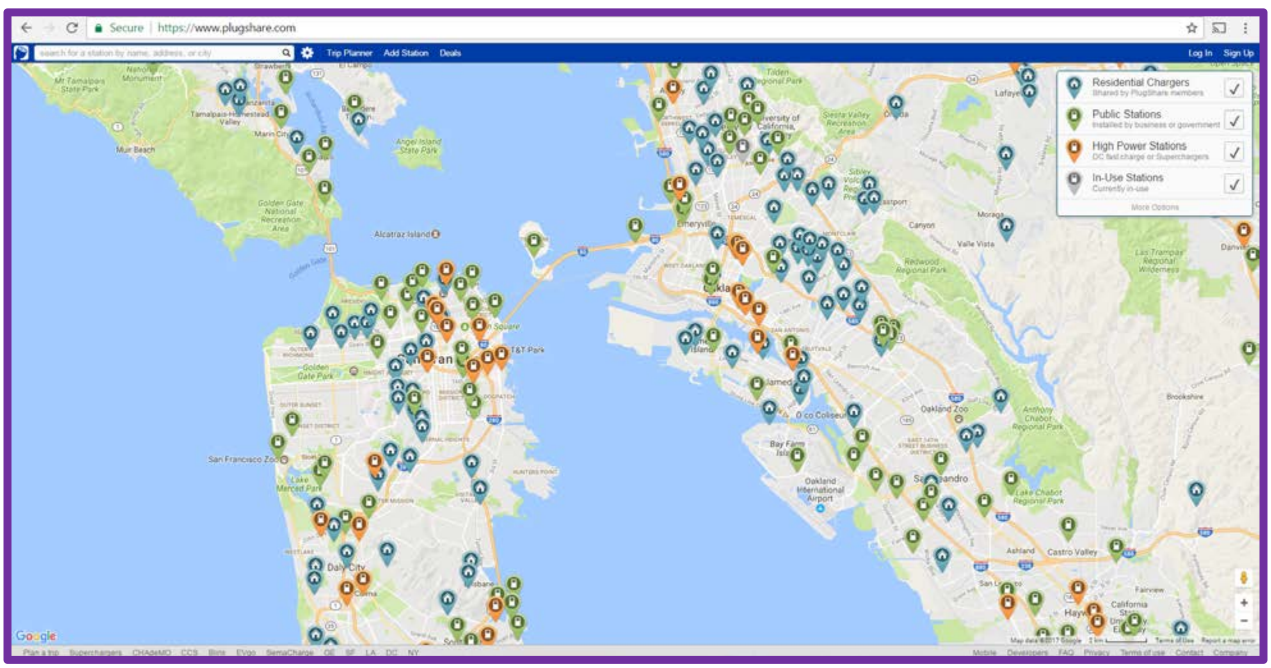

Figure 3: Electric Vehicle Charging Station Web-Based Mapping Platform, PlugShare[12]

The infrastructure sub-team will investigate types of electric vehicle charging, compatibility of infrastructure and vehicles, and smart connections with charging stations. Car-share operations in Brooklyn will be analyzed to determine how an electric vehicle fleet could be optimized. Platforms like PlugShare will be investigated to determine what the most appropriate solution is for the future of electric vehicle infrastructure. The goal will be to increase parking efficiency and reduce traffic caused by the search for available parking spaces in urban areas.

Shared Mobility ***Transportation Users***

Shared mobility changed in 2009 when Uber was founded. Planners expect autonomous, electric vehicle fleets to be primarily shared-use economies. This is due to the high cost of owning autonomous vehicles coupled with the energy and economic benefits of reducing the idle time vehicles spend in parking spaces. The USDOT has approved the following ten locations for autonomous vehicle testing[13]:

1. City of Pittsburgh and the Thomas D. Larson Pennsylvania Transportation Institute
2. Texas AV Proving Grounds Partnership
3. U.S. Army Aberdeen Test Center
4. American Center for Mobility (ACM) at Willow Run
5. Contra Costa Transportation Authority (CCTA) & GoMentum Station
6. San Diego Association of Governments
7. Iowa City Area Development Group
8. University of Wisconsin-Madison
9. Central Florida Automated Vehicle Partners
10. North Carolina Turnpike Authority

This transportation user VIP sub-team will look into creating a shared autonomous vehicle (SAV) service that connects commuters to rail transit. Focusing on the first and last mile trips to the transit station will alleviate overcrowded parking at transit hubs. The sub-team will perform user experience surveys, analyze data and logistical needs, and develop a mobile application algorithm to test the feasibility of a SAV system.

Conclusion and Recommendations

The Smart Cities Technology Vertically Integrated Project is bringing together several missions including those of the American Society for Engineeering Education, the National Academy of Engineers, and New York University Tandon School of Engineering. By connecting undergraduate curriculum with graduate research programs, industry partners, and real ongoing projects students can become more engaged in their education. It also gives students a chance to study in a non-traditional class environment – where lectures, note-taking, quizzes, exams, and homework problems are replaced by team search and discovery projects. The smart cities focus offers students a true multidisciplinary set of problems to explore. A scaffolding structure of multiyear participants allows students to work at their own level, while pushing those with experience to positions of leadership.

Further research will be documented in a follow up paper that assesses the impacts of this course on students and the success of the student's learning objectives. Assessment of the course will include student perceptions of the projects and opinions of the course. Future efforts will focus on developing effective assessment techniques for a non-traditional project-based course in the Vertically Integrated Projects program. The course instructor hopes to provide quantitative evidence of the effectiveness of the course and the impact on student learning.

Typical barriers associated with faculty and industry involvement are overcome through the primary instructor being a non-tenure track, full-time faculty member. The instructor's title, Industry Assistant Professor, is similar to Professor of Practice or Teaching Professor and therefore can focus on curriculum development and the undergraduate education experience. His affiliation with the professors currently working on funded research allow for the coordination between the research projects, the University Transportation Center, and industry partners.

There is a potential for this VIP to support students outside the course. The instructor and co-advisors hope the VIP can support the development of a National Science Foundation Research Experience for Undergraduates (REU). Vertically Integrated Projects often lend themselves to undergraduate research and internship opportunities, which are being explored by the course instructor and co-advisors. One student enrolled in the course will be working as a paid undergraduate researcher this summer.

Figure 4 shows the initial progress made by the sub-teams in their first 1 credit hour semester. The exhibit was interactive and was their final presentation for the semester. The exhibit includes:

1) Cities: An Arduino based air quality sensor that could track PM2.5 particulate matter in real time. A soldering iron was used to demonstrate a real time plotting of the air quality data.
2) Vehicles: An Arduino "hacked" remote control car that used a LIDAR sensor to cut power to the motors when the car was at risk of colliding with an object.
3) Infrastructure: A solar panel phone charger that modeled an electric vehicle charging station. Guests could charge their phone and monitor the current and voltage output.
4) Transportation Users: A mobile application that allows users to input an origin and destination, then visualize a vehicle traveling in real time with the Google Maps API shortest route.

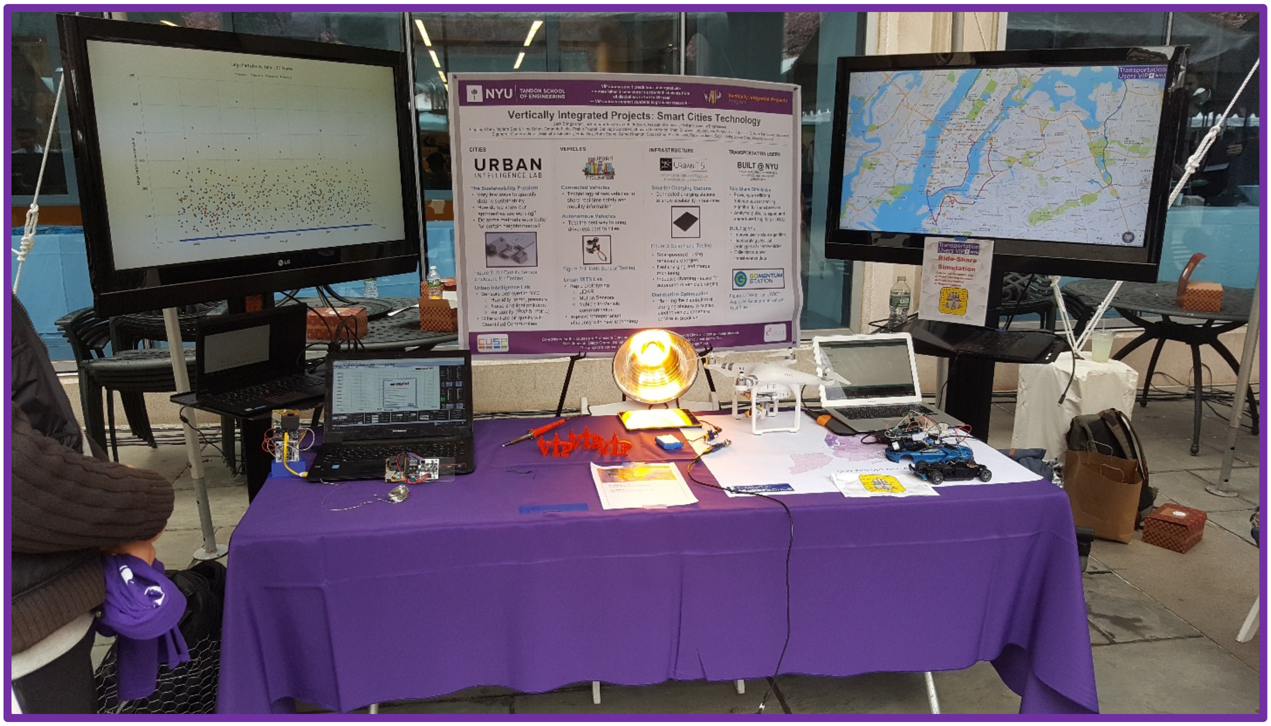

Figure 4: Vertically Integrated Projects Smart Cities Technology Exhibit New York University Tandon School of Engineering Research Expo 2017

The goals of this VIP Smart Cities Technology course address three major initiatives: 1) the president of New York University's push for smart cities research projects and activity-based curriculum, 2) the call for the President of the United States to create new technology for cities, and 3) the National Academy of Engineering Grand Challenges - to Restore and Improve Urban Infrastructure.

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