FLORIDA STATE UNIVERSITY

FAMU-FSU COLLEGE OF ENGINEERING

DEVELOPMENT OF A DISCRETE EVENT SIMULATION MODEL FOR THE BUS SYSTEM AT THE FAMU-FSU COLLEGE OF ENGINEERING

By

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I want to dedicate this work to my parents, Chandana and Shankar, my brother Abishek, family members, and my dear friends Akshay and Sainath for all the support, love, and being there for me anytime.

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ABSTRACT

Mobility and access are the two essential criteria for evaluating any mode of transportation. A private vehicle comes at the top when we think about mobility and access. But an increase in the utilization of private vehicles has many drawbacks, such as an increase in traffic congestion, air pollution, fuel consumption, etc., which also affect public health. It is essential to provide an efficient public transportation system to minimize these effects, especially in urban areas. Bus transportation is one of the significant modes of transport with a good capacity compared to private vehicles, but there is a need to compromise for access. Bus transportation is an essential mode of transportation for students, faculty, and staff, especially to travel to, around, and from school and work. It is always necessary that buses reach the stop on time and service all the passengers waiting at the stop, considering peak hour demands and potential uncertainties in transportation time. To achieve such an objective, it is essential to improve the serviceability of the bus transportation network.

This study focuses on improving the operations of the Florida State University (FSU) campus bus service, Seminole Express, for the "INNOVATION" bus route in Tallahassee, Florida (USA). The "INNOVATION" bus route service connects the main FSU campus with the FAMU-FSU College of Engineering and is heavily used by the FSU students. A simulation model is built using the FlexSim simulation software to emulate the operations of the "INNOVATION" bus route service to determine the required number of buses to be deployed. An excessive number of buses may increase the operational costs and idling time. In the meantime, an insufficient number of buses will cause significant waiting times at the bus stop, which are not desirable as some students may be late for their classes. The developed simulation

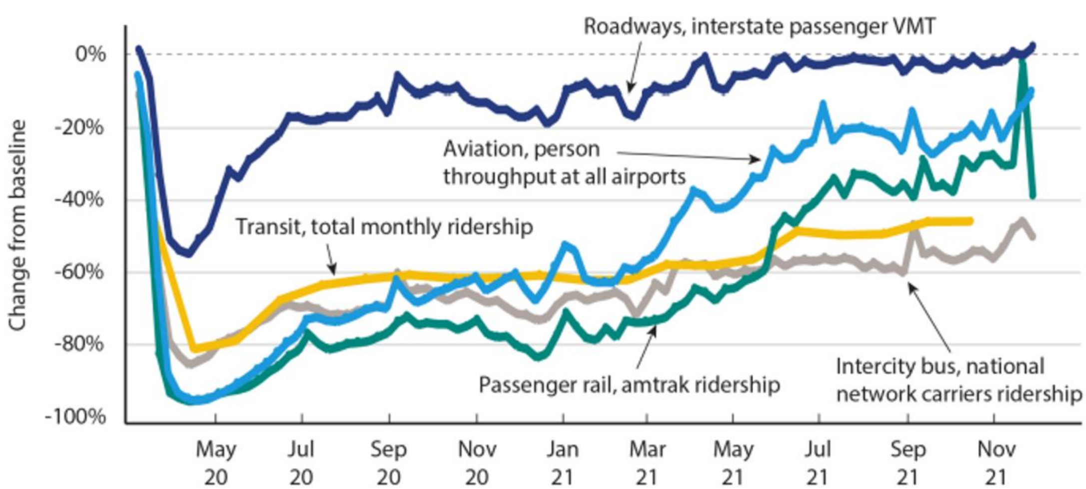
model will assist with effectively planning the bus route connecting the main FSU campus with the FAMU-FSU College of Engineering by providing solutions with adequate waiting time and operational costs.

CHAPTER 1
INTRODUCTION

1.1. Current Tendencies in Passenger and Freight Transport

The role of passenger and freight transportation network across the globe cannot be overestimated (Abioye et al., 2019; Godil et al., 2020; Rahimi et al., 2021; Pasha et al., 2021a,b; Zhang et al., 2021; da Silva et al., 2022). The transportation networks serve people and freight to move from place to place. It is a fundamental requirement and part of the economic and social life. People require transportation to travel every day to work or other activities. Especially with people moving from rural areas to urban regions for education, employment, and a better lifestyle, the demand for the basic transportation infrastructure is enormous. Transport demand will nearly double by 2050 compared to the demand in 2015 (ITF, 2021). The population density in the urban areas and metropolitan cities is getting higher than ever. More population means there is a demand for more facilities like infrastructure for transportation, employment, and recreation. A smooth and efficient transport is required for the movement of people and goods. Around 40% of the greenhouse gas emissions from passenger transport are generated in urban areas (ITF, 2021). Quality of transportation services and standards of living correlate with each other; for example, metropolitan areas provide various means of transportation to travel for work, food, or leisure. While rural areas have very few transportation means, they mainly depend on their vehicles and limited public transportation.

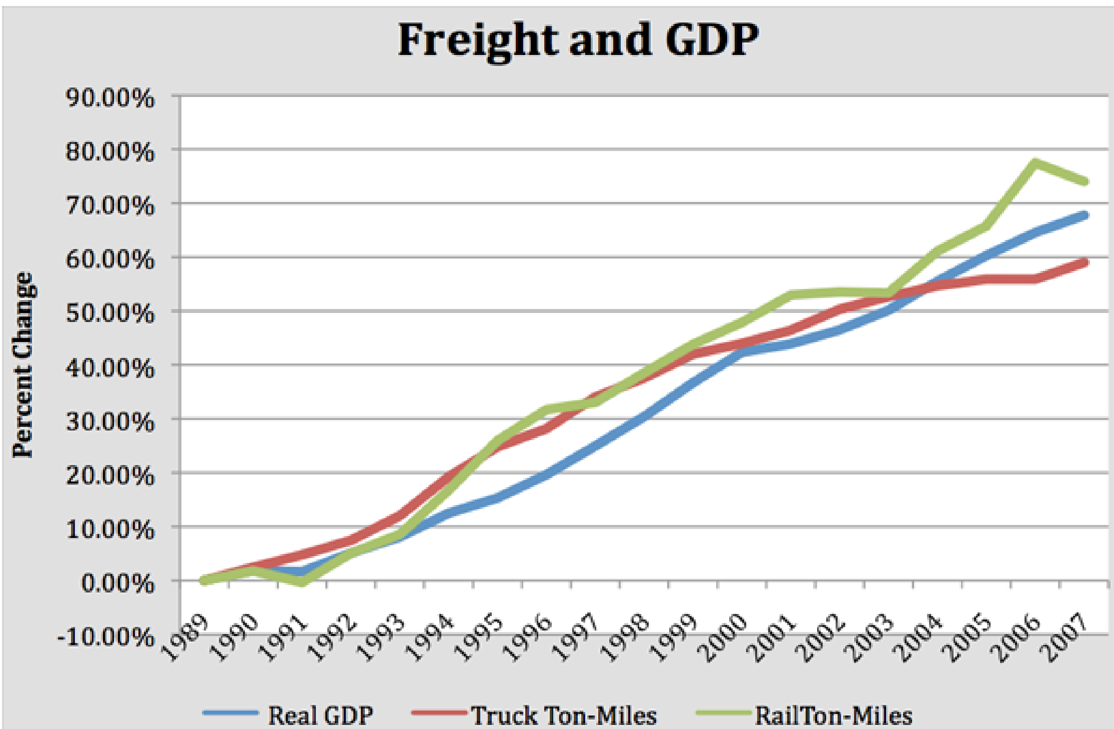
There is a misalignment between initiatives made by individuals and countries for climate change with the income levels. Societies with the lowest economic performance contribute the least to climate change, but they also suffer the most (ITF, 2021). Countries with lower income usually depend on the public transport service provided to them, and developing countries need to focus more on providing mass passenger transport. Commuting in personal vehicles, public transportation, shared-ride services, bicycles, and walking are examples of passenger transportation (Dean and Kockelman, 2021; Le Hong and Zimmerman, 2021; Twisk et al., 2021; Ribeiro et al., 2022). Long-distance trips by private vehicles, commercial airlines, trains, and intercity bus carriers are also examples of passenger transportation. Over the past few decades, the demand for passenger and freight transport has been increasing (Dulebenets, 2018a-d; Abioye et al., 2021). However, the COVID-19 pandemic affected the transportation demand patterns across the globe (Chen et al., 2022; Elmi et al., 2022; Moosavi et al., 2022; Pasha et al., 2022a,b).



Source: U.S. Department of Transportation

Figure 1 Percent Change in Passenger Travel from 2019 by Mode in the United States.

Figure 1 shows the percent change in passenger travel by various modes from 2019 in the United States (U.S.). It could be noticed that the most significant effects on public transportation occurred at the beginning of the pandemic, and the recovery to the pre-pandemic conditions took a significant amount of time. Policies to reduce unnecessary travel and shorten journeys are critical, but they must also ensure adequate access. Integrating land use and transport planning would minimize the trips and reduce emissions. Restricting car usage in the urban space and private car users' need to pay the actual urban car traffic costs and parking costs might reduce urban traffic problems as well. Improvising the public transport infrastructure and providing shared mobility services can reduce the usage of private vehicles (ITF, 2021).



Source: The Economic Importance of Freight – Mid-America Freight Coalition (midamericafreight.org)
Figure 2 Percent Change in Freight Ton-miles and GDP.

The global economy relies heavily on freight movements (Daramola, 2022; Ghisolfi et al., 2022; Gonzalez et al., 2022; Trent and Joubert, 2022). Figure 2 shows the percent change in freight ton-miles and gross domestic product (GDP) from 1989 to 2007 and clearly indicates an increasing trend. Freight transportation is the essential component of the supply chain of goods.

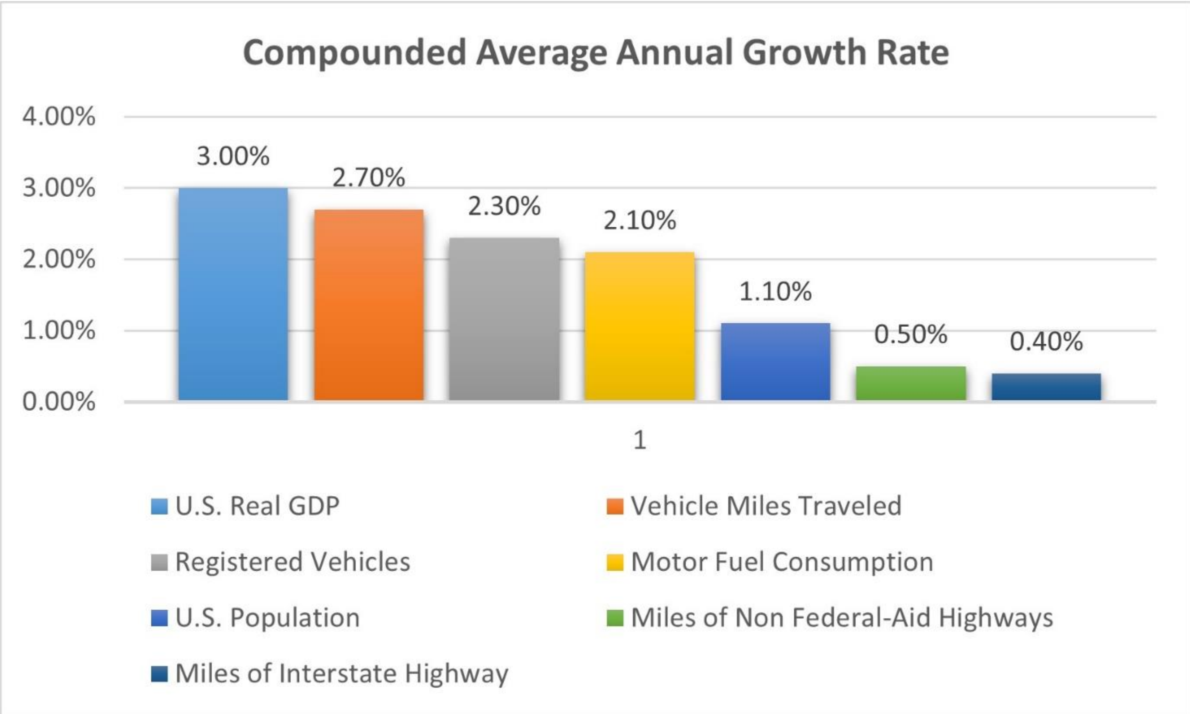
Every day, freight volumes with the overall values of billions of U.S. dollars move worldwide. Necessities, such as food, fuel, and cars, are imported and exported over land, sea, and air. Each product we consume daily must travel from its origin to its destination. This is because all natural resources are not available everywhere. Each finished product that a consumer consumes travels through a supply chain network. Growing/extracting the raw material to storing, manufacturing, packing, distributing, and delivering it to the consumer requires a sophisticated supply chain and freight distribution network. Whether by road or rail, by water or by air, each mode of transport has its benefits and complements each other. Intermodal passenger and intermodal freight transport, which are the combination of multiple modes of transportation, were introduced to increase public transport use and reduce freight costs and handling time.

Ton-miles of freight traveled and diesel fuel consumption are closely correlated with the change in GDP, and around 10 percent of the U.S. economy is accounted for by the transportation sector (Mid-America Freight Coalition, 2022). It was found that more than 70% of the ton-miles of freight activities are dominated by maritime transport, and about 65% of surface freight transport is dominated by road freight transportation (ITF, 2021). Increased population and consumption growth, international trade growth, and modern supply chain management are some of the factors for increased freight transport (Mid-America Freight Coalition, 2022). Automation, digitalization, e-commerce, collaboration between freight companies, and optimized operations planning can be some of the initiatives to serve the freight demand and provide timely deliveries to customers (Dulebenets et al., 2017; Dulebenets, 2019a,b; ITF, 2021; Fathollahi-Fard et al., 2022; Kavoosi et al., 2019a,b; Kavoosi et al., 2020a,b; Pasha et al., 2020a-c). A number of studies have been conducted over the past years aiming to show how proper scheduling of operations could provide additional benefits to the relevant stakeholders in the transportation industry (Corsten et al., 2019; Selma et al., 2019; Tadumadze et al., 2019; Theophilus et al., 2019; Gholizadeh et al., 2021; Theophilus et al., 2021). The following sections of the manuscript will elaborate more regarding the basic features of the main transportation modes (i.e., road, rail, water, and air).

1.1.1. Road transport

Roadways are a significant mode of surface transportation (Titiloye et al., 2021; Plötz, 2022; Hussain, 2022; Omonov, 2022; Uliasz-Misiak et al., 2022). France was the first country to formally establish a national road transportation system in the 18th century (Rodrigue et al., 2017). Road transport is the most preferred means of transport for mobility and access worldwide. It is an effective means of passenger transportation in the United States as well. Road infrastructures are primarily provided to the public by the government, and they are expensive to provide. Constructing a simple two-way lane could cost around 2 to 3 million dollars per kilometer. The public sector gets the funds by registering vehicles, gas taxes, sales taxes, tolls, insurance, and indirect income from traffic violation tickets. Most likely, roads will be funded by the public sector even in the future because they are not so economically profitable but need to be provided to serve the population (Rodrigue et al., 2017).

Most of the passenger travel in the United States is through highways. Around 5.6 trillion passenger miles and 54 billion passenger miles in public transport have been recorded in a pre-pandemic year (ITF, 2021). Over the past 50 years, the urban population has increased, and about 20 percent of the road network serves 60 to 80 percent of the traffic (Rodrigue et al., 2017). Figure 3 shows the average annual growth rate in the major economic and transportation indicators from 1956 to 2021. From the figure, we can say that the transportation sector is a significant driving factor for growth in the economy of the United States, based on the GDP values and vehicle miles traveled. The road transportation plays as an important means to serve the growing population.



Note: This figure was prepared based on the data reported by the U.S. Department of Transportation

Figure 3 Average Annual Growth Rate in Major Economic and Transportation Indicators, 1956-2021.

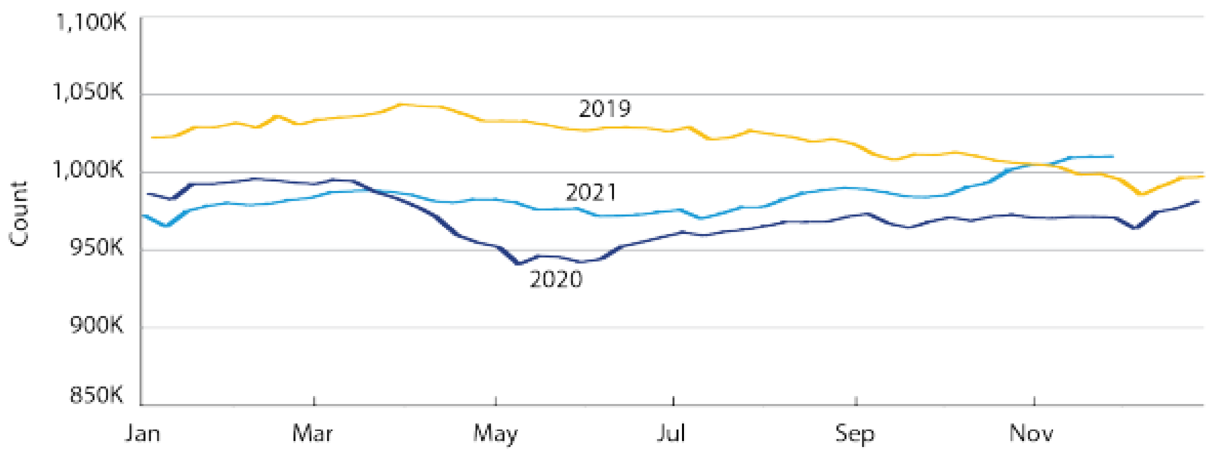
The American Interstate Highway System (IHS), which links all major American cities from coast to coast, is one of the exceptional achievements in the modern era (Rodrigue et al., 2017). The development of IHS is a major driving factor that led to the growth of the American economy by 340 percent, from $3 trillion to $19 trillion over the past 65 years (ARTBA, 2021).

Even though the 48,000-mile IHS accounts for only 1 percent of the total roadway miles, around 75 percent of the freight trucks and 26 percent of the vehicle miles traveled were carried out on the interstate highways (ARTBA, 2021).

1.1.2. Rail transport

Railway systems were first widely implemented in Europe, North America, and Japan. Such a pattern can be explained by the essential role of rail transport in the economic development (Cartenì et al., 2021; Kuriakose and Bhattacharjee, 2021; Pietrzak et al., 2021; Licciardello and Ricci, 2022). Because of its reliability and consistency with schedules, it was incorporated into the planning, production, and distribution of different goods (Rodrigue et al., 2017). The United States freight network, which runs about 140,000 route miles, is considered as one of the world's largest, safest, and cost-efficient freight networks. Private organizations spend around $25 billion annually on freight rail maintenance to improve network capacities (Federal Railroad Administration, 2020). About 48% of the consumer goods and 52% of bulk commodities are shipped by rail freight. Goods can be transferred from rail to trucks, planes, vessels, and vice versa (Association of American Railroads, 2017).

There is an increase in using containers on flat cars (COFC), which eases the adoption of intermodal transportation for cargo transport. Double stack rail technology, effective for long distances, has lower transport costs, and a fully double-stacked train carries up to 300 containers (Rodrigue et al., 2017). Companies invest in improving overhead clearance to accommodate double-stack rails, improve capacity, and reduce transport costs, especially for long distances. Figure 4 shows the amount of cargo on railcars for 2019, 2020, and 2021, where it can be observed that the amount of cargo was substantial for all the considered years. Furthermore, substantial funds have been invested over the years into rail safety improvements, aiming to prevent potential accidents (Abioye et al., 2020; Singh et al., 2021; Pasha et al., 2022c; Singh et al., 2022).



Source: U.S. Surface Transportation Board (STB)
Figure 4 Rail Carloads 2019 - 2021.

1.1.3. Water transport

A port is a gateway that serves maritime transportation to load and unload cargo containers. Maritime transportation is critical for numerous countries, as substantial volumes of cargo around the globe are transported by vessels sailing at sea (Amin et al., 2021; Özer et al., 2021; Wan et al., 2021; Wang et al., 2021). Ships have initially been the efficient means of transportation before the industrial revolution for transporting goods. Earlier, to discharge the goods, ships used to stay several weeks at a berth, allowing for continuous loading or unloading of the cargo (Rodrigue et al., 2017). Around 62,000 vessels were docked at the U.S. seaports in 2010, which carry goods worldwide. China and Japan are the two major maritime trading partners for the United States; about $271 billion and 92 billion dollars of cargoes by value are imported by vessels, respectively. Mineral oil, fuel, bitumen, and mineral wax were the top value imports by vessels for the year of 2011 (Chambers and Liu, 2013).

Containerization is one of the greatest innovations in the modern era of freight transportation (Rodrigue et al., 2017; Delfim et al., 2021; Styliadis and Chlomoudis, 2021; Varnavskii, 2021). Containers can be discharged and loaded into trucks or rail for overland transportation from vessels. Efficient handling and the ability to handle various types of cargo led to the growth of maritime transport. About 69.6% of ton-miles shipped in 2005 were accounted for by bulk freight, and there is an increasing trend in the share of break-bulk mainly because of the containerization (Rodrigue et al., 2017). Even though the entry costs are higher, maritime transport is the cheapest per unit across all transport modes. Carriers are responsible for establishing and maintaining profitable routes in a competitive economy. Frequency of service, fleet and vessel size, number of port calls, fleet deployment, and vessel scheduling are the major decision level problems that need to be addressed to maintain profits in the competitive environment (Dulebenets, 2016; Rodrigue et al., 2017; Dulebenets et al., 2021).

1.1.4. Air transport

Air transport is becoming very common and dominant in domestic and international travel (Cai et al., 2021; Chiambaretto et al., 2021; Mężyk, 2021; Law et al., 2022). It is the most preferred mode of travel for longer distances, and it is generally used to transport time-sensitive products. Around 4 billion passengers traveled globally, and airlines collectively earned about $30 billion worldwide in 2018. Air transport supports the economy through lower-cost connectivity between cities for tourism and trade. International travelers spent about 850 billion dollars by air in 2018, and about 33% of the world trade by value was also transported through air (IATA, 2022).

Air transport also has a significant contribution of about 4.2% of GDP to the United States economy. This sector provides 6.5 million jobs and around $779 billion in contributions by value to the GDP (IATA, 2022). Speedy connections between the cities through air transport allow for the flow of goods, investments, and people necessary for economic growth. It was estimated that around 1.4 million people were airborne on an airline worldwide at any moment. Most air cargo is in the belly hold of passenger aircraft, and the emergence of separate air cargo airlines provides scheduled services for transport. Airfreight integrators that integrate air and ground freight provide ease to transfer cargo between modes for seamless door-to-door deliveries (Rodrigue et al., 2017).

Table 1 Change in Air Transport Statistics in 2020 and 2021.

	February 2021 - January 2022			February 2020 - January 2021		
System	Scheduled	Non-Scheduled	Total	Scheduled	Non-Scheduled	Total
Revenue Passenger Enplanements (000)	690,660	3,945	694,605	326,250	2,813	329,063
Revenue Passenger Miles (000)	716,530,502	4,698,455	721,228,957	324,931,142	3,995,556	328,926,698
Available Seat Miles (000)	962,816,565	12,396,068	975,212,633	597,377,999	11,160,952	608,538,951
Passenger Load Factor (%)	74.42	37.90	73.95	54.39	35.79	54.05
Revenue Freight Ton Miles (000)	6,023,498	331	6,354,179	3,564,717	337,647	3,902,364
Total Revenue Ton Miles (000)	78,283,884	803,004	79,086,888	36,597,320	758,396	37,355,716
Available Ton Miles (000)	132,211,783	2,839,198	135,050,981	81,984,428	3,476,939	85,461,367
Ton Miles Load Factor (%)	59.21	28.28	58.56	44.63	21.81	43.71
Revenue Departures Performed	7,498,173	182,216	7,680,389	5,200,052	119,098	5,319,150
Revenue Aircraft Miles Flown (000)	6,178,297	103,345	6,281,642	3,997,993	76,266	4,074,199
Revenue Aircraft Hours (Airborne)	14,283,426	269,631	14,553,057	9,375,424	196,491	9,571,915

Note: This table was prepared based on the data reported by the U.S. Bureau of Transportation Statistics

The United States is ranked as 122nd for visa openness according to the World Economic Forum's Travel and Tourism. Out of 124 countries, the United States is ranked as 15th for the facilitation of air cargo through customs and border regulations (IATA, 2022). **Table 1** compares passenger and freight transport indicators for 2020 and 2021, where the increases in the total revenue passenger enplanements, revenue freight ton miles, total revenue ton miles, and passenger load factor can be clearly observed.

Table 2 Modes of Transportation to Work in the United States for 2019.

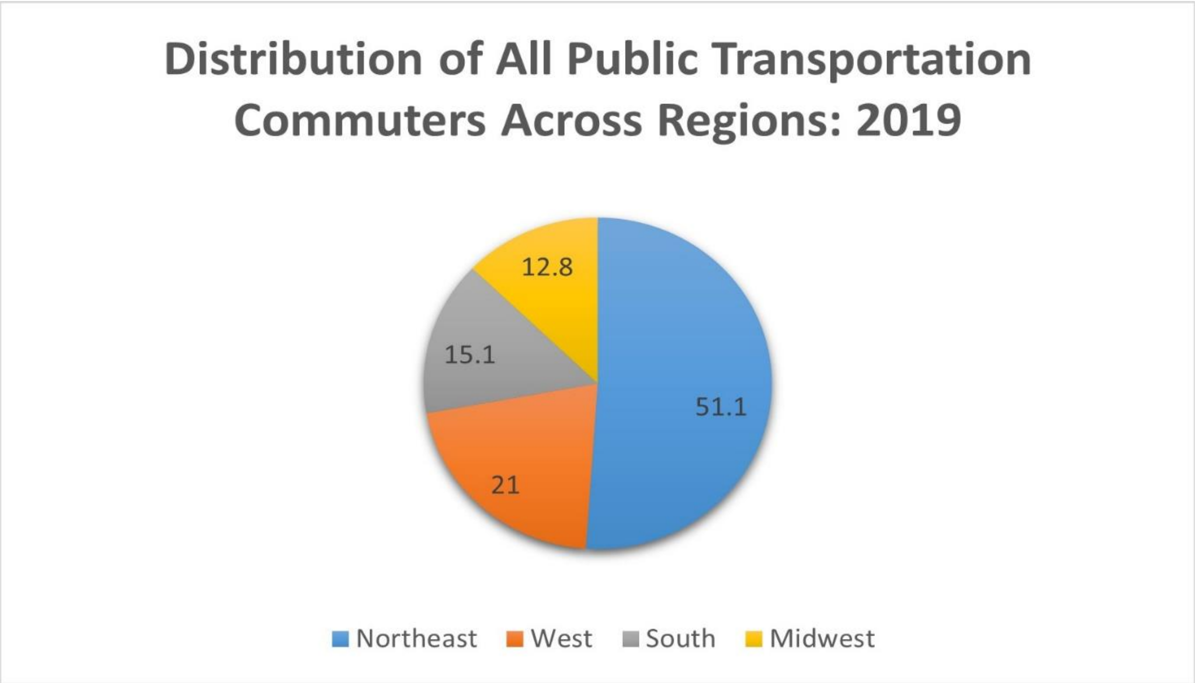
Means of Transportation	Number	Margin of error(+/-)	Percent	Margin of error(+/-)
Total	**156,941,346**	**161,399**	**100**	**0.1**
Car, truck, or van	133,054,328	173,377	84.8	0.1
Drove alone	119,153,349	145,368	75.9	0.1
Carpooled	13,900,979	82,351	8.9	0.1
Public Transportation	7,778,444	42,450	5	0.1
Bus	3,601,403	34,897	2.3	0.1
Subway or elevated rail	2,935,633	29,091	1.9	0.1
Long-distance train or commuter rail	921,391	17,465	0.6	0.1
Light rail, streetcar, or trolley	242,776	8,667	0.2	0.1
Ferryboat	77,241	5,055	0	0.1
Taxicab	385,756	13,467	0.2	0.1
Motorcycle	221,923	7,785	0.1	0.1
Bicycle	805,722	19,868	0.5	0.1
Walked	4,153,050	43,355	2.6	0.1
Other means	1,571,323	27,465	1	0.1
Worked from home	8,970,800	53,611	5.7	0.1

Note: This table was prepared based on the data reported by the U.S. Census Bureau

1.2. Public Transit and Bus Transportation

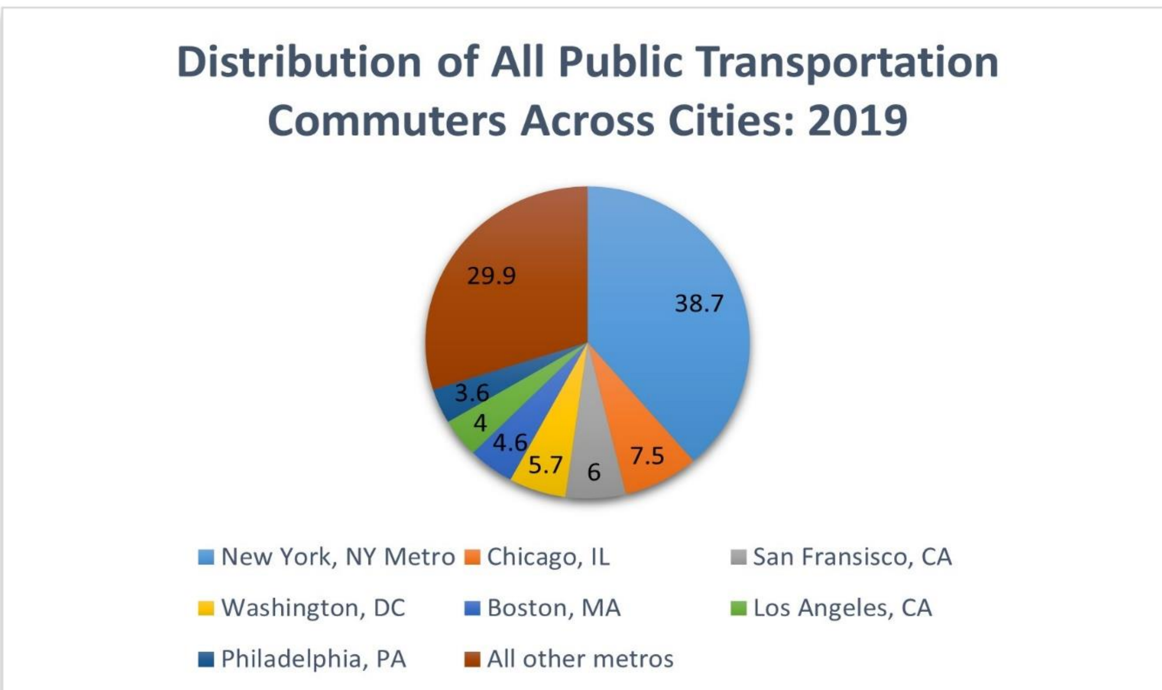
In the United States, public transportation was not a standard mode of transportation to work. Personal vehicles are viewed as more preferential in many United States cities. Public transit only played an important role in the cities like New York and San Francisco, where over 2 million commuters and over one-third of the workers commute. The American Community Survey (ACS) conducted by the U.S. Census Bureau in 2019 (Table 2) found that driving alone and carpooling were the significant modes of transportation to work. About 75.9 percent of the

U.S. workers drive alone to work, while 8.9 percent use carpooling. Only about 5 percent of all the U.S. workers combined all kinds of public transportation modes (bus, light rail, commuter rail, streetcar, trolley, subway or elevated rail, and ferryboat). The share of the workers who commuted using public transportation was lesser than the workers who worked from home, which was about 5.7 percent in 2019 (U.S. Census Bureau, 2019).



Note: This figure was prepared based on the data reported by the U.S. Census Bureau
Figure 5 Distribution of All Public Transportation Commuters Across Regions for 2019.

Approximately 70% of metro-based transit passengers (public transportation commuters in the U.S. metro areas) resided in one of the seven transit-heavy metro areas. About half of the nation's public transit commuters lived in the Northeast region in 2019 (see Figure 5), where three of seven cities with transit heavy metros are located, including New York, NY, Washington, DC, and Boston, MA (see Figure 6). In 2019, about 32 percent of the New York Metropolitan Area workers and 55.6 percent of workers in the City of New York used public transit. Notably, the New York-Newark-Jersey City, NY-NJ-PA Metro Area accounted for 38.7 percent of all public transit commuters in the United States. About 3 million of the nation's 7.8 million public transportation passengers lived in the New York metro area. Another 21.0 percent of transit commuters in the United States lived in the West, including 6.0 percent from the San Francisco-Oakland-Berkeley, CA Metro Area. About 19 percent of workers in the San Francisco Metro Area and 36.3 percent of workers in the City of San Francisco commuted by public transit (U.S. Census Bureau, 2019).



Note: This figure was prepared based on the data reported by the U.S. Census Bureau
Figure 6 Distribution of All Public Transportation Commuters Across Cities for 2019.

About 15.1 percent of all transportation commuters came from the South. Many of them are from the Washington-Arlington-Alexandria, DC-VA-MD-WV Metro Area, which accounted for 5.7 percent of all metro-based transit riders in the United States. In 2019, approximately 34% of workers in Washington, DC commuted by public transit, compared to 13.1 percent of workers who live in the greater Washington, DC metro area. Even though the Chicago-Naperville-Elgin, IL-IN-WI Metro Area had the second highest percentage of metro-based transit passengers, at 7.5 percent, the Midwest had the lowest regional group of public transportation commuters. Over half a million transit commuters lived in the Chicago Metro Area in 2019, with 12.4 percent of workers commuting by public transportation (U.S. Census Bureau, 2019).

However, those who rely on mass transit as their primary mode of transportation, such as the elderly, disabled, low-income, young individuals, and others, may see the most significant impact. As a result, mass transit provides transportation resources for those who may be disadvantaged. It promotes the inclusion and community engagement of all city dwellers in the city's life, improving its livability. Mass transit contributes to a city's economic viability by attracting visitors and tourists and promoting and supporting cultural and social activities (Gershon, 2005).

Communities with efficient public transportation develop thriving communities, reduce travel time due to decreased traffic congestion, create jobs, and boost local and national economies. Every dollar spent on public transportation delivers 5 dollars on average in economic returns. In cities with public transport, the home values are 24 percent higher. The hospitality industry’s revenue is 11 percent more per room than other communities (APTA, 2022). Public transit has various benefits, direct and indirect. Public transit helps to reduce the utilization of privately owned vehicles. By choosing public transportation instead of driving, a person can minimize their chances of getting in an accident by more than 90%. Traveling by public transit is ten times safer per mile than driving any other automobile. Taking public transit and living with fewer automobiles can save a family about $10,000. The average household spends 16 cents of every dollar on transportation, with vehicles accounting for 93 percent, making them the second largest expenditure behind housing (APTA, 2022).

The role of mass transportation will become even more crucial as urbanization continues in the United States and notably in the developing world, where the most considerable rates of urbanization continue to occur. As a result, identifying and resolving health and safety issues associated with urban mass transit is critical (Gershon, 2005). Integrating active transportation with public transit has health benefits because users need to walk to the nearest transit stop to access public transport. Transportation is one such sector that contributes a significant amount of greenhouse gas emissions worldwide. Improving the usage of public transportation could help reduce emissions. In 2018, public transportation saved about 63 million metric tons of carbon dioxide equivalent (MMT CO2e). People using public transit rather than personal vehicles saved 9 MMT CO2e of GHG emissions. About 148 billion miles of vehicle miles travel were avoided because of public transit. A total of 6.6 billion gallons of gasoline were saved in 2018 through transportation efficiency and land-use efficiency (NASEM, 2021). People always had a poor opinion of public transit mainly due to its discomfort and unreliability. One of the main challenges is to attract people into using public transportation.

1.3. Focus of This Study

The present study focuses on simulation modeling of the Florida State University (FSU) campus bus service for the “INNOVATION” route in Tallahassee, Florida (USA). This route is associated with the bus service from the main campus to the FAMU-FSU College of Engineering

(COE). It mainly helps students, faculty, and staff travel to and from the main campus and the COE. The FlexSim simulation environment is used to create the model for the selected bus route. The model aims to understand the changes in passenger waiting time versus the number of buses scheduled for the way and the utilization of the scheduled buses and the reduction of waiting times at the stop, and meet the demand during peak hours which is the time of the day having most of the classes scheduled at the COE. The priority would be to understand the requirements to upgrade the service. The model's outcome will help identify how additional scheduled buses would benefit the network. Providing efficient services would eventually increase bus utilization and reduce the usage of private cars, traffic, and carbon emissions from the vehicles.

CHAPTER 2
LITERATURE REVIEW

This chapter provides a review of the studies relevant to the theme of the present work focusing on public transportation issues. The collected studies were classified into different categories, including the following: (a) environmental sustainability concerns; (b) new generation vehicles; (c) modeling of alternative fuels; (d) addressing service quality issues; and (e) others. A description of the aforementioned study groups is provided in the following sections of the manuscript. Furthermore, a literature summary along with contributions of the present study is discussed as well.

2.1 Environmental Sustainability Concerns

Sinha (2003) highlighted that the rising in owning a private vehicle for faster and more reliable means of transportation was observed in developed countries earlier. The same phenomenon appears in developing countries with an increase in income. This also resulted in a decrease in urban density, impacting urban public transportation. It has become difficult to lure people to use public transport, and it can only be possible by enhancing transit services and land-use policies. The author stated that with an increase in urban population density, privately owned vehicles decline, influencing the use of non-motorized cars and walking. This results in a reduction in energy consumption and greenhouse gas emissions. Intermodal transportation is significant for avoiding the shift from transit to privately owned vehicles for a household. The realistic approach for sustainability is to encourage the urban areas to use all modes of transportation.

Armstrong and Khan (2004) introduced a framework for transportation planning in urban areas to reduce emissions. The study was applied to Canada's National Capital Region (NCR). The travel demand model was simulated using the TRANS model, and the considered scenarios (all road modifications are made according to the plan; the travel demand outlines the infrastructure growth) were tested for emissions. Percentage change in emissions for the two scenarios ranged between 2.8% and 20.9%. Moreover, it was observed that for the third scenario (50% increase in parking charges at peak hours), the change in emissions was 3.4%.

Lindsay et al. (2011) studied the impact of air pollution in urban areas in New Zealand if trips were traveled by bicycle instead of light motor vehicle. For the analysis, the travel survey data of the trips less than 7 km was considered because the distance can be covered in 30 minutes with an average cycling speed. Also, most of the trips in urban areas by the adults were less than 7 km. The Health Economic Assessment Tool (HEAT), developed by United Nations Organization (UNO), was used to estimate the reduction in costs and mortality from the increase in commuting through cycling. Based on the analysis of the data obtained from the National Injury Query System, it was found that the injury rates declined by 34% if the commuting using a bicycle is doubled. Results from the HEAT tool showed that the benefit to cost ratio was about 3:1 if the rides of 1% were substituted, and about 40:1 if the rides of about 30% were covered with a bicycle. If 30% of trips were made by cycling, about 132 million liters of fuel could be saved, and 300,000 tons of CO_2 emissions could be reduced. The health benefits of substituting bicycle trips outweighed the costs incurred from road crashes. Authors suggested implying new policies to increase the use of bicycle commuting, as these policies could potentially reduce emissions, improve air quality, and improve public health.

Fan and Lei (2015) discovered the forces that change the carbon emissions of the transportation sector in the City of Beijing (China) by constructing a Generalized Fisher Index (GFI) decomposition model. To identify the factors contributing to carbon emissions, a method known as Kaya Identity was used to analyze energy characteristics, population growth, and economic growth level (GDP). The following primary drivers of carbon emissions from the transportation sector were considered: (1) energy intensity, (2) economic growth, and (3) population size. The economic growth of Beijing was found to be the most significant contributor to urban transportation carbon emissions. In contrast, the transportation intensity could effectively prevent emissions to a certain extent. The city stakeholders could use the study's outcomes to promote the deployment of new energy vehicles, control the number of privately owned automobiles, and facilitate the use of public transportation.

Titos et al. (2015) evaluated the impacts of transportation changes on air quality. The authors analyzed the effect on air quality by comparing the transportation pattern changes in two similarly sized cities. Air pollutants for both the cities (Granada, Spain, and Ljubljana, Slovenia) were measured before and after the changes in transportation patterns. The traffic for private cars was restricted in both the cities and the improvements in air quality were evaluated. The authors found about a 72% reduction in Ljubljana and a 37% reduction in Granada in terms of black carbon emissions. However, the improvement in air quality was found to be local. The authors suggested that closing streets to private traffic and reducing the overlap between public transportation could reduce air pollution by 80%.

Nanaki et al. (2017) examined the factors that cause CO_2 and other air pollutant emissions from the bus fleets of 9 major European cities. CO_2 and pollutants like CO, HC, PM, and NOx were studied for the CNG (Compressed Natural Gas) and diesel bus transportation systems. Metropolitan cities (Athens, Barcelona, Bari, Copenhagen, Madrid, Newcastle, Riga, Rzeszow, and Valencia), which are diverse in many socioeconomic aspects, were considered in the study. Barcelona and Madrid had the most extended bus networks of 28,705 km and 25,916 km and the most significant number of bus lines of 693 and 692, respectively. The authors found that the diesel buses were majorly responsible for emitting the pollutants mentioned above that form smog associated with respiratory illness. The European emission control legislation categorizes the vehicles from EURO I to EURO V based on their engine technology. The vehicle emission decreases as the category goes up, but the higher category vehicles were not available in some cities. The City of Rzeszow, which has the lowest number of passengers traveled, was the city with the lowest carbon emissions. The cities with CNG bus fleets led to a decrease in NOx emissions compared to diesel engine buses. Using a biodiesel blend (B100) instead of diesel reduced the CO_2 emissions by 78.45%, but there was an increase in the NOx emissions compared to equivalent diesel engine emissions.

Glazener and Khreis (2019) underlined the importance of clean air and active transportation, especially in urban areas. The authors stated that by 2050 many people residing in urban areas might experience city-related health risks, which get even worse with climate change. Some cities like Paris, Oslo, and Madrid planned to ban the use of cars in urban regions to encourage people to walk and use cycles. The authors suggested some practices to improve local air quality and active transportation in the urban areas. The recommended practices were to introduce car-free zones, improve urban design for the safety of cyclists and pedestrians, provide green spaces to increase the physical activity of people, innovate vehicle technologies like EVs (Electric Vehicles) and AVs (Autonomous Vehicles) that reduce the GHG emissions and improve the fuel efficiency, encourage people to use public transportation, and introduce policies that can incorporate the practices mentioned above. The authors suggested conducting more research on the low-income and medium-income developing countries because around 90% of the future urban population growth would be in those regions.

Xylia et al. (2019) highlighted that road transport accounts for nearly 75% of the total carbon emissions from the transportation sector. So, to ensure that the electrification of public transport reduces emissions and improves the local air quality, the study quantified the impact of the act of climate change. Two significant factors that affect carbon emissions are emissions related to the fuel and batteries of electric powertrains. Emissions were translated into CO_2 equivalents, and the Global Warming Potential (GWP) was derived. Fuels were modeled in SimaPro to analyze the life cycle environmental impact, and for the background data, v3.2 was used. The IPCC 2013 GWP method was used for calculating carbon emissions. Mixed Integer Linear Programming (MILP) was used to build the optimization model for the distribution of the charging stations, and optimization was performed in GAMS (General Algebraic Modeling System) software package. Out of the selected 143 bus routes, the cost-optimization model for total emissions, energy consumption, and annual costs resulted in 91 of them should operate using biodiesel (Hydrotreated Vegetable Oil). The rest 52 should run on electricity. Though higher battery capacities are advantageous for bus networks, the results showed that they also could produce higher emissions. Furthermore, the life cycle impact of battery capacity of 120 kWh was better than 60 kWh or 300 kWh. Buses that operate on electricity mix emitted nearly the same as the buses operated on biofuels like Hydrotreated Vegetable Oil. Only the buses that run on electricity generated from renewable sources had lower life cycle emissions.

Chen et al. (2021) analyzed the impact of private vehicle restriction policies on air quality before and after the COVID-19 pandemic. Though these policies showed significant reductions in air pollution, they also significantly impacted the city's economy. The study was focused on the cities in China. A regression analysis of the restriction policies was conducted to find the most effective type of restriction on air pollution. The impact of restriction policies on air pollution varied based on the population size and economy of the city. It was observed that the cities with a GDP of $3.6x10^6$ yuan had a 32% reduction in air pollution compared to 31.6% for the cities with a GDP of less than 7%. The authors could not conclude that these reductions were only restricted by restricting private vehicles because public transportation was also restricted during the pandemic. The restrictions based on the last digit of the license plate number had more impact than the others. The authors suggested using alternate sources of fuel and encouraging people to use public transportation to reduce air pollution.

2.2 New Generation Vehicles

Frade et al. (2011) conducted a study to plan optimal locations for electric vehicle charging stations. With the introduction of the new framework for electric mobility systems in Portugal, the authors found the key issues would be recharging the batteries and the location of the charging stations in the network. The study was conducted in Lisbon, Portugal's capital city, with a huge population density and employment. The authors considered slow charging for this area because most vehicles would remain in the parking lots during working hours. The maximum covering model was used to find the number of stations and capacity. The model optimized the locations considering the demand within an acceptable level of service of charging stations. The optimal locations of the charging stations could serve the estimated nighttime demand from residences and daytime demand in workplaces.

De Filippo et al. (2014) studied the feasibility of deploying electric buses using longitudinal dynamics and simulation modeling instead of conventional deployment. The longitudinal dynamic model evaluated the energy required to operate an electric bus on its line, considering a mixture of urban and suburban traffic. Unlike conventional vehicles, electric bus frequencies and passenger wait times vary due to the charging time required for each trip. A case study was conducted on the Campus Area Bus Service (CABS), a transportation service operated at the Ohio State University's main campus. Simulation models were created to examine the effect of the number of chargers deployed on the transportation system on electric bus charging patterns and queuing at the charging stations. Results showed that around 22 buses could share the two chargers with minimal interruptions in bus frequencies. If the frequencies were not acceptable, strategies like larger battery buses, induction charging, and higher power chargers could be deployed to minimize the disruptions.

Lajunen (2014) analyzed the energy consumption and conducted a cost-benefit analysis of hybrid and electric city buses over conventional diesel ones. The study was performed for energy consumption by using extensive simulation runs for various types of bus routes. A total of five full-size electric and hybrid city bus configurations were carefully investigated as a part of the study. Plug-in hybrid and electric buses showed a significant reduction in energy consumption. The lower average speed of the buses and a high number of bus stops led to an increase in energy consumption for auxiliary bus engines when operating in an electric model.

Choosing the type of bus based on the operational route was essential to ensure the life cycle costs of electric and hybrid city buses would be lower than the conventional diesel buses. Reducing the life cycle costs of the hybrid and electric buses could be achieved by reducing the capital costs and the cost of the energy storage systems.

Lajunen and Lipman (2016) examined the lifecycle costs and CO_2 emissions of different types of buses. CO_2 emissions of fuel and energy production were also considered in this study. Autonomie vehicle simulation software was used to simulate the buses with different powertrains. Battery charging, energy storage, and fuel cell development were the challenges in choosing alternative powertrain buses. High power type batteries are a better alternative than high energy type batteries since the former is best for fast charging, and later one increases the weight of the bus. Six different driving cycles (Braunschweig, Manhattan – diesel-powered buses; Espoo 11(E11), Helsinki (H550) – electric-powered buses; Line 18 and Line 51B of Berkeley, California – fuel cell-powered buses) were simulated. The bus purchase, operation, maintenance, and CO_2 emissions costs were considered to calculate the total life cycle costs. Diesel hybrid buses could be considered an immediate choice replacing conventional diesel buses and fuel cell-powered buses if there were expected cost reductions in the future. The main challenges with electric buses were highlighted to be the charging infrastructure and solving their vulnerability to power grid outrages.

Zhu et al. (2016) proposed a new paradigm for the public transportation systems called PVs (Public Vehicles), which provide affordable, flexible services. Rides made by passenger vehicles, taxis, single-occupant vehicles, etc. that are used for daily commuting have low utility and sharing factor. Public buses might provide a higher sharing factor, but the routes are fixed and have long travel times. The public vehicles system proposed in this study had three components: data center, users, and PVs. The user would place a request from the smartphone, and a private vehicle will be assigned to the user. If another user also puts a request, then the scheduling strategy considering minimal detour will be calculated by the scheduling algorithm developed in the study. Unlike the ridesharing and carpool systems, the drivers and users have the choice to choose the ride. These PVs should be larger than the conventional taxis and smaller than the public buses to improve the flexibility of the service. Sharing factors were compared between the PVs, buses, conventional vehicles, and Uber vehicles. During peak hours, PVs had the highest sharing factors after buses of about 4.54 compared to 1.99 for conventional vehicles and 3.51 for Uber. The proposed PCI algorithm in the study for the Public Vehicle path showed excellent performance by reducing the number of vehicles, travel time, and distance, mitigating traffic congestion. Some other issues like privacy and price need to be studied in the future.

Michalowska and Oglozinski (2017) studied autonomous vehicle technologies to know whether they impact road safety. Improving road safety could also reduce fatalities and decrease economic, social, and environmental costs. By 2030, road accidents could be among the top three causes of premature death and financial losses of about 500 billion U.S. dollars a year. The authors stated that it is necessary to ensure road safety with the increase in road travel. Reducing human factors in the decision-making process could help improve road safety. A study conducted for Volvo cars showed that the human error was the primary cause of accidents, and only a tiny percent was related to road and vehicle issues. Developed countries like Europe proposed a road safety program to create a road system and minimize human errors since most of the incidents were caused by them. Autonomous vehicles could reduce these errors by interacting with other vehicles and infrastructure, reducing congestion, and improving the fluency and safety of road travel. Some challenges could arise as autonomous vehicles, non-autonomous pedestrians, cyclists, and motorcyclists will participate in road traffic. Decision-making in case of an emergency, cybersecurity, inclusion of human behavior, and emotions were found to be the other limitations, and the main problem was whether people were ready for them or not.

Buehler (2018) compared the key features of the public transportation demand of the United States with western countries. The author provided pathways to encounter connected and automated vehicles (CAVs) with public transportation. The author stated that the affordability of CAVs and the space efficiency in urban regions were found to be critical strengths for public transit. From the travel survey data, it was found that a quarter of daily trips were made by public transportation in Switzerland, which is 12 times greater than in the U.S. Lower population densities and land-use policies were found to be the major factors affecting the public transport in the U.S. Integration of connected and automated technologies with public transportation, connecting the services to transit like airports and rail services, and coordinating land-use policies with public transportation services could provide customers with reliable, safe, and affordable options.

Hough and Taleqani (2018) discussed the future of rural transportation and the impacts of the long-term implication of emerging technologies on rural communities. The authors presented two probable scenarios for the future of rural America; one is “the green countryside” and “rural growth development along corridors.” Transportation to rural communities provides access to essential services in urban areas. Population, economy, and technology were found to be the key factors that influence rural areas. Market trends showed that retired and older adults tend to live in rural areas, and autonomous vehicle technology would improve the accessibility to urban areas for the rural residents. Autonomous buses could be more efficient by rerouting based on the demand data it receives from the surveillance cameras and the capacity of the bus itself. Other technologies like automated aerial vehicles, service robots, hologram communication, etc. will make the future of rural America more accessible and can be considered for residence and retirement.

Qiao et al. (2020) studied Life Cycle Costs (LCC) and Greenhouse Gas (GHG) emissions for Electric Vehicles (EVs) and compared them with Internal Combustion Engine Vehicles (ICEV). The study was carried out to understand the benefits of EVs concerning costs incurred in China. The study was conducted under various driving cycles, driving patterns, and vehicle parameters, such as acceleration and velocity. Vehicle costs, fuel, recycling, and costs associated with the charging infrastructure for EVs were also considered to evaluate LCC. The life cycle was divided into three stages: Cradle-to-Gate (CTG), Well-to-Wheel (WTW), and Grave-to-Cradle (GTC), representing the manufacturing, usage, and recycling stages that the vehicle goes through. The authors incorporated all manufacturing and recycling data for the whole life cycle to evaluate GHG emissions in this study. Recycling would be an efficient way to reduce GHG emissions, but that would increase the LCC. The authors found out that the EV's LCC was 9% higher than the conventional ICEV, and this was because of the higher manufacturing cost. Life cycle GHG emissions were 29% lower than ICEVs, mainly from lower emissions in the usage stage.

Soe and Müür (2020) analyzed the factors for mobility acceptance of an automated shuttle bus last-mile service. The authors' main goal was to know passengers' perceptions of the safety and security of automated shuttle service. The authors conducted a last-mile automated bus pilot ride for four months in late 2019 in Tallinn, Estonia. Around 3,877 passengers took the autonomous bus pilot ride, and out of them, 152 provided feedback about the experience. The passenger feedback survey collected the data by asking questions related to traffic safety, personal security, willingness to use the service when there was no operator on board, safety for children, overall experience, frequency, and suggestions. The results were compared with a control group of 55 students who did not take the ride. Pilot ride experienced passengers gave more positive feedback than those who had not taken a ride. The authors said that further research activities must be conducted in an uncontrolled environment since controlled operations for the pilot ride might affect safety feedback.

Pathak et al. (2020) analyzed the impacts on sustainability by placing electric and autonomous buses for public transportation instead of human-driven diesel buses. The study was conducted on seven bus routes in Singapore. The Life Cycle Assessment (LCA) and Total Cost of Ownership (TCO) analyses were performed to evaluate the life cycle costs and greenhouse gas emissions. Twelve-meter human-driven diesel buses with a capacity of 90 passengers were replaced with six-meter human-driven electric minibuses and six-meter autonomous electric minibuses. A timetable for each route was obtained by the trip schedule. The required fleet size was determined by linear programming of the timetable. The distance traveled by electric and autonomous vehicles was increased from 28,146 to 68,368 km, with an increase in the number of trips from 1,383 to 2,847 for human-driven diesel buses and electric buses, respectively. Autonomous Electric Buses (AEB) were found to have the least operating costs, nearly one-third of Electric Buses (EB), which reduces the price per passenger per km. AEB also resulted in lower GHG emissions of 51.62g CO_2/passenger-km compared with the twelve-meter diesel buses of 94.62g CO_2/passenger-km despite an increase in the number of trips.

2.3 Modeling of Alternative Fuels

Karlstrom (2005) assessed fuel cell buses' potential local environment benefits compared to natural gas buses and EURO 5 diesel buses. The study was conducted in Goteborg, Sweden, for a central bus route. Greenhouse gas (GHG) emissions and noise reduction were evaluated in monetary values. The operation costs (capital, fuel, and salary costs) were the same for diesel and fuel cell buses. Environmental cost benefits of about EUR 0.06 per bus kilometer were recorded for fuel cell buses and EUR 0.04 per bus kilometer were recorded for CNG buses. An estimate of noise pollution costs of diesel buses relative to fuel cell buses was evaluated, and it was found to be EUR 0.02 per bus kilometer.

Cooper et al. (2014) compared the different fuel choices for public bus transportation to evaluate the emissions and find the best-performing fuel with fewer emissions in India and Brazil. About 90% of the data used in the analysis were collected in the laboratory, and the rest was from field tests. ANOVA (Analysis of Variance) was tested for each type of major emissions (CO, THC, NOx, PM) to know the impact of fuel on the emissions. The results were compared with the EURO emission standards for transit vehicles. Brazil’s fuel technologies met the EURO standard V for NOx vs. PM, and only CNG (Compressed Natural Gas) + 3WC (three-way catalyst) met the EURO standards. The best-performing fuels for India and Brazil were

CNG with a 3WC and a 20% mixture of biodiesel with diesel particular filter and selective catalyst reduction (B20+DPF+SCR).

Alam and Hatzopoulou (2014) studied emissions of conventional diesel and compressed natural gas buses under different traffic operation conditions. The study was focused on bus operations in the City of Montreal, Canada. The simulations for two types of fuel (conventional diesel, Compressed Natural Gas (CNG)), buses, and scenarios for traffic operations like Transit Signal Priority (TSP), bus stop relocation, and queue jumper lane were evaluated. CNG-fuelled buses showed a significant reduction in emissions compared to conventional diesel buses. The drop was minimal when there was no traffic congestion, and for overcrowded conditions, TSP operations alone reduced 14% of the emissions.

2.4 Addressing Service Quality Issues

Murray et al. (1998) underlined the importance of transportation for society due to its crucial role in economic growth and social interaction. The economy and rapid urban population growth increase the stress on transportation planning. People are likely to use public transportation when there is ease of access to the service at an affordable cost. The study focused on evaluating the public transportation system in the Southeast Queensland region (Australia). It was found that the performance of the public transportation system was poor. The study indicated that the public transportation system could be improved in the regions with high transport access by applying specific promising alternatives (e.g., modification of the route service, altering the placement of service stops). Furthermore, service considerations, demographic information, socioeconomic characteristics, and dynamic proximity measures should be considered.

Meignan et al. (2007) adopted a multi-agent approach to describe the interactions between certain operational features like public behaviors, traffic dynamics, and bus-network operations. Simulations including these specificities were modeled, and the results were analyzed at different time and space scales. The model was applied to a Belfort city (France) bus network. The emphasis of the results was on the passenger load and waiting time. Results allowed us to know the requirement for more buses during peak hours and avoid scheduling unused buses based on the passenger load issues. Thirty-six buses need to be scheduled for the Belfort city bus network to obtain the average waiting time of 10 minutes. The proposed multi-agent simulation model integrated the traveler behavior (microscopic view) within a macroscopic view of traffic dynamics.

Daniels and Mulley (2013) investigated the possible influences on walking distance to access public transportation. The study aimed to understand those influences on public transit to improve accessibility in Sydney, Australia. The data for the research was obtained from the Sydney Household Travel Survey (HTS), and the data was focused on the commuters who already chose to walk to access public transport. It was found that about 90% of the bus commuters chose to walk to the bus stop from home and only half of the train commuters walk from home to the train station. The HTS data found that 18% of commuters who travel used public transport to work because it was close to their home, and 12% of car users said they did not have accessibility. The authors noted that the most influential factor in choosing public transportation was the availability of nearby stops or stations, and demographic characteristics did not have a significant impact. However, increasing stops and stations to improve access was expensive. The authors suggested further research to understand the maximum distance people would be ready to walk for public transportation and the value of walking distance for meeting minimum daily physical activities.

Deb and Filippini (2013) assessed the effects of income and price on public transport demand. The study was focused on twenty-two large states in India. Panel datasets between 1990 and 1991 and 2000 and 2001 were used to estimate the public transit demand in India. Statistical analyses for passenger kilometers, public transit fares per kilometer, density of coverage, per capita, and other factors were evaluated. The LSDV model estimated price, income, and service quality elasticity values. It was found that the role of price had a limited impact on the public transit demand. Service quality primarily affects public transport and significantly impacts the transit demand. The authors suggested that new policies according to the region's goals need to be implemented. A reduction in environmental pollution or traffic congestion for providing access plays a significant role, leading to higher costs. A cost-benefit analysis needs to be performed before investing in public networks.

Islam et al. (2014) examined the factors that contribute to the satisfaction with public bus transportation. The study was conducted in Sintok, which is in the Kedah province of Malaysia. The data was collected from 300 bus commuters to evaluate the quality of service and passenger satisfaction. Quality of service was estimated based on five variables (service, access, availability, time, and environment). A hypothesis test was used to conclude whether there is a significant relationship between these variables and passenger satisfaction. A regression analysis of quality of service and satisfaction was evaluated to know the dependency of satisfaction on those variables. Waiting time had the most effect on passenger satisfaction. Apart from that, the behavior of service providers, especially drivers, and reliability and frequency of the service also impacted continuing use of public transportation.

Geurs et al. (2016) studied the impacts of train ridership and ease of access to work for bike-train integration policies. The study was conducted in Randstad South, a metropolitan area in the Netherlands, where bicycles played a vital role in train station access. The metropolitan area consisted of a dense train network with 54 stations. The authors integrated the Dutch multimodal transportation network with a bicycle network linked to access public transportation. Several scenarios were developed to determine the effect on travel demand concerning access. Results showed that increased train frequencies produced more ridership and total accessibility to workplaces. Suburban and smaller stations had a more substantial effect with increased train frequencies, and large train stations showed more profits with improvement in bicycle-train integration policies.

Shaaban and Kim (2016) conducted a study to determine the relationship between mode of choice and bus service among university students. The study aimed to know the influential factors to encourage people to use public transportation. The answers determined the service satisfaction expressed by the university students regarding their transport mode of choice and bus service. The study was focused on the evaluation of public transportation at the Qatar University. The responses from the questionnaire were divided into three categories: service at bus stops, service of buses, and service of drivers. The authors presented a structural equation model (SEM) to determine student satisfaction and its relation to deciding the choice of transport. AMOS 21 tool was used to identify the factors influencing the transport mode of selection. The results showed that the above three factors correlated with the transportation mode of choice. It was found that the method of choice also depended on early experience with public transportation. In countries like Qatar, where people are oriented toward using private vehicles, social acceptance of public transport also plays a significant role.

Mándoki and Lakatos (2017) evaluated the quality of both bus and train transportation to understand the commuter's choice of transportation modes. In Hungary, the study was conducted for long-distance transport, where bus and railway transportation co-existed. To know the optimal demand for the development of public transportation, the authors prepared a questionnaire that targeted especially the perception of the quality of service. Three hundred eighty-nine respondents filled out the questionnaire, and it was found that the average traveling distance by train and bus was 150 kilometers. Longer distances were traveled by carpooling, up to 180 kilometers. The answers to the questionnaire led to the conclusion that the people who use national bus services look for reliability and minimal traveling time, and those who choose railway look for comfort.

Susilawati and Nilakusmawati (2017) studied user satisfaction with public transportation. Transportation between the districts of Bali was the study area. Bali is a popular destination for tourists, increasing transportation between the communities. Optimizing public transportation and maintaining the quality service of public transportation is the solution to lessen congestion due to the limited capacity of the roadways. The data was collected from the public via questionnaires consisting of the variables determining public satisfaction. Factors affecting user satisfaction were determined using the factor analysis of the collected data. Safety and comfort were the most influential factors that affected satisfaction. Responsiveness, Capacity, Tangibility, and Reliability were other factors. The study suggested the government of Bali focus on the safety and comfort of the passengers traveling via public transportation.

Sieber et al. (2020) compared public train transportation with hypothetical mobility systems in rural areas. The authors compared them to know whether public transit in rural areas with low utilization ratios can be replaced with on-demand autonomous mobility systems in terms of accessibility and cost. The study focused on Switzerland’s four rural train lines with low utilization. Simulations for four case scenarios (Homburgertal, Thunersee, Boncourt, and Tösstal) were carried out in the MATSim simulation environment. Three out of four cases showed higher service levels with low operation costs when autonomous mobility-on-demand systems serviced a line. The authors suggested including ridesharing in autonomous mobility-on-demand systems for further research.

Andrade-Michel et al. (2021) addressed the driver reliability to lessen the number of no-covered trips and improve the serviceability of the public bus transportation system. Public bus transport operations generally consist of Vehicle Scheduling Problem (VSP) and Crew Scheduling Problem (CSP). Both VSP and CSP aim to minimize the operational cost by reducing the required number of vehicles and crew by ensuring the trips. Usually, they are calculated daily because crew availability varies day to day. The authors integrated the VSP and CSP with drivers’ reliability information called Vehicle and Reliable Driver Scheduling Problem (VRDSP). Constraint Programming was proposed to consider all the characteristics of the problem. Since there was uncertainty about the drivers’ availability, the Monte Carlo method was used on random samples to minimize the missed trips. A variable neighborhood search (VNS) method was proposed to focus on route priority and driver reliability. The algorithm assigned the most reliable driver to the top priority route. Results showed that the VNS methodology focused mainly on the driver's reliability, unlike VRDSP, which did not consider driver reliability.

2.5 Others

Fernandez and Tyler (2005) examined the interactions between buses, traffic, and commuters to know their impacts on delay and capacity at the stops. The authors carried out a microscopic simulation to analyze delays at bus stops, causes of the delays, and bus frequency. Poor design of bus stop operations could cause queues of buses during the holidays, which could interrupt smooth traffic flow. The authors stated that usually capacity of the bus stops was ignored, thinking that the buses were less in number. In major cities, this could result in oversaturation at the finish resulting in a queue of buses at the stops, and it could lead to poor accessibility to the commuters. Results showed that if a visit is overcrowded, it could increase the delay of the bus at the stop by about 30-40%. So, it is essential to consider bus and passenger data for arrival and departures to design a bus stop. Bus stops need to be located so that when they enter and leave a stop, they do not obstruct any major traffic, traffic signals, car parking, or bus bays.

Reynolds et al. (2010) explored the potential health benefits and risks of active transportation in urban regions. Walking and cycling were found to be the most common means of active transportation, while skating and running also come under active transportation. The authors stated that active transportation has health benefits and reduces noise pollution and traffic-related emissions. Active transportation incorporates moderate-intensity activities like cycling and walking, which are sustainable in the long run. In Canada, one out of three adults is overweight, and only 12 percent of the children and youth get enough physical activity. Many studies showed a lower risk of cardiovascular disease and disease-specific mortality among people who use active transportation. But the main concern for active transport is safety; pedestrians and cyclists have more risk for fatality and injury. It was not clear whether pedestrians, cyclists, or motorists are exposed to a greater level of air pollution. Reduced air pollution, GHG emissions, healthcare costs, traffic noise, and congestion are benefits of increased active transportation. To minimize the safety concerns cities need to be planned carefully for operational modes of transportation.

Xie and Levinson (2011) evaluated the effects on road users due to the collapse of the I-35W bridge. The authors assessed the economic loss due to the increase in travel time and compared the travel scenario before and after the collapse. The bridge collapsed on the 1st of August 2007. Hence, the authors calibrated the model using the peak hour traffic volume for the last week of July 2007 to represent the traffic conditions before the bridge’s collapse. The travel demand and investment model SONG 2.0 developed for the Minnesota Department of Transportation forecast the vehicular traffic volumes and estimated the vehicle trips. After the collapse, the model showed an increase in the daily vehicle travel hours by 0.35%, from 1.427 million to 1.432 million. Total vehicle travel kilometers were decreased by 0.31% due to people switching to nearer destinations. The authors compared the forecasts with the traffic count data and achieved an error of below 2% to know the model's accuracy. The authors estimated the loss to be around US$71,000 to US$220,000 a day, depending on the trip destinations of the road users in the given area.

Mattson (2011) highlighted the importance of transportation to access healthcare facilities, especially for older people in suburban and rural areas. The author developed a model based on the Health Behavior Model, considering transportation and distance as the factors that impact health care utilization. The data were collected from a random sample of individuals aged 60 and over through mail, and around 20% (543 individuals) responded. The study was focused on the states of Montana, North Dakota, South Dakota, and Wyoming. Results from the model indicated that transportation and distance were not the dominant factors. Inconvenient timings of the public transportation system concerning the health care service were the major problem—availability of transportation was impacted during the emergency visits to healthcare facilities. The author suggested having effective communication among the public transportation providers, healthcare facility providers, and individual users for an efficient use of provided services.

Zhu and Levinson (2012) reviewed disruptions in transportation networks to understand the commuters' network system effects and behavioral effects. The public transit strike lasted for 13 days in New York City and increased the traffic congestion due to the increase in personal vehicles. The bridge closure due to the collapse of the I-35W Mississippi River Bridge resulted in a network collapse. The disruption caused longer travel distances, congestion levels, and rerouting costs by around $400,000 per day for travelers. Changing routes and longer travel distances was one of the significant changes due to disruption in the transportation network. The lack of data was why the authors could not empirically measure the equilibrium state of the traffic flow after the disruptions. The authors concluded that advanced technologies like loop detectors and Global Positioning Systems (GPS) need to be deployed for accurate data of traffic flow information.

Mulay et al. (2013) conducted a study to apply Intelligent Transportation System (ITS) technologies and develop a data center of ITS for a city. The aim was to improve traffic flow, control traffic congestion, and provide real-time information for the users about congestion and public transport. The users would initiate a query for a bus using the website or mobile application or through an SMS. The datacenter in the city processes the query, gets the coordinates of the bus from the GPS tracker, and locates the nearest bus stop to the user. The user receives the distance and the time taken for the bus to reach its nearest bus stop. Image processing CCTV camera data identified traffic congestion by comparing the percentage of roads occupied to an empty road. According to the traffic congestion data, signal synchronization was adjusted to reduce traffic density issues and wait times at signals.

Elkosantini and Darmou (2013) integrated the ITS technologies for public transportation systems to control transportation networks and optimize performance. The study focused on the architectural integration of information and communication technologies rather than their technical aspects. Automatic Vehicle Location Systems (AVLS) use the Global Positioning System (GPS), a satellite-based technology, to track location and time information. Advanced Travel Information Systems (ATIS) use mobile phones or the internet to provide information for the users about the traffic conditions. Automatic Passenger Counters (APC) count passengers waiting at stations and onboard passengers using technologies like treadle mats, infrared beams, and computer image processing. The collected data could be used for the performance analysis of the transportation system. Geographical Information Systems (GIS) map the collected GPS data and provide the progress of vehicles and disturbances in the transportation network. Decision Support Systems (DSS) analyze the data from the systems mentioned above and make suitable decisions to minimize the deviation from the scheduled timetable of the transportation network. Decision makers interact with DSS to execute updated strategies.

Kaplan (2015) analyzed the modal share of bicycling and walking to find opportunities and improve transportation sustainability. The author investigated the present level of sustainability of transportation of these modes on a large university campus in the U.S. Midwest. Levels of walking and bicycling were measured on campus. Secondly, a survey questionnaire was tabulated, and infrastructure aspects that do not allow people to use walking or bicycles were enlisted. The author found that the existing on-campus infrastructure does not encourage students to use sustainable transportation means. Understanding the hindrances to bicycling and walking was significant to design and improve the infrastructure. Attention to those improvements could help improve the campus environment and the health of students, faculty, and staff.

Benevolo et al. (2016) highlighted the importance of incorporating the concept of a smart city and information communication technology to solve the growing urban problems. Traffic-related problems were found to be the most challenging problem in urban regions. Effective interaction between economic, environmental, technological, and people behavioral aspects of the city are significant. Initiatives were classified into four groups, namely, public transport companies and organizations, private companies and citizens, public bodies and local governments, and intelligent transport systems. Each citizen plays an important role in implementing successful and effective smart mobility systems.

Faria et al. (2017) analyzed the Internet of Things (IoT) applications for smart mobility, real-time traffic management, and intelligent transportation systems. The authors highlighted increasing traffic problems in the cities and how smart technologies can help to improve the quality of life. Wireless communication technologies could be adapted to vehicles, allowing them to communicate with each other and with roadside units. Vehicle-to-Vehicle and Vehicle-to-Infrastructure communications are helpful to reduce road accidents and improve safety by sharing the speed, position, and other relevant data with each other and infrastructure. Smart parking systems allow users to locate the nearest available free parking slot. Intelligent traffic lights reduce traffic congestion by optimizing the cycle lengths based on the vehicle data received from sensors in different directions. The authors found that the performance of these smart technologies was not at the desirable level, and advancements in communication, automotive, and sensor technologies would solve the urban mobility problems more effectively.

Boyle (2018) incorporated his thoughts on the information collected from the participants that took part in the workshop conducted on the future of public transit. It was indicated that the people's perception of public transit use as a downgrade of economic status is a significant barrier that affects transit use. Driverless technology might make public transportation more profitable because most of the service expenses are for the drivers, which might cause the shift in the industry from public to private. People's opinion on driverless vehicles and their willingness to travel in them is unknown. In terms of the sheer amount of people, public transit can transport a significant amount of people and can be further advanced with innovative technologies. This would always be one of the key advantages over a single-occupant vehicle.

Nguyen-Phuoc et al. (2018) studied the impact of bus transit operations on traffic congestion. The study was focused on bus operations in Melbourne, Australia. Positive and negative impacts were evaluated to find the net impact of bus operations on traffic congestion.

The survey data was collected from the bus users to get the information regarding the mode shift from car to bus and calculate the positive impact. It was found that about 33.5% of bus users would shift to a car if bus operations were ceased. The negative impact was evaluated by considering the factors causing traffic congestion in microsimulation models. The net effect of bus operations on the Melbourne Road network was found to be positive. Bus operations for the outer regions of Melbourne reduced the vehicle travel time and the total delay by only 2% compared to 7% and 6% in inner and middle areas.

Watkins (2018) discussed whether the future of mobility depends on public transportation or not. Each mode of transportation occupies a certain amount of space on the road, and the spatial and environmental impact caused by the single occupied vehicle was not sustainable. The author stated that transportation network companies (TNCs) like Uber and Lyft do not make the situation better. Even though they are ride-sharing services, the transport is provided by an individual-occupied vehicle. Carpooling trips in these companies is far less than typical rides. Mobility as a Service (MaaS) is a technology that integrates public and private transportation (TNCs, bike-share, and paratransit) without the intervention of privately owned vehicles. This technology was found to be successful for both Sweden and Finland. They provide right-of-way to high-occupancy vehicles, focusing on the service (transporting people from origin to destination) rather than one mode of transportation (rail, bus, etc.) that makes an effective public transportation system. The author indicated that ensuring new technology integration and collective mobility would be the future of transportation systems.

Luo et al. (2019) conducted an impact analysis of the IoT environment on the public transportation system. The authors presented a new framework for better transfer between different modes of public transportation. Subway, buses, and shared taxis were considered in this study due to their extensive use in urban regions. Methods to predict transport flow and mathematical models for solving scheduling and controlling problems were also presented. The proposed model was evaluated via the application to the public transportation system of Shenyang City, the capital of Liaoning province, China. Modifying the bus dispatch time and bus running time reduced the overall waiting time for passengers for a single planning horizon experiment. Multiple planning horizon experiments effectively utilized the data received from the IoT, and the proposed dynamic scheduling strategy improved the system's performance.

Cheng et al. (2019) studied a package distribution problem by utilizing the idle capacity in the public transportation system. Usually, package delivery services led to traffic congestion, consumption of resources, and created environmental pollution. The authors found that most public transport vehicles were underutilized outside the peak hours. Using crowdsourced public transportation systems (CPTSs), the authors named the package distribution problem as the CPDCP problem. The presented model used Integer Linear Programming to propose an efficient solution. The framework planed the states (waiting, riding, re-waiting, and unloading) in the package delivery scheme by minimizing the time to deliver packages.

Karoń and Żochowska (2020) analyzed the smoothness and the need for priority services for the public transportation systems (PTS) in the ITS environment. Tram stops were found to be disrupting the private vehicle and pedestrian movement, especially when they stop at the signalized intersections. Travel time of the public transit vehicles data should be used to adjust the vehicle's timetable, but they can also be used to understand the delays, disturbances, and reasons. It was essential to understand them from the perception of the PTS vehicle commuters.

Understanding these disruptions in the traffic flow would improve the serviceability of public transportation and its attractiveness among different modes of transportation.

Šurdonja et al. (2020) examined the survey conducted in Croatia in 2017 to know the users' opinions on smart mobility initiatives. Further, the survey results were compared to the results of the same survey that was conducted in Italy. The study's objective was to understand the need for behavioral change to implement smart mobility solutions. The survey data was collected for 1,000 users in Italy and 185 in Croatia. In-vehicle navigation tools, delivery goods travel, info mobility signage, and demand-responsive transport (DRT) were some mobility solutions that Croatian users mainly used. At the same time, e-ticketing and in-vehicle navigation services were primarily used in a survey conducted in Italy by UNIKORE (which is a transportation research group). About a third of the survey sample stated that real-time information on public transportation, e-ticketing, and e-parking were the most innovative mobility solutions. Only a tiny percentage of Croatian users think that future smart mobility solutions will impact their daily lives. The authors concluded that there is a need to educate people to benefit from smart mobility solutions.

Tirachini and Cats (2020) highlighted the challenges and the need for research in public transportation for the post-pandemic phase. Public health considerations should be incorporated into transportation service planning, and evidence-based decisions need to be made involving trade-offs between risk and efficiency. The authors said that it was unknown how much physical distance and occupancy must be maintained in public transportation. In Tokyo and Seoul, a physical distance of less than one meter when all travelers wear masks worked well, but more evidence was required to understand and replicate it in other cities. More research is needed to analyze the risk of traveling in public transportation versus the phases of contagion. The authors stated that it is the service providers' responsibility to change the unhealthy perception of public transport and make it healthy to fulfill accessibility and sustainability goals.

2.6 Literature Summary and Contributions of the Present Study

A detailed review of the relevant literature indicates the growing attention of the community to public transportation. Various aspects of public transportation have been thoroughly investigated over the years, including environmental sustainability concerns, new generation vehicles, modeling of alternative fuels, and service quality issues. The literature review shows that many studies were conducted for specific locations (Armstrong and Khan, 2004; Lindsay et al., 2011; De Filippo et al., 2014; Fan and Lei, 2015; Titos et al., 2015; Nanaki et al., 2017; Chen et al., 2021). Such a pattern can be justified by the fact that certain public transportation solutions can be location-specific (i.e., the outcomes revealed for one location may not be applicable for the other location). Therefore, this study focuses on improving the operations of the “INNOVATION” bus route service provided by the FSU’s Seminole Express in Tallahassee, Florida (USA). A simulation model will be built using the FlexSim simulation software to emulate the operations of the “INNOVATION” bus route service to determine the required number of buses to be deployed. The developed simulation model will assist with effectively planning the bus route connecting the main FSU campus with the FAMU-FSU College of Engineering by providing solutions with adequate waiting time and operational costs.

CHAPTER 3
MODEL DESCRIPTION

3.1 Simulation

A model is the representation of the system of interest that is similar and simpler than the real-world system that it represents. The model can be modified and experimented with. However, in real-world systems, the experimentation can be impossible, too expensive, or impractical to do. The model's operation can be examined, and hence properties about the behavior of the actual system or its subsystem can be deduced (Maria, 1997). The simulation can be defined as an imitation of the real-world process or systems over time (Banks, 1999). It means creating an artificial process to observe and to derive inferences about the operating characteristics of the systems in the real-world. To solve many real-world problems, simulation is an essential problem-solving methodology. Simulation is used to explain and analyze a system's behavior, to ask "what if" questions regarding a real-world system, and to assist in the design of real-world systems. Simulation can be used to model both real and hypothetical systems (Banks, 1999).

A model that represents an actual system should be complex enough to address the questions but not excessive. There's always a concern regarding the model's limits and boundaries that are supposed to represent the system. In a simulation, there are both external and internal events which are also called as exogenous and endogenous events (Banks, 1999). For example, when a passenger at the bus stop started to use the bus service is the beginning of the internal event which is called as endogenous event. Any other events that are occurred outside the simulation are called as exogenous events.

The model type that will be presented in this study is called as a discrete event simulation model. A discrete event model tries to accurately reflect the components of a real-world system and their interactions, so that the study's goals can be effectively addressed. Discrete event simulation models are dynamic, and a passage of time plays a crucial role here. During each event, the system state is updated, as well as any resource capturing and freeing that may occur at that moment (Banks, 1999).

3.2 Advantages and Disadvantages of Simulation

With the advancement in the computer industry, other related industries that use simulation are steadily growing. Many managers are seeing the advantages of using simulation for more than simply a one-time building renovation. Managers are increasingly adopting simulation into their daily operations as a result of developments in software (Banks, 1999). Simulation lets us test the change in the system without consuming the resources. It allows to test the design prior to implementing it in the real world (Banks, 1999). We can view the entire change in the system and examine all the events in a span of seconds by time compression in the simulation environment. Alternative modeling methods can take hours to examine for a minute change in the real-world system operations (Banks, 1999).

To understand why something occurs in a real system by microscopic examination of the simulation model, one can find why. This may not be possible in the real-world system, because the behavior of the real-world system is not in control entirely (Banks, 1999). Simulations can be used to explore possibilities, diagnose problems, identify constraints, develop understanding of the real-world systems, and clearly visualize the operations. Simulation is a wise investment because it costs only about 1% of the amount that is required to implement the design, since the costs that might require for modification or change in the system are greater (Banks, 1999).

Along with numerous advantages of simulation modeling, there are some drawbacks as well. In particular, simulation results can be difficult to interpret because most of the outputs are random variables. It is difficult to find whether the result of the system is because of any interrelationships of the model variables or of randomness. Simulation modeling can be also time consuming (especially, when it is necessary to emulate a large system with many objects), expensive, and require special training to construct the models (Banks, 1999).

3.3 FlexSim Simulation Environment

FlexSim is an object-oriented software environment for creating modeling, simulating, visualizing, and monitoring dynamic-flow processes and systems (Nordgren, 2003). FlexSim has a comprehensive set of tools for creating and compiling simulation applications. FlexSim is an advanced analysis tool that assists engineers and planners in making informed decisions about system design and operations. Using FlexSim, the user can create a 3-dimensional computer model of a real-world system, and then study this system in a fraction of the time and for a fraction of the expense. FlexSim provides quantitative feedback on a variety of recommended solutions, allowing to rely on the best option (FlexSim, 2017).

The FlexSim Compiler, the FlexSim Developer, and the FlexSim Application products are the three major components of the FlexSim environment. The FlexSim developers proposed their own programming language, called as flexscript, which is based on the C++ programming language. The complier is fully integrated with the C++ compiler, so we can use either flexscript or C++. FlexSim has been used in the field of supply chain for manufacturing, warehousing, and material handling operations (Nordgren, 2003).

3.4 Modelling in FlexSim

In FlexSim, the 3D model and the Process Flow tool are the two main interfaces one can use to develop a simulation model. Using the 3D model, we can visualize the system, and the process flow is the foundation for building the logic for the system. Figure 7 shows the major parts of the FlexSim workspace, where one can develop a 3D simulation model of the system. To start building the simulation model, it is necessary to drag the appropriate objects from the library into the model. The library, which can be found in the left pane, has a range of objects that one can utilize to create a 3D simulation model. According to the model needs, the user can change the specific properties for each type of item (for example, the user can change the speed of the task executers, the speed of the transporters, or the processing time of a processor).

The objects in the simulation model will start to move and interact when we run a simulation based on the logic that has been created in the simulation model. Objects are the fundamental units of a 3D simulation model. Within the simulation model, different types of objects serve a variety of functions. Flow items are those that travel through the simulation model, typically from one object (which is normally a fixed resource) to another object downstream. Products, people, paperwork, boxes, parts, and any other items that travel to different objects in the system can all be represented as flow items. Usually flow objects appear as boxes by default, but the user can change the type of flow item that is required for the system using the properties menu of the source object.

The Object labelled as “Source1” in Figure 8 represents the fixed resource called as source. The source object can create the flow items based on the required inter-arrival times or based on a scheduled list or based on a defined arrival sequence and establish them into the model. In the inter-arrival time mode, the source creates a flow item based on the inter-arrival function. The source generates an item, assigns properties (such as labels or color to the flow item), and then releases it to the model environment. After that, the source object will wait for a certain amount of time to create the next item. In the arrival schedule mode, flow items are created based on the schedule table that is provided by the user. The arrival sequence mode is similar to the arrival schedule mode but only with the number of flow items. Once the source creates the flow items of a row, it will move to the next row.

Flow items that are created and released from the source can be stored in the queue, which is the object in Figure 8 labelled as “Queue1”. The queue object can be used to store the items until they are required downstream. When a flow item is required for the downstream objects, the queue will send the flow item that is waiting for the longest time. The queue object provides an option to batch flow items, if turned on. When the batch option is used, the queue will wait until it gets its intended batch of flow items before releasing the flow items at the same time. During the simulation run, the user can view the state of the queue from the statistics panel (i.e., whether the queue is empty, or collecting, or releasing, or waiting for transport).

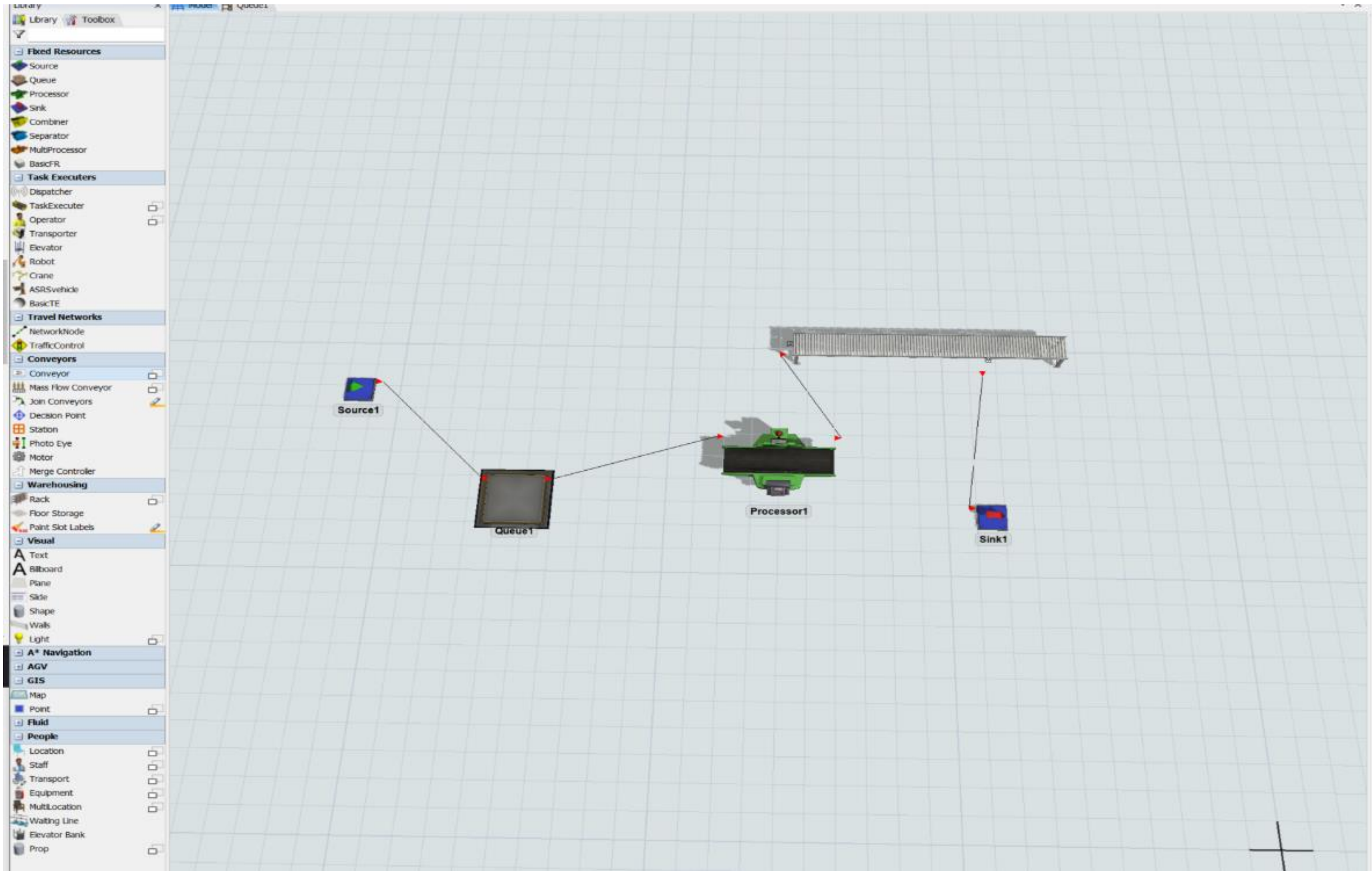


Figure 7 3D Workspace in FlexSim.

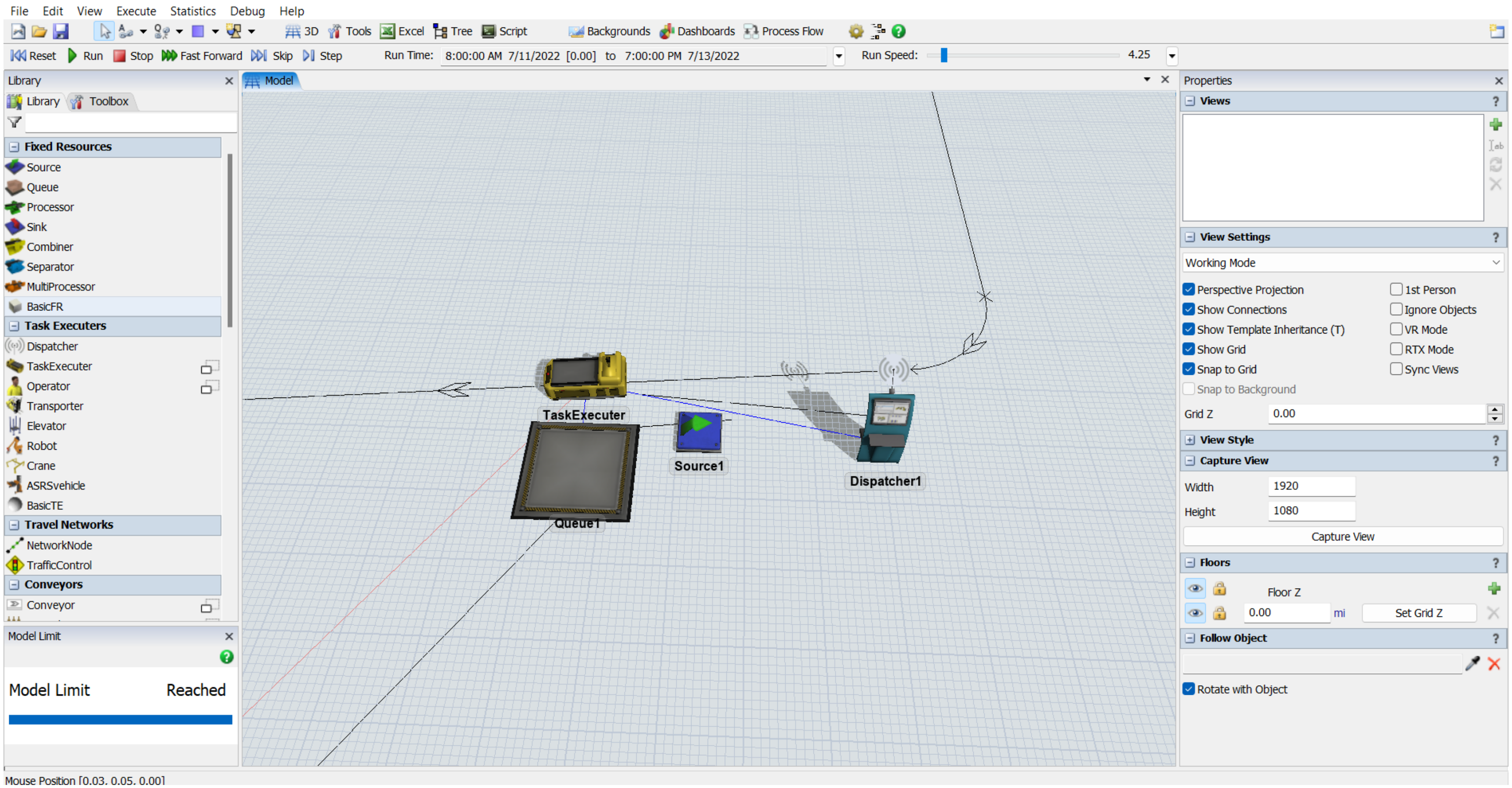


Figure 8 Objects in the FlexSim Environment.

Task executers are one of the key objects in the FlexSim library. Task executers inherit several mobile resources, such as Operators, Transporters, Elevators, Robots, Cranes, ASRS vehicles, etc. These objects can all move around, load and unload flow objects, serve as a resource sharing for processing stations, and carry out a variety of other simulation-related functions. The object in Figure 8, which is labelled as "TaskExecuter", is one of the task executers in the FlexSim environment. It provides several options for the user to define its properties, capacity, maximum speed, acceleration, deceleration, load time, unload time, etc. All the default fields can be further modified by the modeler.

Transporters and operators follow a network of paths that are defined by network nodes. Spline points can be used to alter the pathways and add curvature to that path, but by default the networked objects will take the shortest route between their starting point and the ending point. The travel network objects can be used to specify the precise routes that task executers in the simulation model can take to move from one place to another. A travel path can be formed by adding the network nodes to the model and connecting them together. The entire travel network can be developed by connecting the travel paths.

After the travel paths have been established, the 3D objects need to be connected with them. When a task executer is connected to a network node, that node serves as the task executer's point of entry into the travel network. The network node that is as near as possible to the task executer's initial reset position will be selected by the model. The task executer will show a red line between itself and the network node when it is linked to the node. When a fixed resource is connected with the network node, a blue line connecting both of them will be displayed in the model. For the task executer to travel to a fixed resource is only possible by connecting the fixed resources with the nodes, or else the task executer may not have access to the flow items from the fixed resources during the simulation run.

In the proposed model, the task executer will be connected to the automated guided vehicle (AGV) path, so the task executer becomes the traveler on the AGV network. Since, many constraints, such as traffic, driver handling of the bus, and different types of disruptions, are not considered, the task executer in this model will be emulated as an AGV for simplification purposes. Unlike AGVs which generally transport goods from one place to another, the AGV objects will transport people from one destination to another destination within the proposed simulation model.

The travel network that is created using the network node objects cannot be used to guide AGVs. The path can be created by different objects. The “straight path” object will be used to create a straight path that to be followed by AGVs to travel from one place to another. The “curved path” object will be used to create a route that has curves in the model. Moreover, the “join paths” object will be used to create a small, curved path that connects two paths. In the AGV networks, control points handle much of the logic. A control point will be required for the network entry and exit of AGVs and flow items. Control points are also used to interact with the elevator objects if the user needs to direct AGVs to different elevation levels. AGVs can loop through the network looking for tasks at various locations after connecting control points to one another.

The sink object labelled as “COE” eliminates flow components from the model. The flow items that have been processed in the model are destroyed in the sink. A flow item cannot be reclaimed after it enters a sink. The sink's OnEntry trigger (i.e., before the flow item reaches the sink) should be used for any data gathering involving flow items that are about to depart the model. The sink is a fixed resource, and it has no output logic because it destroys every flow item it receives.

Figure 8 and **Figure 9** show that each object is connected in a way to interact during the simulation run. These connections join the ports of the objects. FlexSim has two types of ports, one is the input/output port, and the other is the center port. The input/output ports control the manner of flow items as they move between fixed resources. The flow item will transfer from the output port of the first object to the input port of the following object. In the center ports, a reference point between two objects is established when their center ports are connected. The center ports enable interaction or communication between items. Most frequently, the center ports link a fixed resource to a task executor.

By using the Properties tool, we can update the properties for any object that is presently chosen in the model, which can found in the right pane of the FlexSim environment. **Figure 10** represents the properties of a source labelled as “Source1”. When objects are selected during a simulation run, we can read critical details, such statistics of throughput, minimum, maximum and average stay time etc., using the Properties pane.

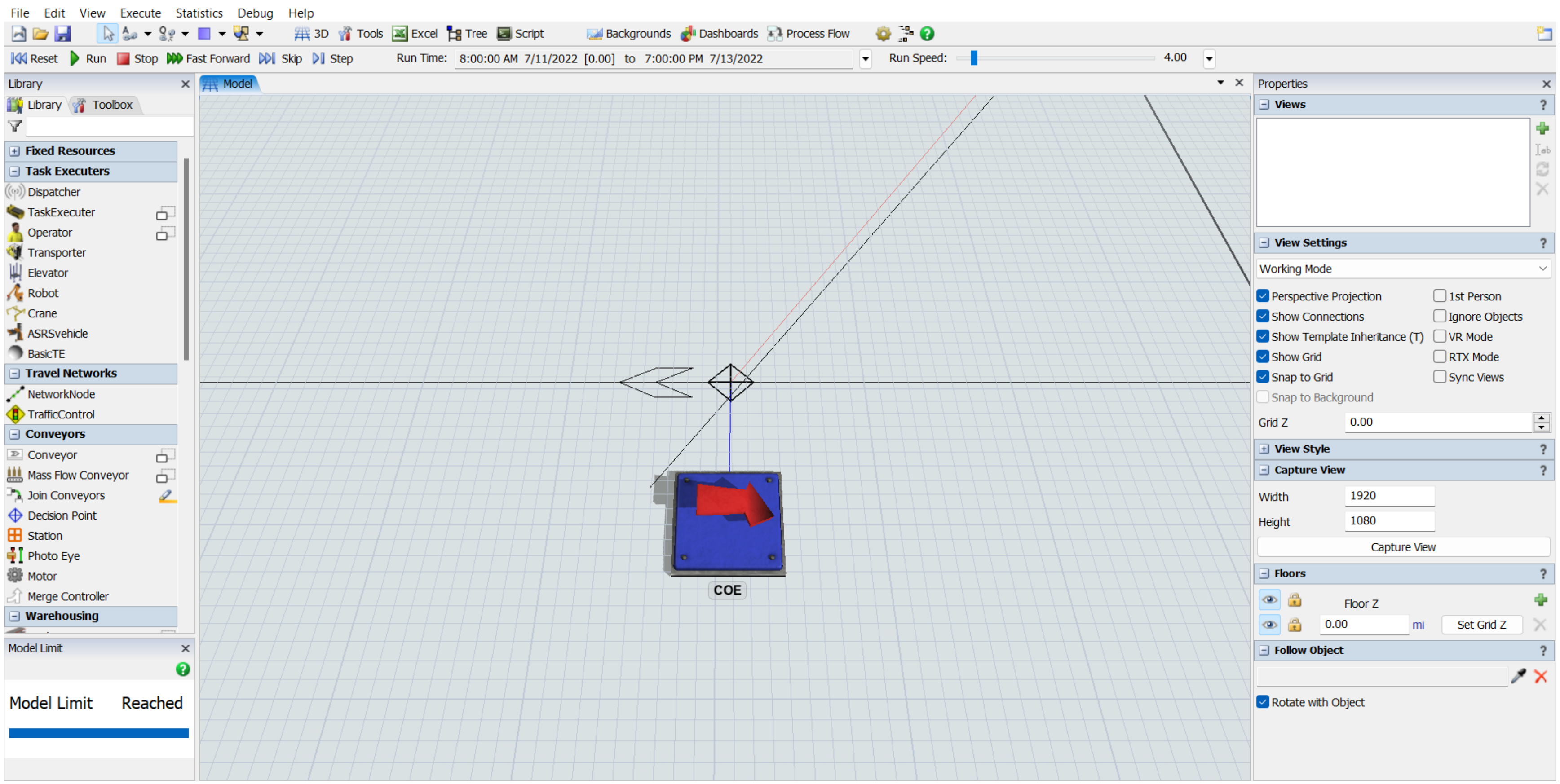


Figure 9 Sink and Control Point Objects in the FlexSim Environment.

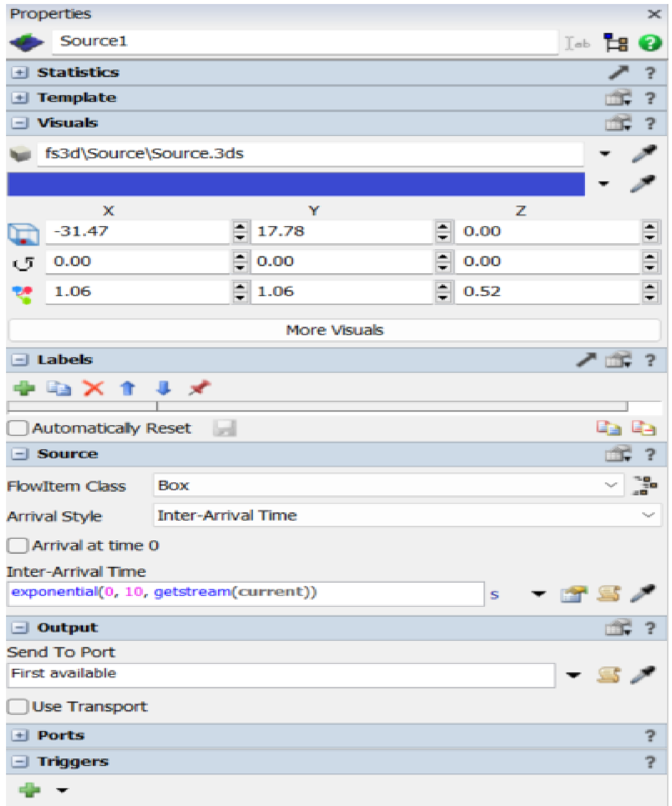


Figure 10 Properties Pane of an Object.

The following objects will be chosen in FlexSim to replicate the function of the objects in real life for the "INNOVATION" bus route:

1. Source – Passenger arrivals (flow items represent passengers using the bus service)
2. Queue – Bus stop/waiting area
3. AGV paths – Travel path
4. Task Executer – Bus
5. Sink – Exit for passengers

3.4.1 Procedure for Modelling

Firstly, the required objects are dragged from the library pane in the model, and the properties of the objects will be chosen according to the model requirements. For the source object (see Figure 11), the flow item class property is set to a person, which means the source object will release a person as a flow item into the model depending on the arrival style of the object. For the model developed in this study, the arrival style was set to arrival schedule. The schedule needs two inputs: the first one is the time the flow items need to be arrived, and the next one is the quantity of the flow items that need to be generated. The time and quantity at the bus stop queuing areas were chosen according to the course schedule and enrollments for graduate and undergraduate students. The peak hour demand was evaluated based on the number of enrollments for the courses in the Civil and Environmental Engineering (CEE) Department. For simplicity, the peak hour demand evaluated for the CEE was multiplied by five since there are five departments at the FAMU-FSU College of Engineering. All the enrolled students were assumed to use the FSU bus services to travel from the main campus to the college.

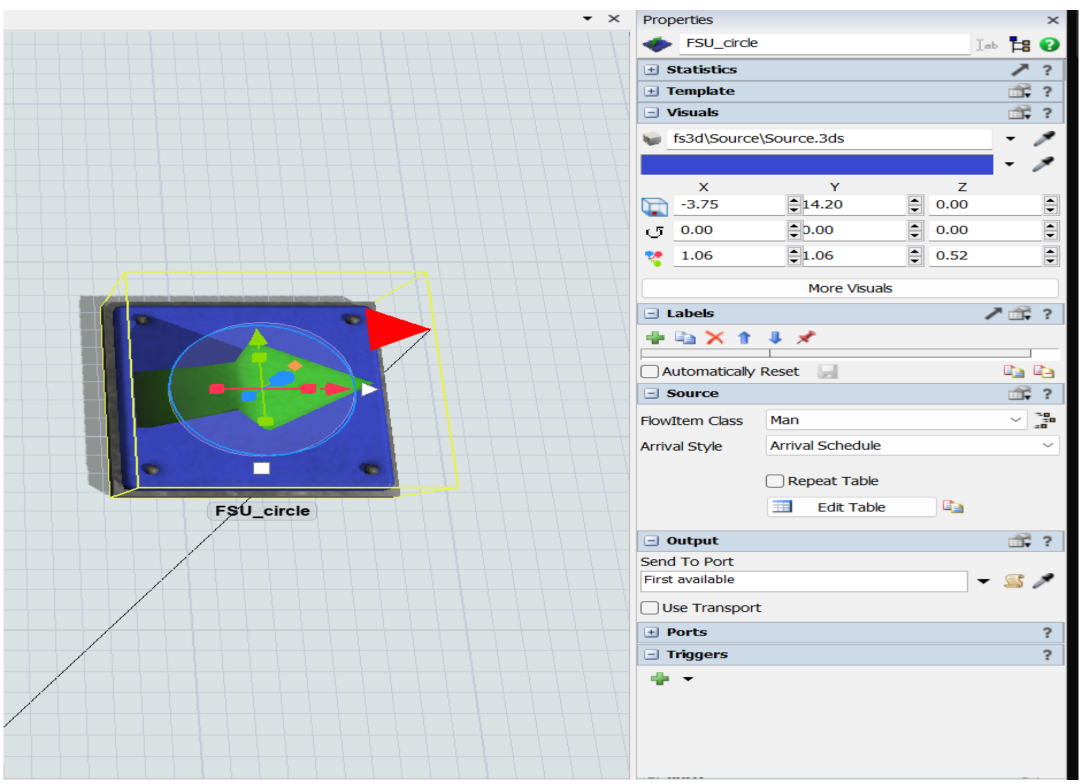


Figure 11 Source Object and Its Properties Pane.

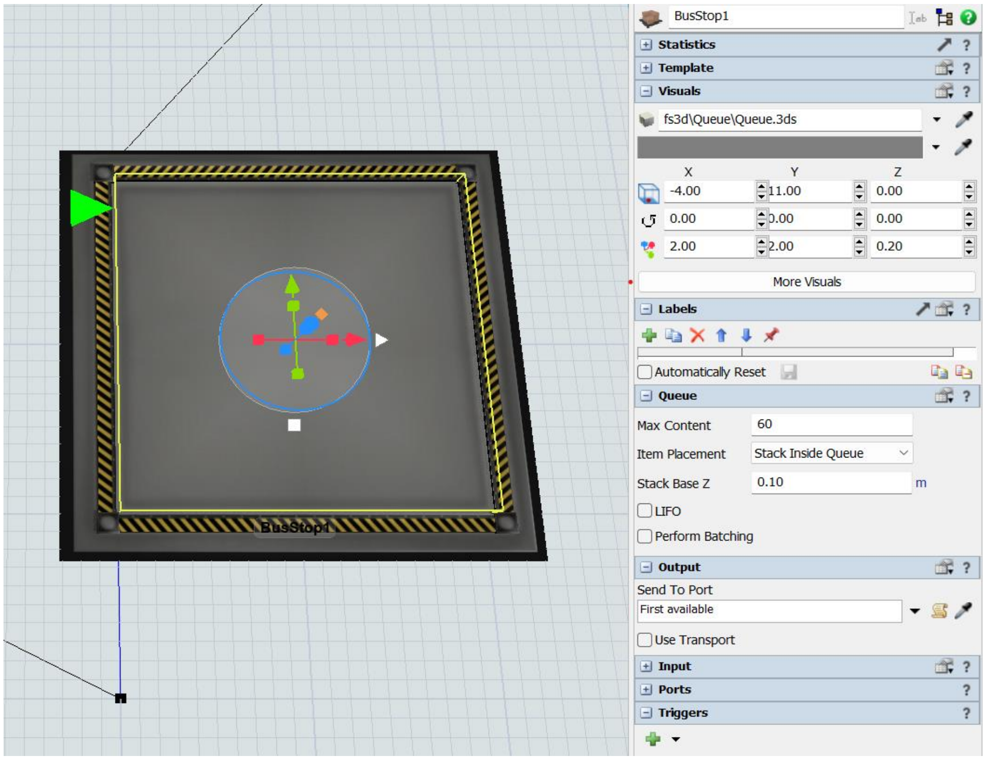


Figure 12 Queue Object and Its Properties Pane.

The item placement was set to stack inside the queue (see Figure 12). The flow items from the queue were assumed to be sent out to the following port by round robin basis, and they were sent with the use of transport, which was chosen by the name from the dropdown menu for the use transport option. The flow items were sent to each available downstream object, which are the task executers when the objects use the round robin logic. The first flow item will go to the first object, the second to the second object, and so forth.

The properties of the Task Executer object are shown in **Figure 13**. The capacity of each task executer, which replicates the bus in our model, was set to 30 passengers. The load time, unload time, acceleration, deceleration, and flip threshold were set default. **Figure 14** replicates the real scenario of the “INNOVATION” bus route. The travel paths for both inbound and outbound routes were created. Control points, straight path, curved path, and join path objects were used to create the replication of inbound and outbound routes with a control point at the bus stops. After that, the “Source”, “Queue”, and “Sink” objects were added at the bus stops.

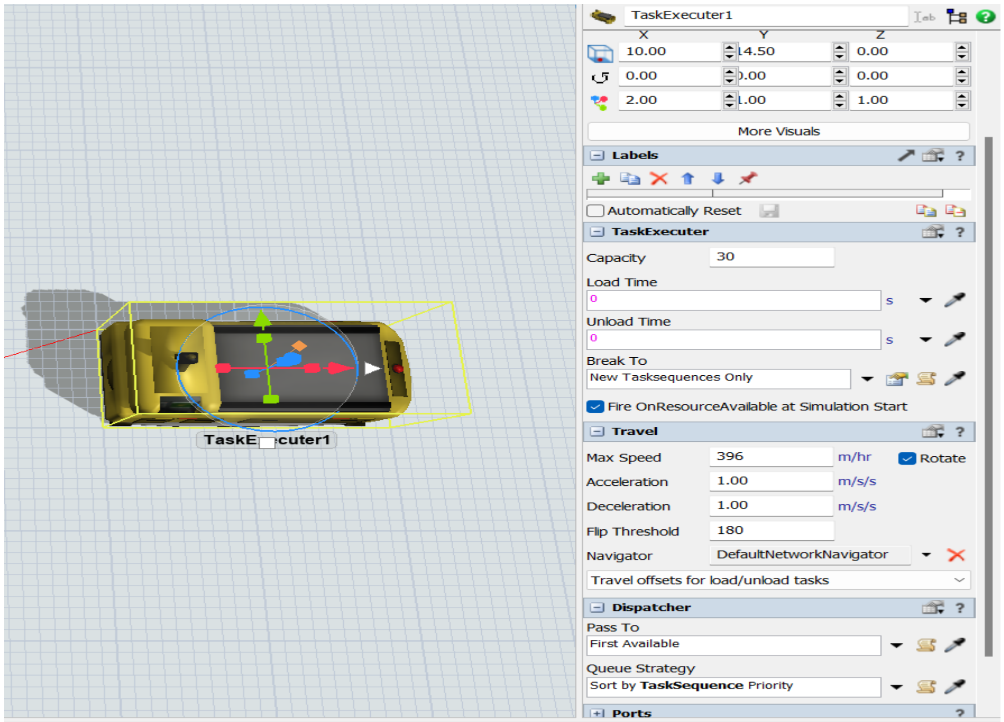


Figure 13 Task Executer and Its Properties Pane.

The source was connected to the queue object. With this connection, passengers arrived from the source and waited at the queue, which represent the bus stop for the model. The queue object was connected to the control points on the AGV travel path, which were created to replicate the bus stop location. The queue object was also connected to the sink at the bus stop. With this connection, on-board passengers from the source could be dropped at the sink of the next bus stop. The “Task Executer” object, which is the “Bus” in the model, was connected to the control point at the starting point of the route. Each bus was scheduled using the properties of the source. The arrival schedule of the passengers in the “Source” object was used to schedule the buses. The flow property of the queue was changed from default to “Use Transport”, and the transport was assigned using the “By Name” function.

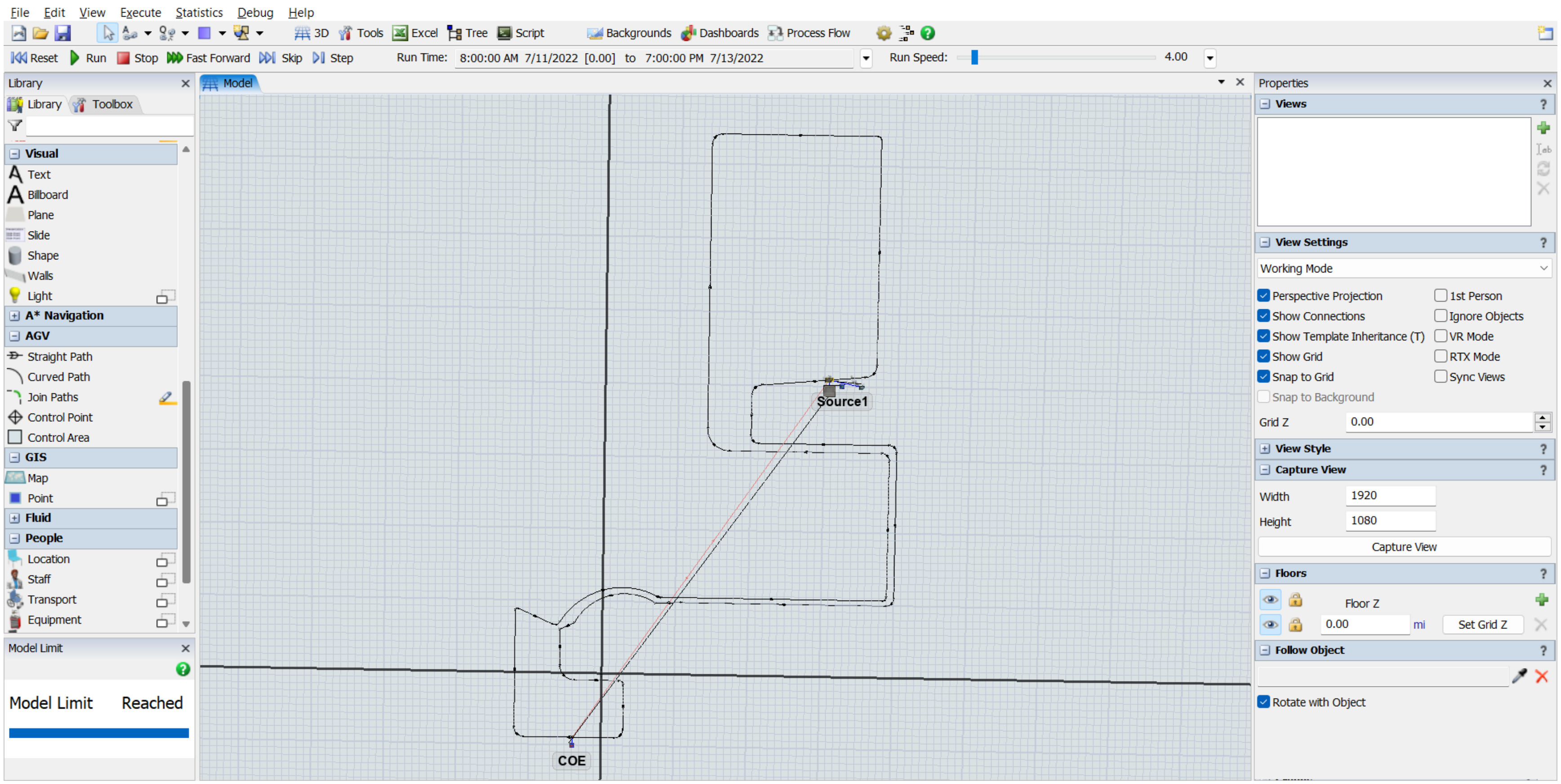


Figure 14 Simulation Model For the INNOVATION Bus Route.

3.4.2 Performance Indicators

The average content in the queue (i.e., the average number of passengers waiting at the bus stop), stay time at the bus stop, passenger waiting time versus the number of buses are the major performance indicators for this simulation model. These performance indicators depend on one another. Varying one factor can change the other factor. The number of buses scheduled for the route impacts the stay time at the bus stop and impacts the average content at the stop. The experiments were conducted by varying the number of buses scheduled for the route. Simulations were performed for the route starting with a single bus for the route with incrementing an extra bus until the route had a sufficient number of buses with the minimum possible waiting time at the bust stop (hence, the least possible stay time and the least possible number of passengers waiting at the bus stop).

CHAPTER 4

NUMERICAL EXPERIMENTS

The first experiment was performed to understand the scenario of the route being served with just one bus. The simulation was conducted for a run time of about three days. Figure 15 shows the simulation model output when the route was served by a single bus. The average number of people at the bus stop was about 936.05, and the maximum time for a passenger waiting at the bus stop was about 3,350 minutes. The results can be explained by the fact that the route was scheduled with a single bus, and the simulation was repeatedly run for three days. Excessively high waiting times and passenger queues at the bust stop indicate that one bus is not sufficient for the “INNOVATION” bus route. The following experiments discuss the results when the route was served by two and more buses.

The second experiment in Figure 16 was modeled with two buses scheduled for the route. We can see that the average number of people at the bus stop has a significant difference from the first experiment, which was dropped from 936.05 to 102.24, and the maximum stay time of the flow items at the queue was dropped from 3,350 minutes to 133 minutes. Therefore, substantial improvements in the passenger service can be observed after adding an extra bus for the route. Even though the route was served with an extra bus, it was not sufficient during the peak hour demand since the waiting time still cannot be viewed as ideal.

Results from Figure 17, which was modeled with three buses for the route, show the average number of people waiting for the bus was about 38.64, and the maximum waiting time at the stop was about 93 minutes. Figure 18 shows that the average number of people waiting at the stop was 58.93 for the model with four buses. Unlike the previous trend, when we added a bus to the model, the average number of people waiting at the stop increased from 38.64 to 58.93. In the meantime, the maximum waiting time of passengers was increased from 93 minutes to 108 minutes.

In the experiment five, the route was scheduled with five buses, as shown in Figure 19, and the simulation results show the least average number of people waiting at the stop so far, which was 37.24. The maximum waiting time for the stop was also reduced to about 100 minutes. In Figure 20, the simulation model with six buses shows an increase in the trend for the maximum stay time and the average number of people waiting at the bus stop as the bus frequency increases. The stay time was increased from 100 minutes to 102 minutes, and the average number of people waiting increased from 37.24 to 41.62. Some fluctuations were observed for the scenarios with seven and eight buses (see Figure 21 and Figure 22). These fluctuations can be explained by the adopted bus deployment strategy (round robin) and the spatial position of buses at the beginning of the model execution. The future research could explore the alternative bus deployment strategies to identify clearer patterns.

However, after a detailed analysis of the simulation results, the alternative with three buses can be viewed as promising (i.e., the average number of people waiting for the bus was about 38.64, and the maximum waiting time at the stop was about 93 minutes). The majority of passengers had a waiting time of less than 20 minutes (see Figure 17). The deployment of additional buses can reduce the waiting time (e.g., see Figure 19 with five buses) but would increase the operational cost of the considered bus service route.

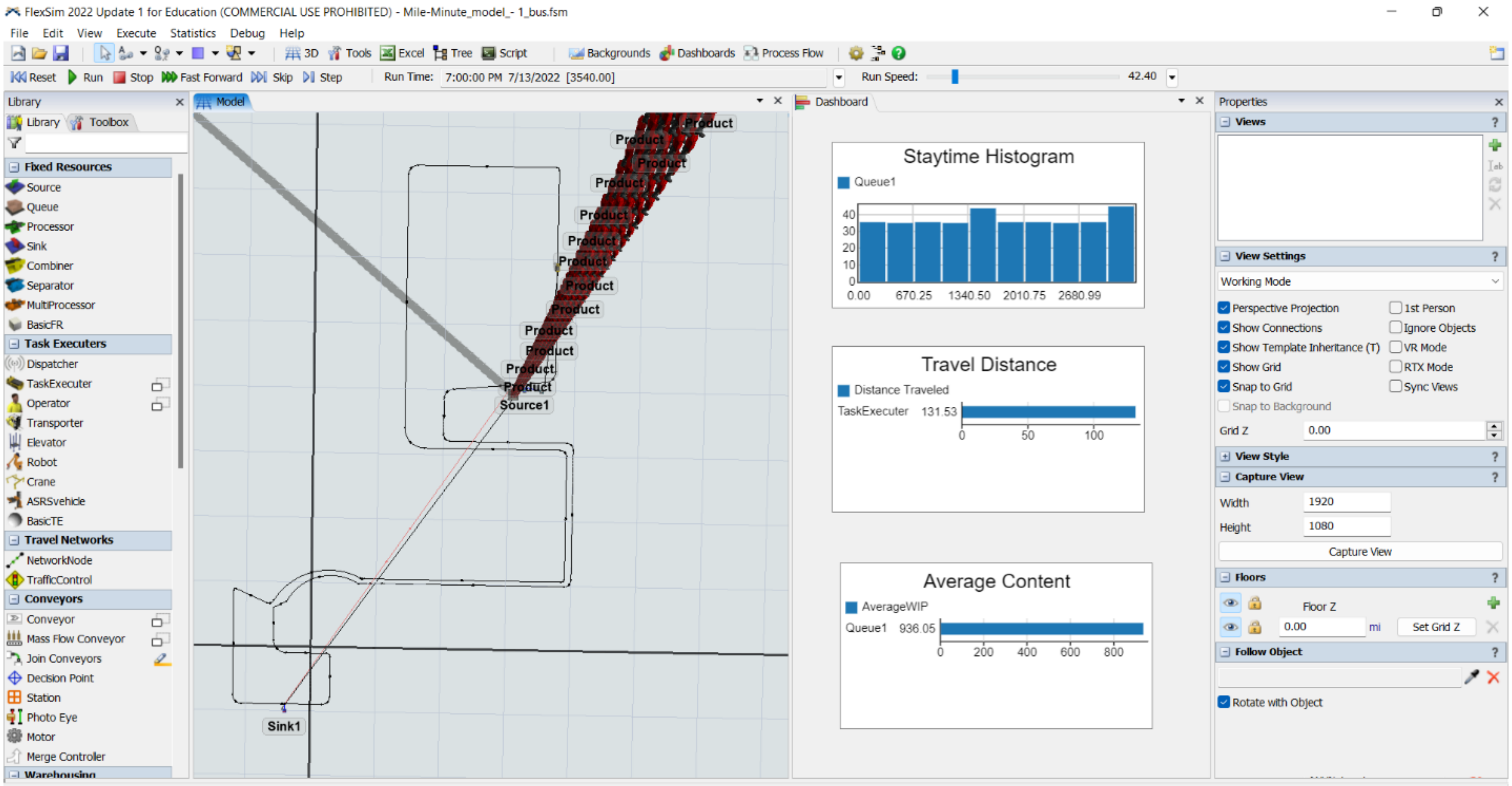


Figure 15 Simulation Model When the Route is Served with a Single Bus.

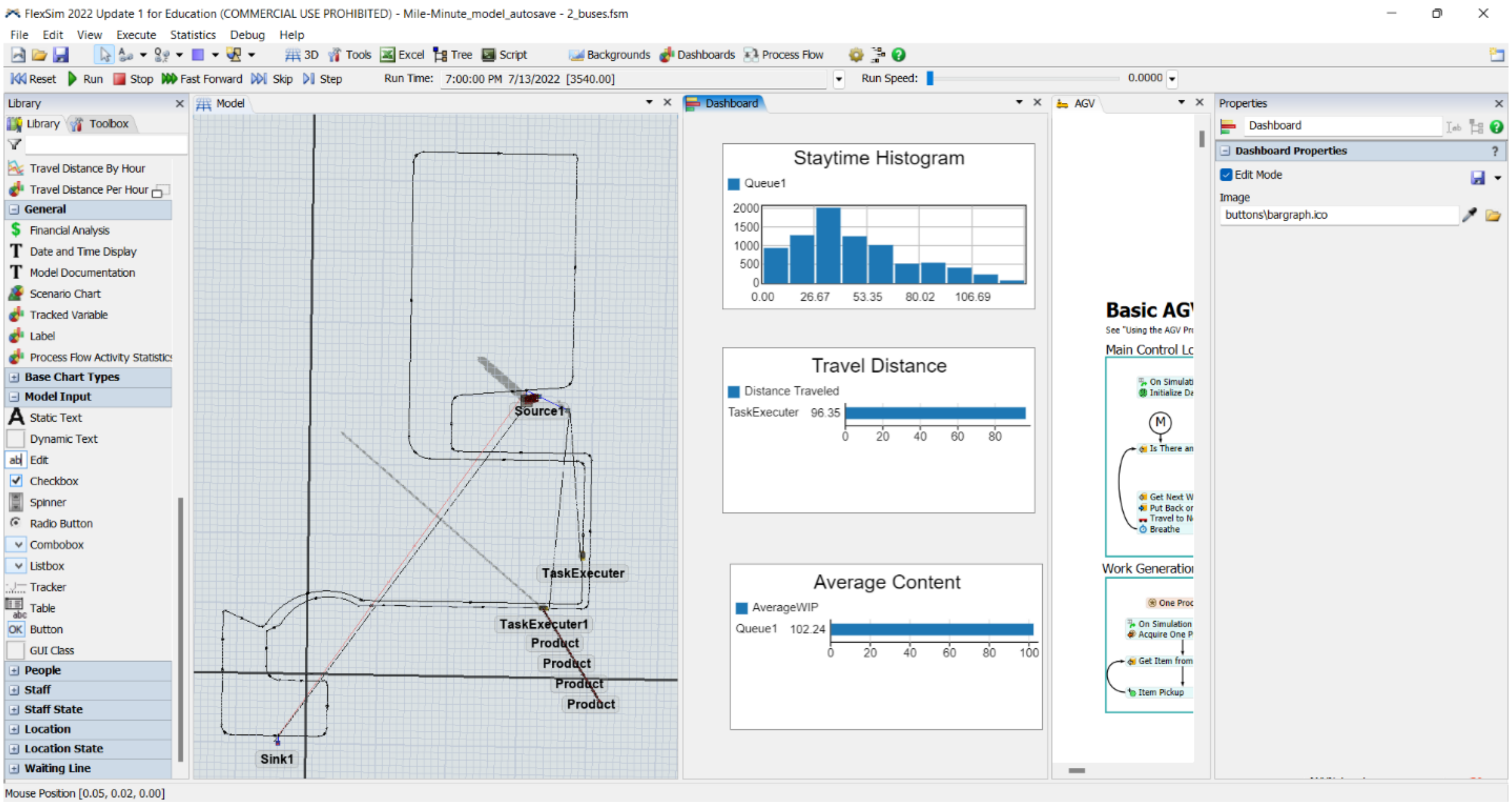


Figure 16 Simulation Model When the Route is Served with Two Buses.

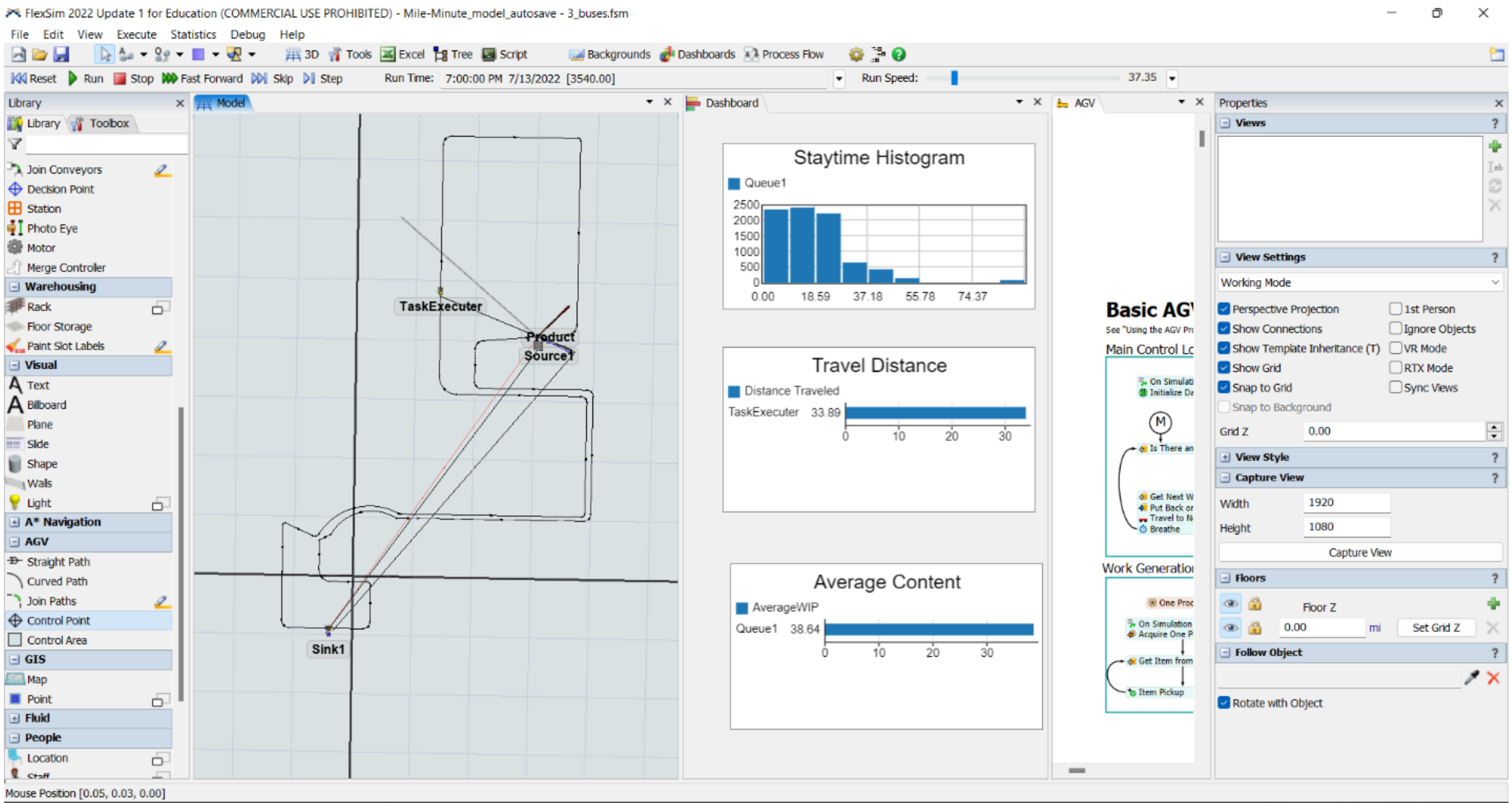


Figure 17 Simulation Model When the Route is Served with Three Buses.

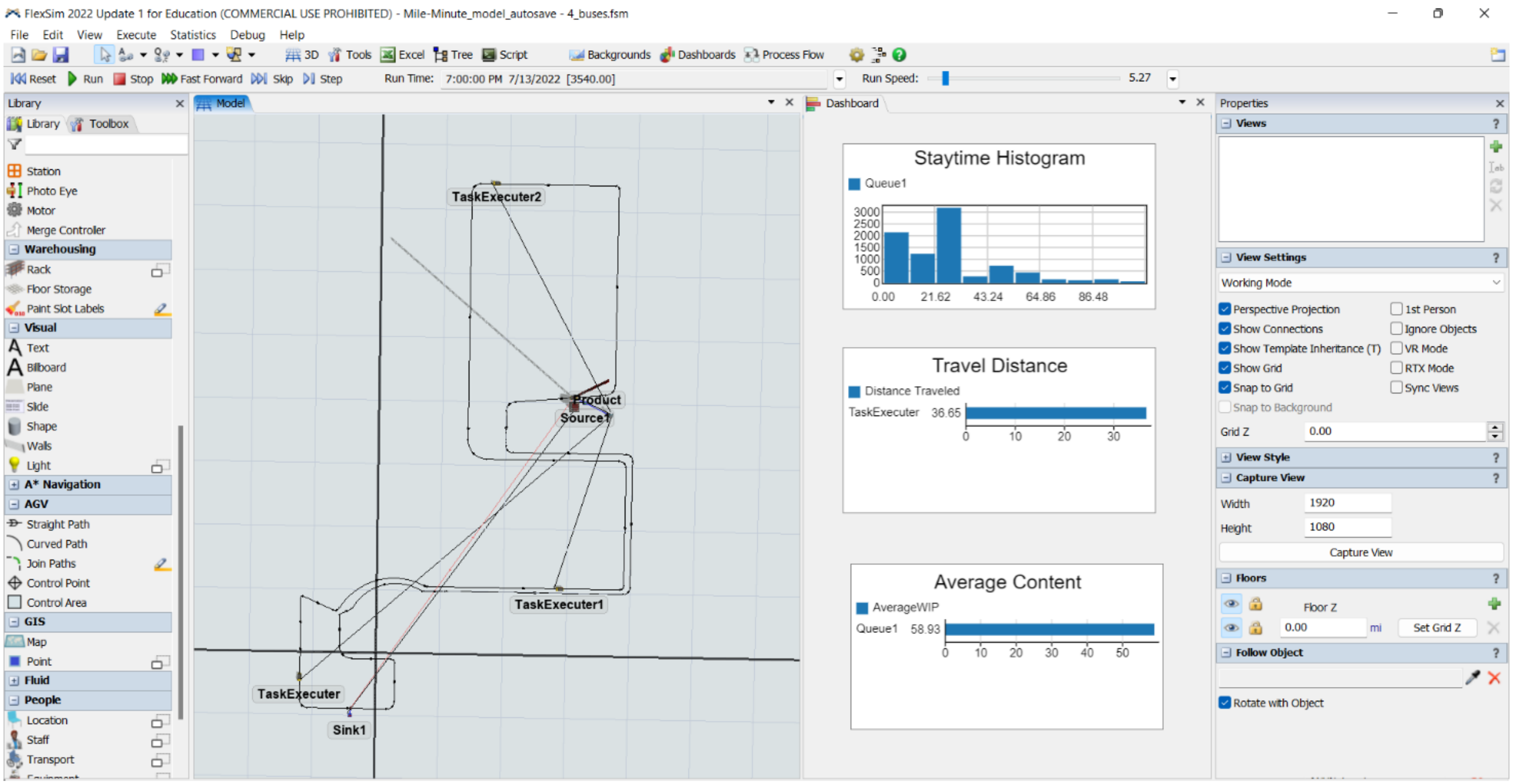


Figure 18 Simulation Model When the Route is Served with Four Buses.

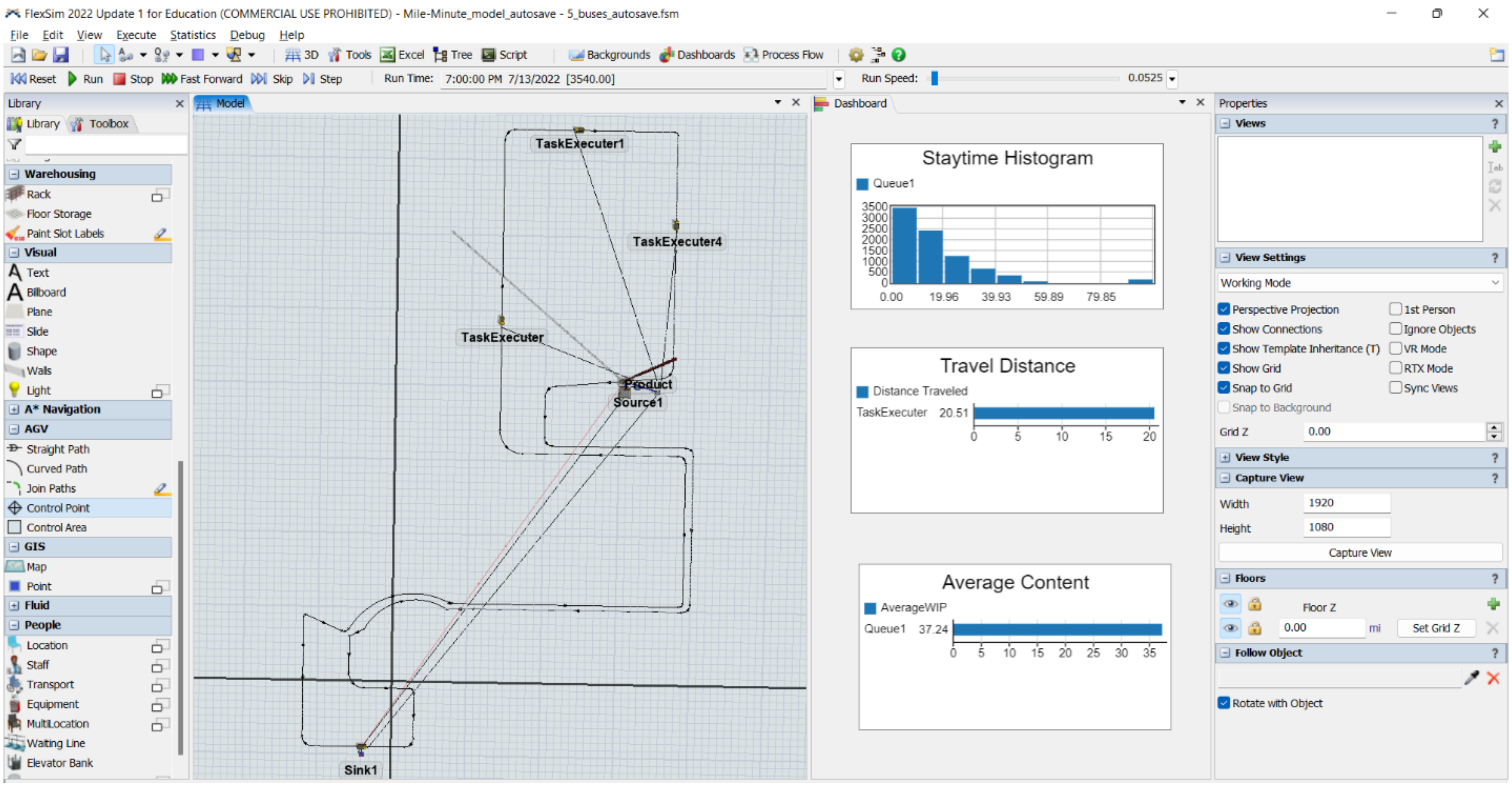


Figure 19 Simulation Model When the Route is Served with Five Buses.

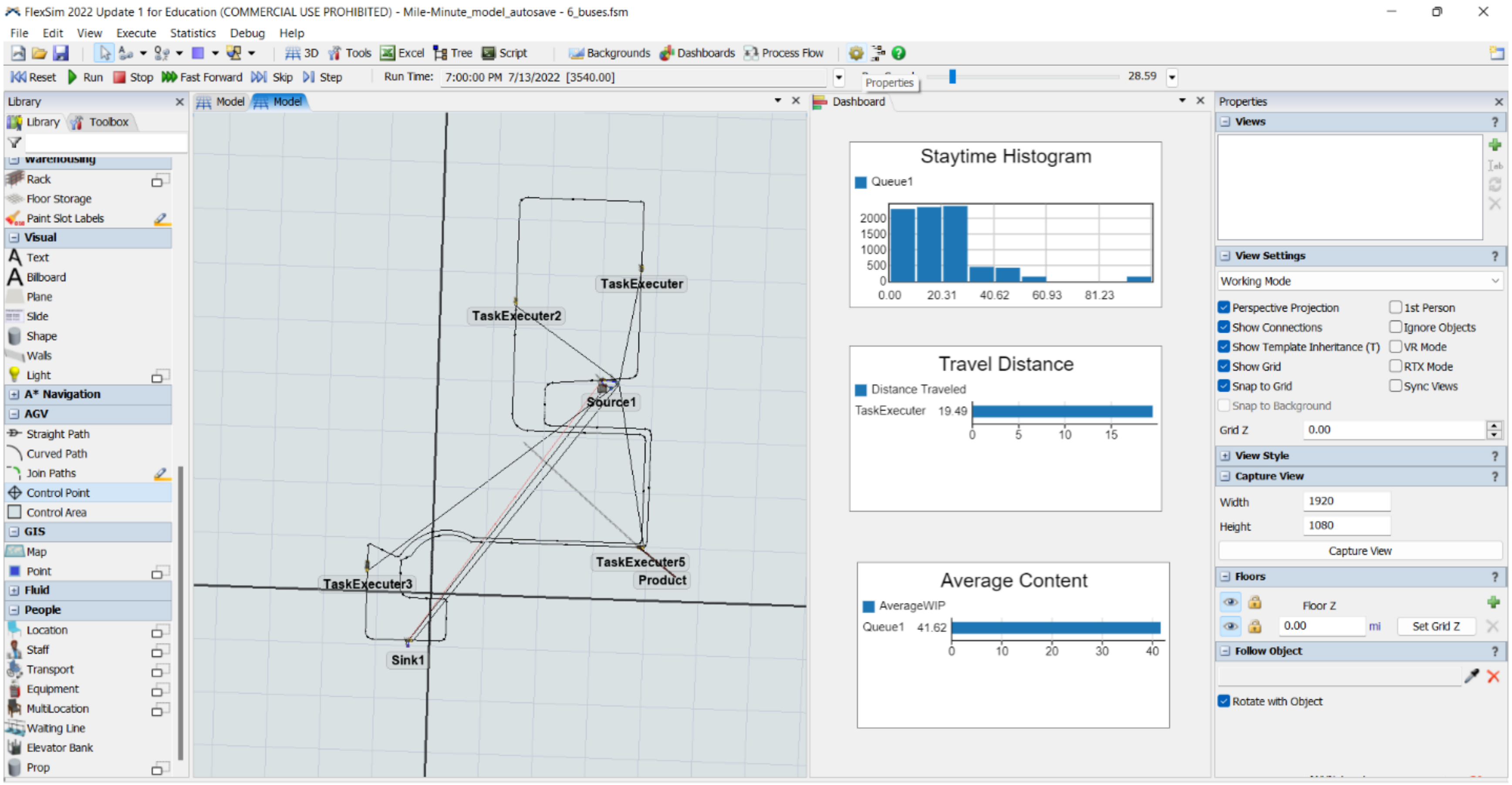


Figure 20 Simulation Model When the Route is Served with Six Buses.

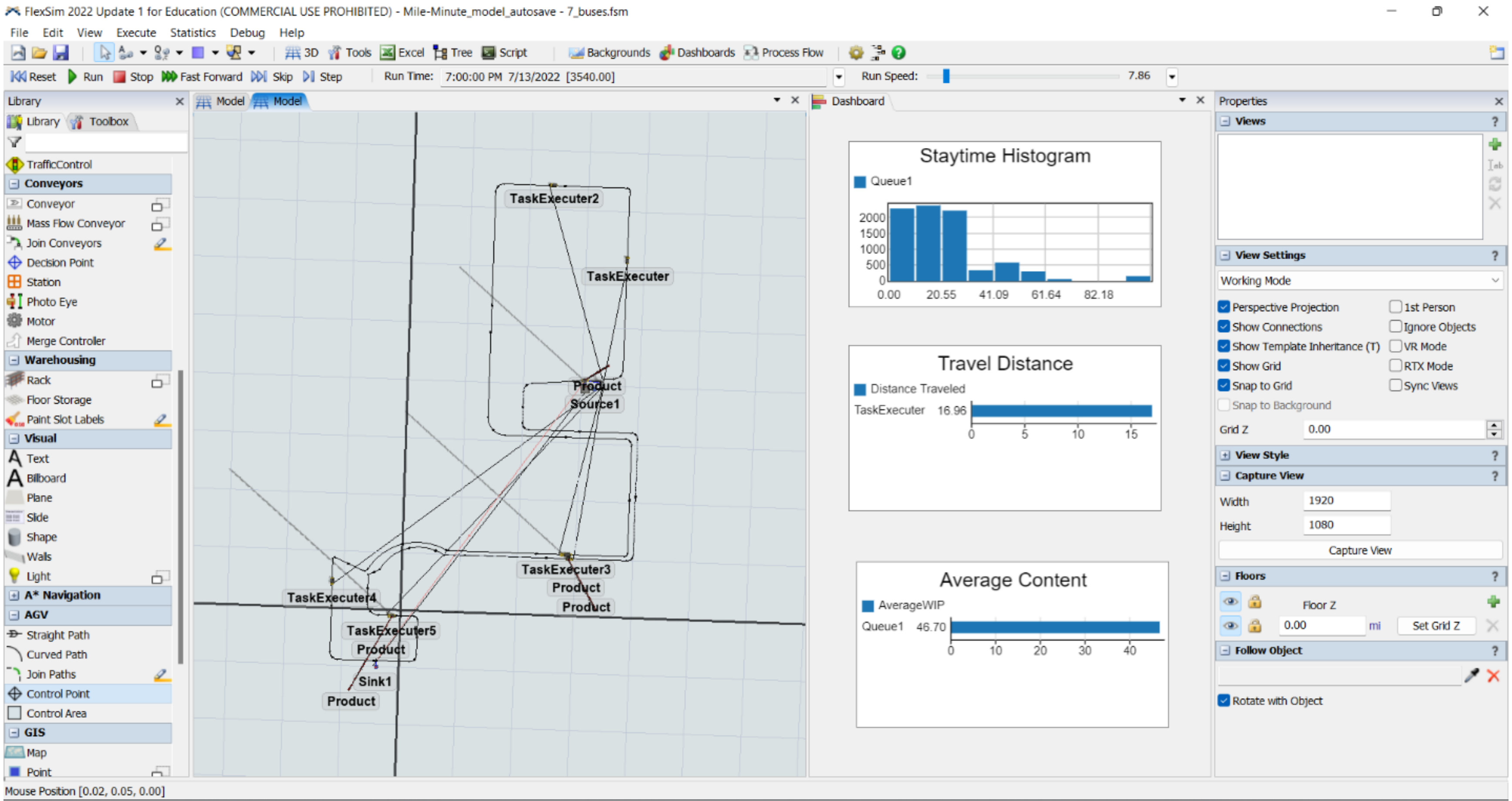


Figure 21 Simulation Model When the Route is Served with Seven Buses.

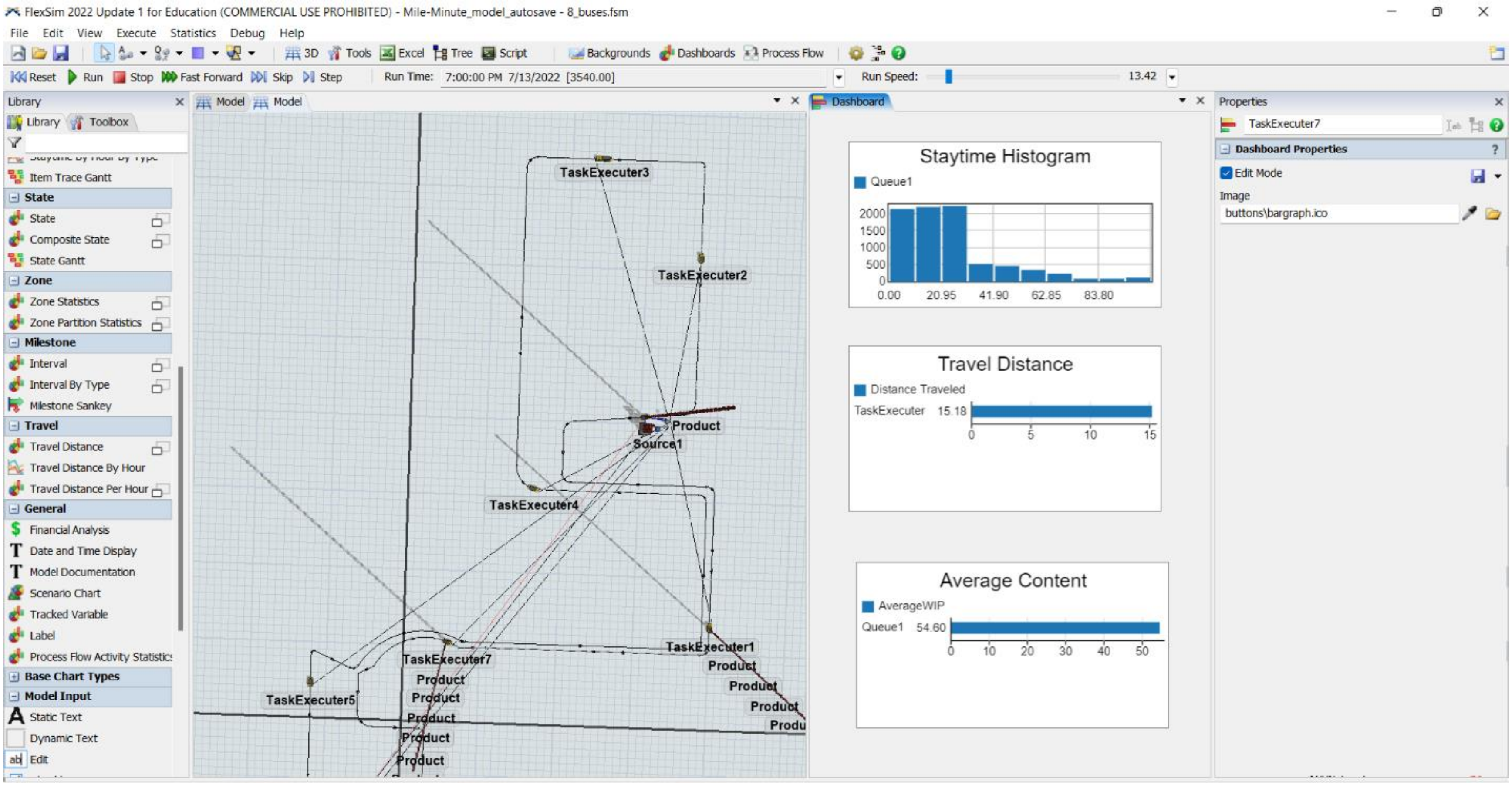


Figure 22 Simulation Model When the Route is Served with Eight Buses.

CHAPTER 5

CONCLUSIONS AND FUTURE RESEARCH

Most public transportation studies conducted worldwide were location-specific because the strategy adopted for one location may not work for another. Each location has different conditions and restrictions when we think of transportation. Whether it might be the demand from the consumers or supply from the local government for providing the service, it varies from location to location. So, this study primarily focused on a bus service “INNOVATION” provided by the FSU Seminole express, which mainly serves the students to travel between the FSU main campus and the FAMU-FSU College of Engineering (COE).

The current work presented in this study evaluated the ideal number of buses that would be required to serve the route for the peak hour demand. The peak hour demand was evaluated based on the number of enrollments for the courses in the Civil and Environmental Engineering (CEE) Department. For simplicity, the peak hour demand evaluated for the CEE was multiplied by five since there are five departments at the FAMU-FSU College of Engineering. A total of eight experiments were conducted to evaluate the ideal condition, from serving the route with a single bus in the first experiment to serving with eight buses in the final experiment. The results from the simulation model showed that “three buses” would be a promising alternative for the route, considering the average queues at the bus stop and waiting time of passengers.

Further research can be conducted on the environmental impact analysis due to the increased bus frequency. An environmental analysis can be focused on the impact of the traffic along the bus route. This can be done by evaluating the traffic movement counts along this route before and after implementing the required number of buses, especially during peak hours. The percentage change in the usage of private vehicles impacts the waiting time at the traffic signals, traffic flow, and pollution. Using the sufficient data from the above, the costs and benefits can be evaluated due to reduced waiting times, traffic incidents, and traffic flow.

Also, future research can be focused on providing information for the primary passengers, for example, students in this case. One of the main reasons for using private vehicles is because they are more reliable than other forms of transportation. Providing valuable information about the bus service for the route is essential to make the service reliable. Information, such as waiting times at the stops, number of seats available on the bus, expected charging time (in case of future electric buses), and departure and arrival times, can improve the service. Providing this information using a suitable application would improve trust of passengers, since they would know when they need to start their travel from home to a bus stop to catch a bus and reach their destination as soon as possible. Integrating this bus route service with other route services can increase the utilization of the buses, and this can only be done by optimizing the bus schedule so that passengers from one bus can board another bus with the minimum waiting times.

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