A Systems Dynamics Model to Improve Service and Maximize Benefits of Public Transit for STM

INSE 691: System Modeling and Simulation

Team Members

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Disclaimer: *This class project was conducted utilizing the research framework, design, methodology, and data analysis developed by Sarah Farahdel as part of her PhD research.*

Introduction and Scope

- Objective - Building a system dynamics model in AnyLogic software to increase service capabilities and the number of trips of the STM.
- Aim: Explore interdependencies among social sustainability indicators within STM's transit system.
- Scope - Identify and analyse the key drivers that can enhance service quality and, in turn, attract more riders to use public transit - thereby maximizing the benefits and efficiency of the system.

System Dynamics

Method for analyzing complex systems over time, utilizing stocks, flows, feedback loops, and time delays.

Stocks: Accumulation of ridership level and service quality.

Flows: Rates at which ridership level and service quality increase or decrease.

Causal loops: Determining reinforcing or balancing loops when two stock values are connected. (primary objective).

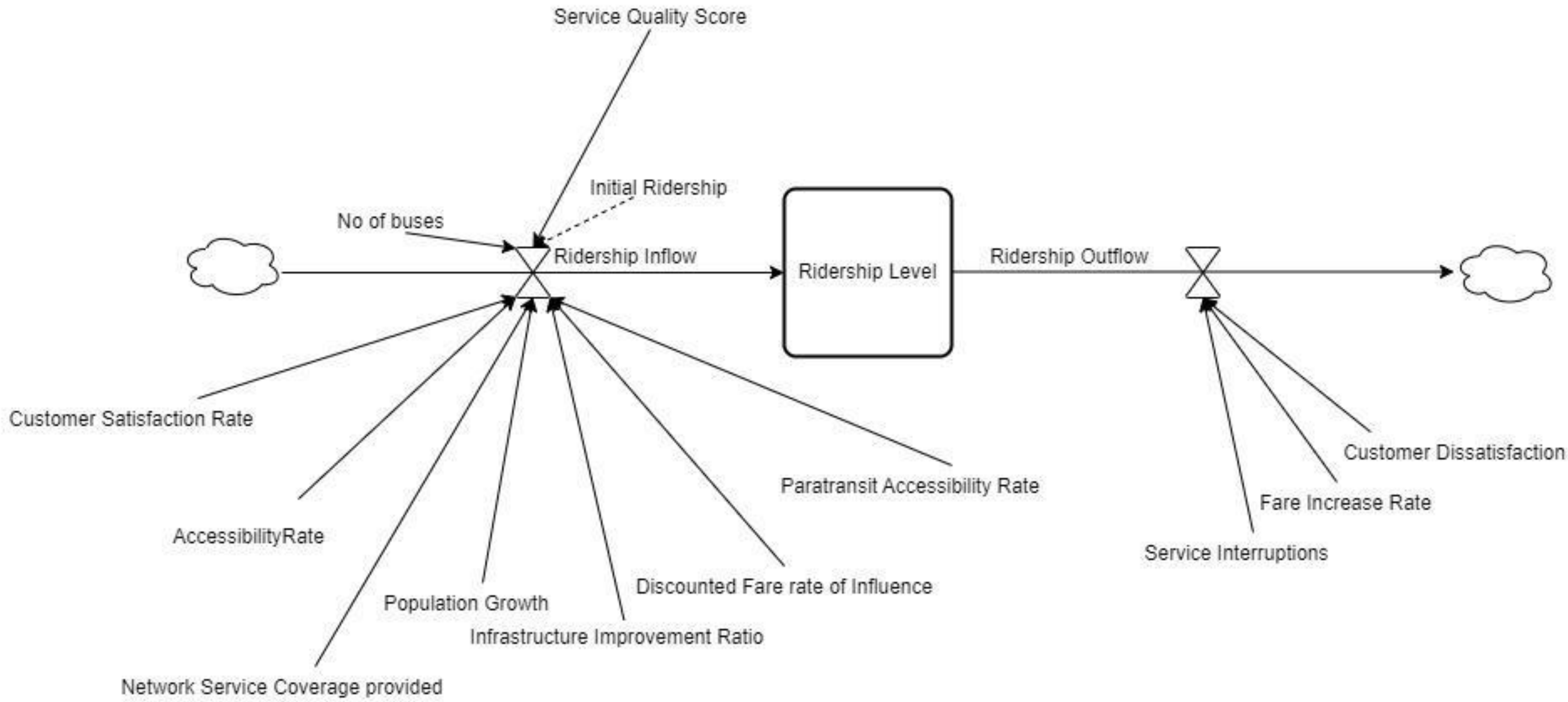
Data Utilization: Historical data from 2006 to 2014 on various social sustainability indicators and other sources.

Verification: Correlation analysis and regression analysis.

Validation: Sensitivity analysis and predictive analysis.

Description of the System

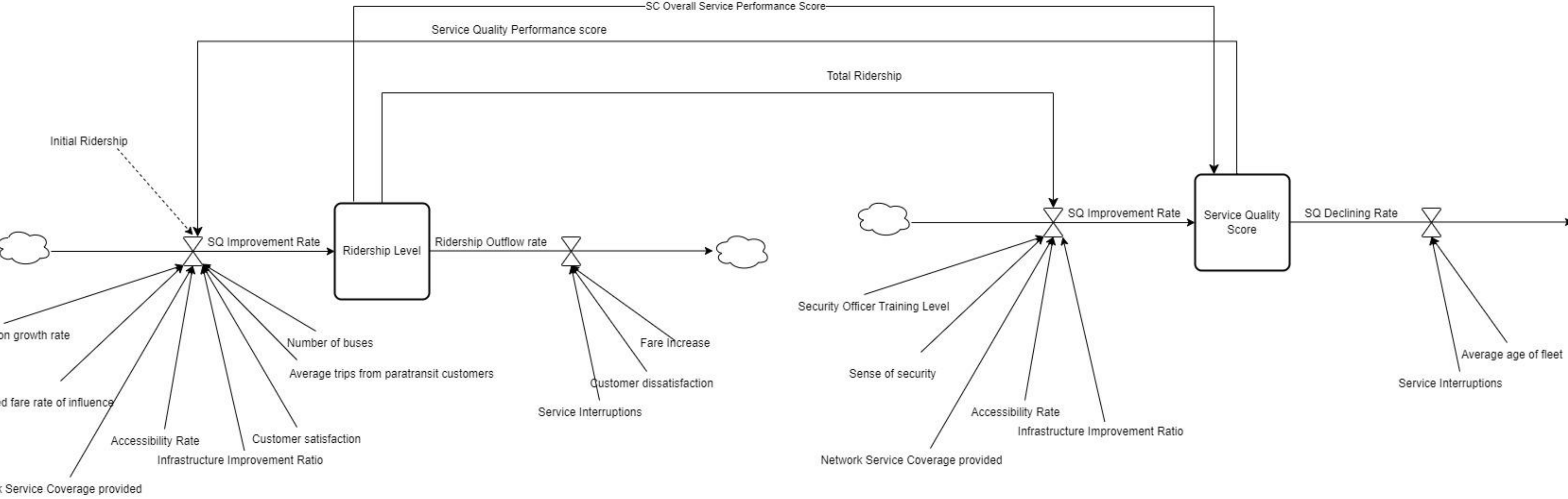
1. A dependency diagram between two stocks - Ridership level and service quality
2. Defined using various dynamic variables which changes with respect to the historic data.
3. Creation of causal loop diagram that influences both the stock levels to explore and understand the intricate dynamics of its public transit system.
4. Understanding the interconnection among the dynamic variables such as accessibility rate to create inflows and outflows.

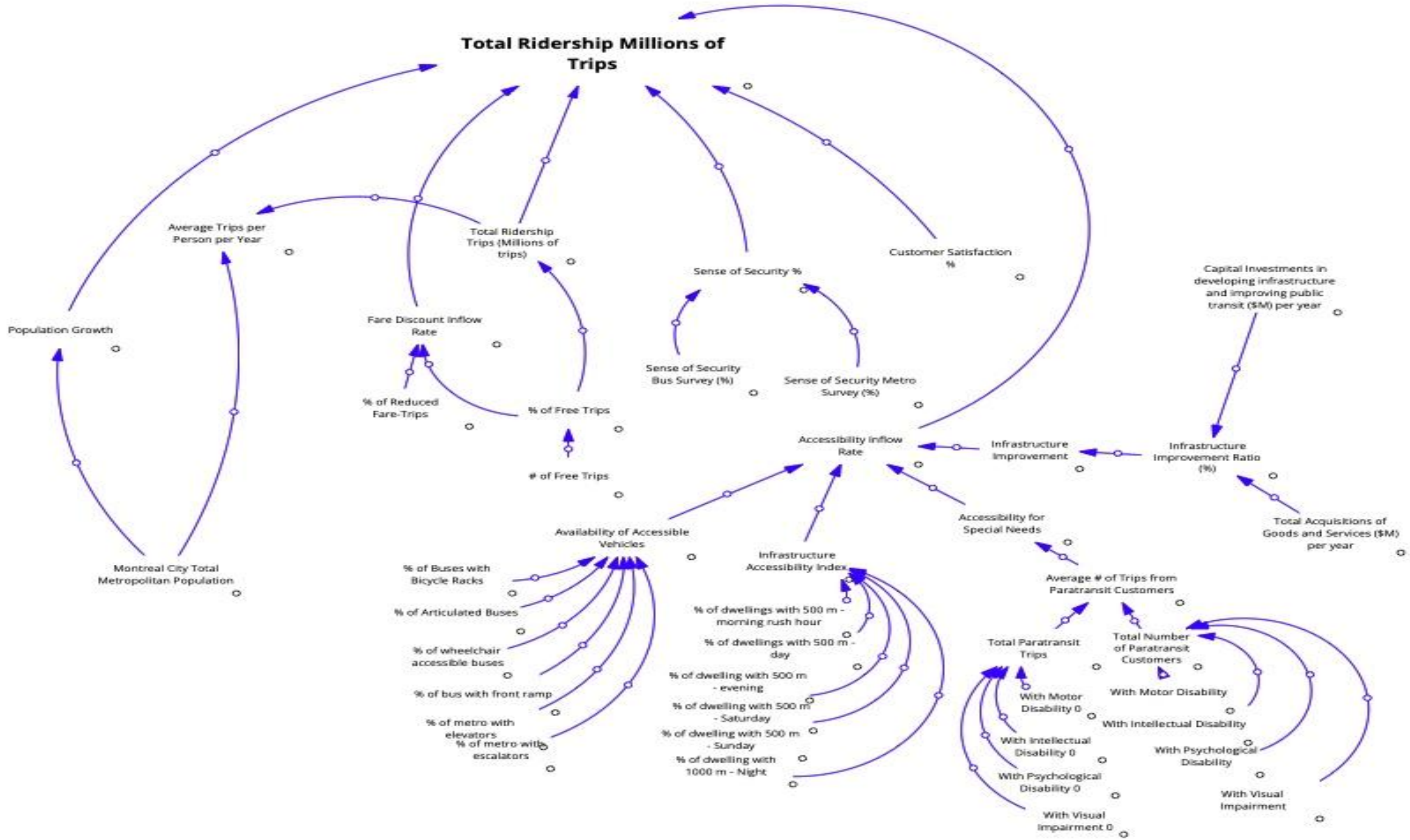

Service Quality Score
Initial Ridership
No of buses
Ridership Inflow
Ridership Level
Ridership Outflow
Customer Satisfaction Rate
AccessibilityRate
Network Service Coverage provided
Population Growth
Infrastructure Improvement Ratio
Discounted Fare rate of Influence
Paratransit Accessibility Rate
Customer Dissatisfaction
Fare Increase Rate
Service Interruptions

SQ Improvement Rate
Service Quality Score
SQ Declining Rate
Security Officer Training Level
Sense of security
Accessibility Rate
Average age of fleet
Service Interruptions

Causal Loops

- Feedback Loops- Cause and effect connections create feedback among the ridership level and service quality level
- Positive perception of both the levels using a reinforced loop.
- Creation of a service quality performance score as an indicator or variable value





Total Ridership Millions of Trips
Average Trips per Person per Year
Total Ridership Trips (Millions of trips)
Sense of Security %
Customer Satisfaction %
Capital Investments in developing infrastructure and improving public transit ($M) per year
Population Growth
Fare Discount Inflow Rate
Sense of Security Bus Survey (%)
Sense of Security Metro Survey (%)
% of Reduced Fare-Trips
% of Free Trips
# of Free Trips
Accessibility Inflow Rate
Infrastructure Improvement
Infrastructure Improvement Ratio (%)
Accessibility for Special Needs
Total Acquisitions of Goods and Services ($M) per year
Availability of Accessible Vehicles
Infrastructure Accessibility Index
Average # of Trips from Paratransit Customers
Montreal City Total Metropolitan Population
% of Buses with Bicycle Racks
% of Articulated Buses
% of wheelchair accessible buses
% of bus with front ramp
% of metro with elevators
% of metro with escalators
% of dwellings with 500 m - morning rush hour
% of dwellings with 500 m - day
% of dwelling with 500 m - evening
% of dwelling with 500 m - Saturday
% of dwelling with 500 m - Sunday
% of dwelling with 1000 m - Night
Total Paratransit Trips
Total Number of Paratransit Customers
With Motor Disability
With Motor Disability 0
With Intellectual Disability
With Intellectual Disability 0
With Psychological Disability
With Psychological Disability 0
With Visual Impairment
With Visual Impairment 0

Steps Involved

- ➔ Problem Definition: Define objectives and scope.
- ➔ System Conceptualization: Develop conceptual model outlining key components and interactions.
- ➔ Model Formulation: Translate conceptual model into formal SD model using mathematical equations.
- ➔ Data Collection: Gather historical data on ridership levels and service quality indicators.
- ➔ Simulation and Testing: Run simulations to test model behavior under different scenarios.
- ➔ Verification and Validation.
- ➔ Additional system development and continuous improvement.

Modeling Process - Questions Answered

1. What parameters should be taken into consideration before building the model? (brainstorming and data collection)

2. Which parameters are the right ones to be connected to the dynamic variables that are dependent on the flow rate of ridership as well as service quality? (developing equations)

3. What are the most effective strategies for increasing ridership while maintaining or improving service quality which can be used as an end goal for developing the system? (developing causal loop diagram)

4. How do changes in service quality influence the other stock – Ridership Level? (connecting influencing factors to test the model)

5. What are the potential impacts of variables such as fare increase, accessibility rate etc. on dynamic variables? (Creating functions to call in various values of parameters from the dataset

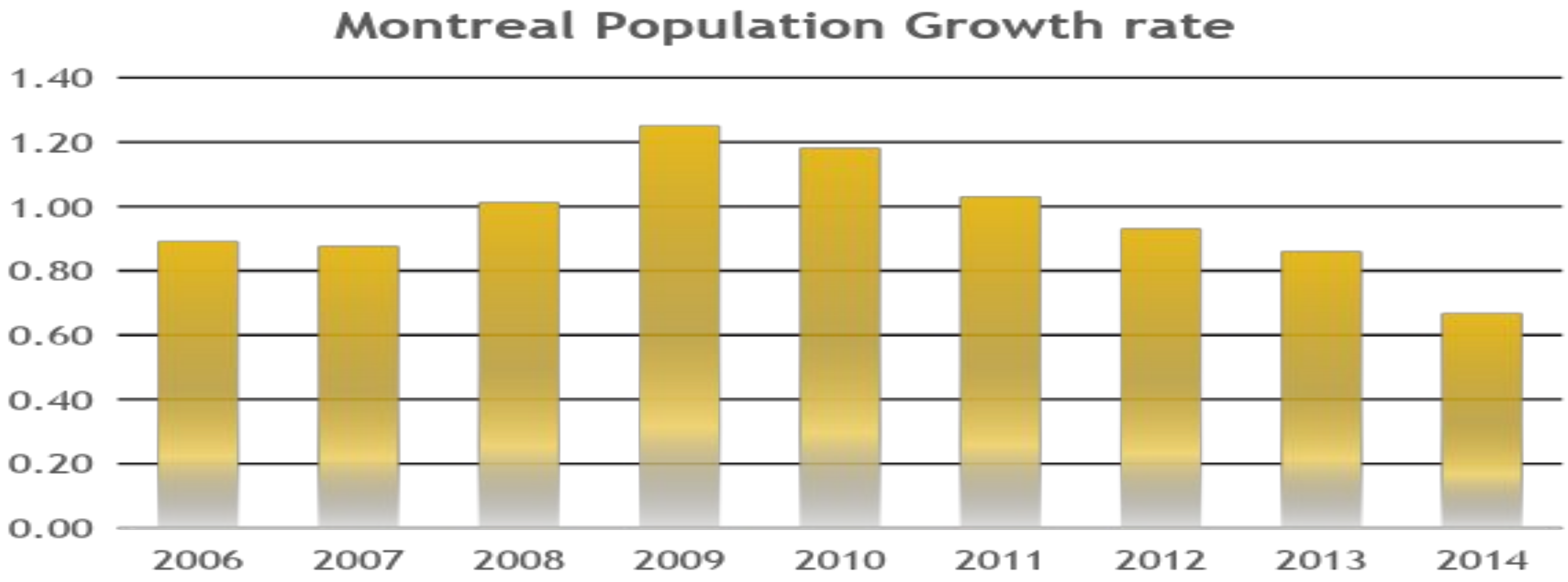
6. How can the transit system optimize its resources to achieve long-term sustainability goals? (optimisation and prospects)

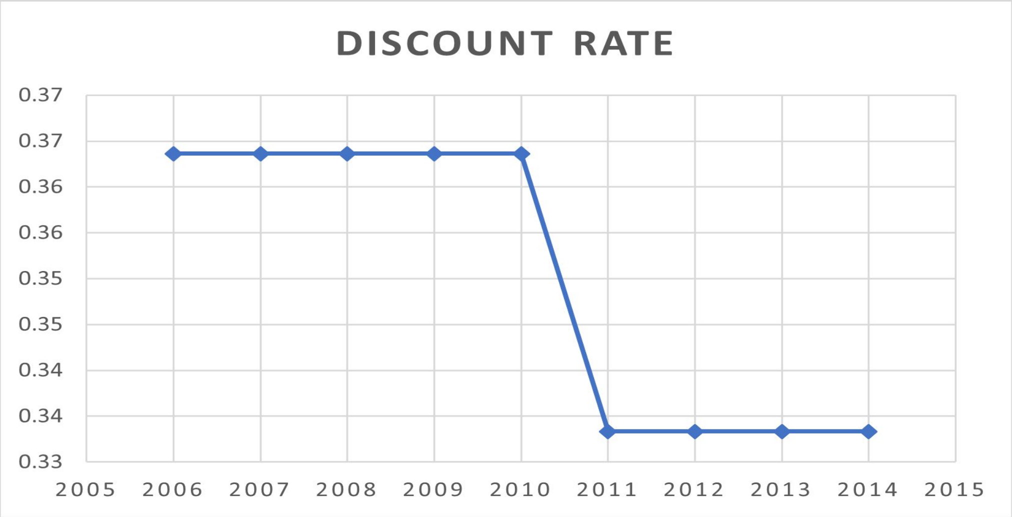
7. What values can be altered to observe various model modifications, how is the procedure verified to see accurate values, and how do the models respond to various values? (Validation and verification)

Data Availability

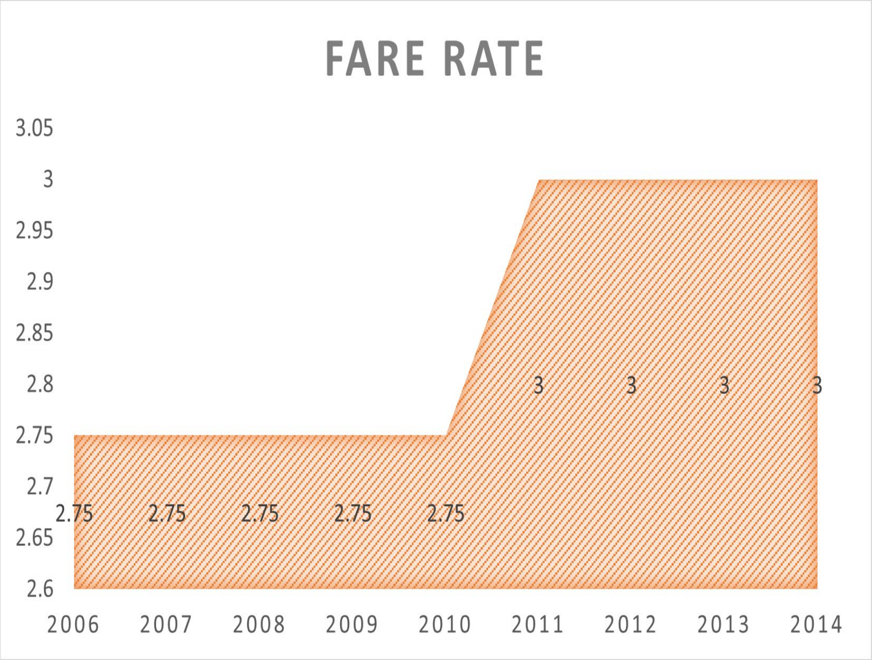
- ➔ STM Annual reports on financial indicators.
- ➔ STM Sustainability reports on social indicators.
- ➔ Other websites for referencing and analysing key dependencies.
- ➔ Statistical charts for analysing population growth rate of Montreal.
- ➔ Other sources to gather further social sustainability parameters.

The Social Dataset





The Social Dataset



Defining Dynamic Variables

- ➔ Population growth rate
- ➔ Total Number of Paratransit Trips
- ➔ Security Officer Training Level as a parameter
- ➔ Number of buses available with the STM.
- ➔ Sense of security in both metro and buses.
- ➔ Total Number of Buses in Fleet
- ➔ Total acquisition of goods and services
- ➔ Operational metrics in terms of reliability
- ➔ Dwelling Proximity
- ➔ Station and Infrastructure accessibility
- ➔ Percentage of Reduced Fare-Trips
- ➔ Total Ridership
- ➔ Network Service Coverage Provided
- ➔ Rate of Increase in Fare
- ➔ Number of free trips

Defining Dynamic Variables

- ➔ Rate of satisfaction and dissatisfaction
- ➔ Sense of Security
- ➔ Average age of fleet
- ➔ Infrastructure Improvement ratio
- ➔ Service Interruptions
- ➔ Discounted fare rate of influence

Description of the system

Structured as two interconnected diagrams:

- Ridership Level and related variables
- Service Quality and its variables

Causal relationships link these diagrams. For example, Service Quality Score influences Ridership Level through the Service Quality Overall Performance Score.

Ridership Level

Represented by the number of people using the transit service.

Influenced by factors like:

Ridership Inflow:

- Service Quality Score (Higher quality attracts more riders)
- Initial Ridership (Baseline number of users)
- Number of Buses (Service capacity)
- Customer Satisfaction Rate
- Accessibility Rate
- Population Growth
- Infrastructure Improvement Ratio
- Network Service Coverage (Wider accessibility)
- Discounted Fare Rate (Attractiveness and accessibility)
- Paratransit Accessibility Rate

    - **Ridership Outflow:**
        - Customer Dissatisfaction
        - Fare Increases
        - Service Interruptions
        - **Service Quality Score (SQS)**
- A crucial indicator for evaluating the level of services provided.
- Impacted by:
    - **SQ Improvement Rate:**
        - Total Ridership (Passenger impact on perceived quality)
        - Security Officer Training Level
        - Sense of Security
        - Accessibility Rate
        - Infrastructure Improvement Ratio
        - Network Service Coverage Provided
    - **SQ Declining Rate:**
        - Average Age of Fleet (Older vehicles decrease quality)
        - Service Interruptions

Simulation System Implementation

Defining Influential Variables

Data from various sources (sustainability reports, surveys) is used to identify and establish parameters influencing the flows. Examples include:

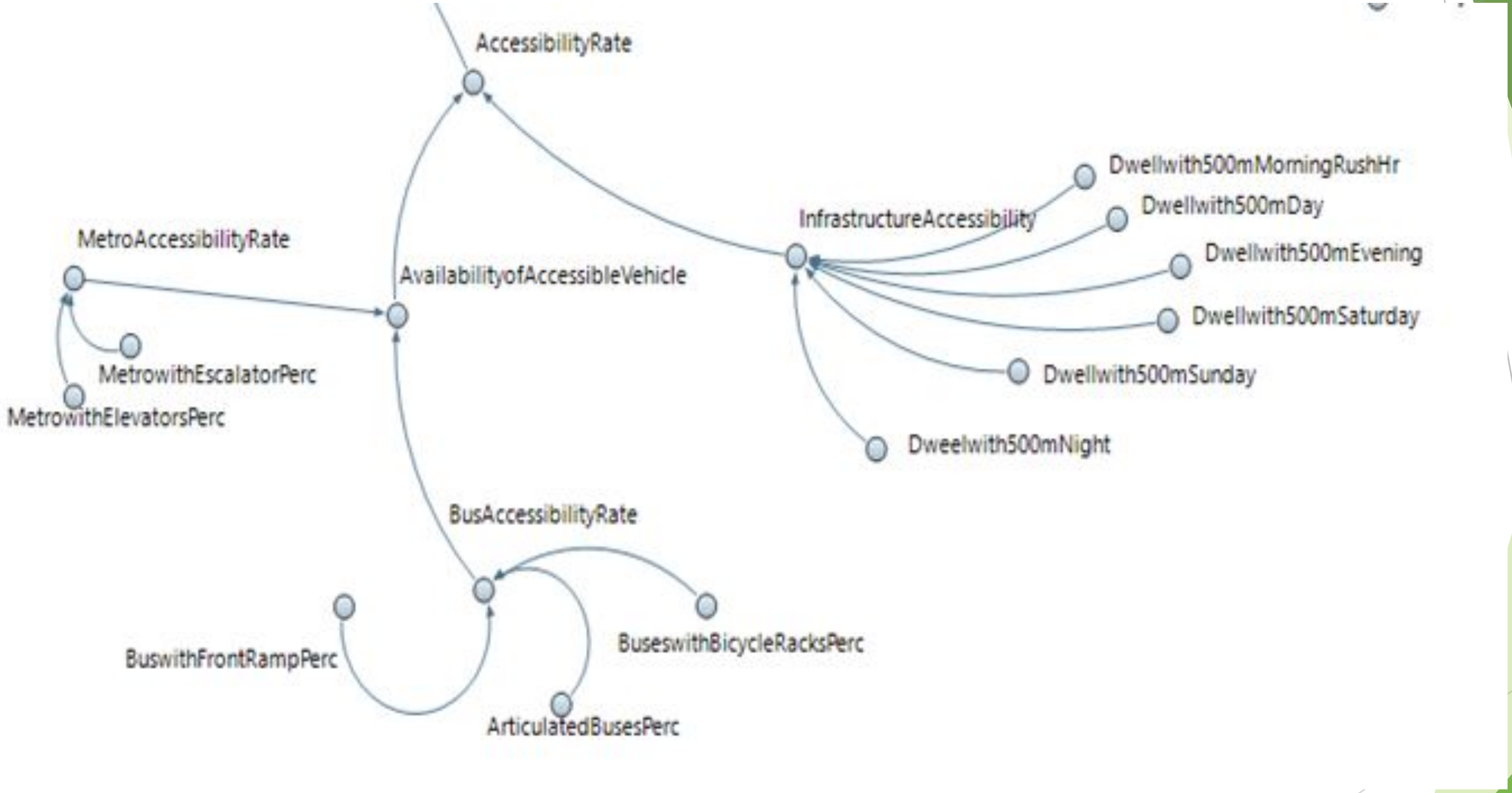
- Population growth rate
- Customer satisfaction/dissatisfaction
- Accessibility enhancements (infrastructure and vehicles)
- Equipment failure rate
- Security level
- Fare policies
- Paratransit ridership
- Capital investment
- Security officer training level
- Number of buses
- Bus fleet composition (bicycle racks, articulated buses, front ramps)
- Operational reliability (delays)
- Dwelling proximity to transit stops (various times of day)
- Metro station accessibility (elevators, escalators)
- Reduced fare-trips

- Equations are established to represent the relationships between variables.
  - Sense of Security: Overall perception of safety in metro and buses, influencing passenger satisfaction.
  - Accessibility Rate: Ease of access for all users, combining infrastructure and vehicle accessibility.
  - Network Service Coverage Provided: Extent of the transit network's reach.
  - Average Age of Fleet: Average age of buses and metro cars.
  - Infrastructure Improvement Ratio: Rate of system upgrades and maintenance, impacting service quality and ridership.
  - Service Interruptions: Frequency and severity of service disruptions.
  - Discounted Fare Rate of Influence: Impact of fare discounts on ridership.
  - Paratransit Accessibility Rate: Level of accessibility for paratransit users.

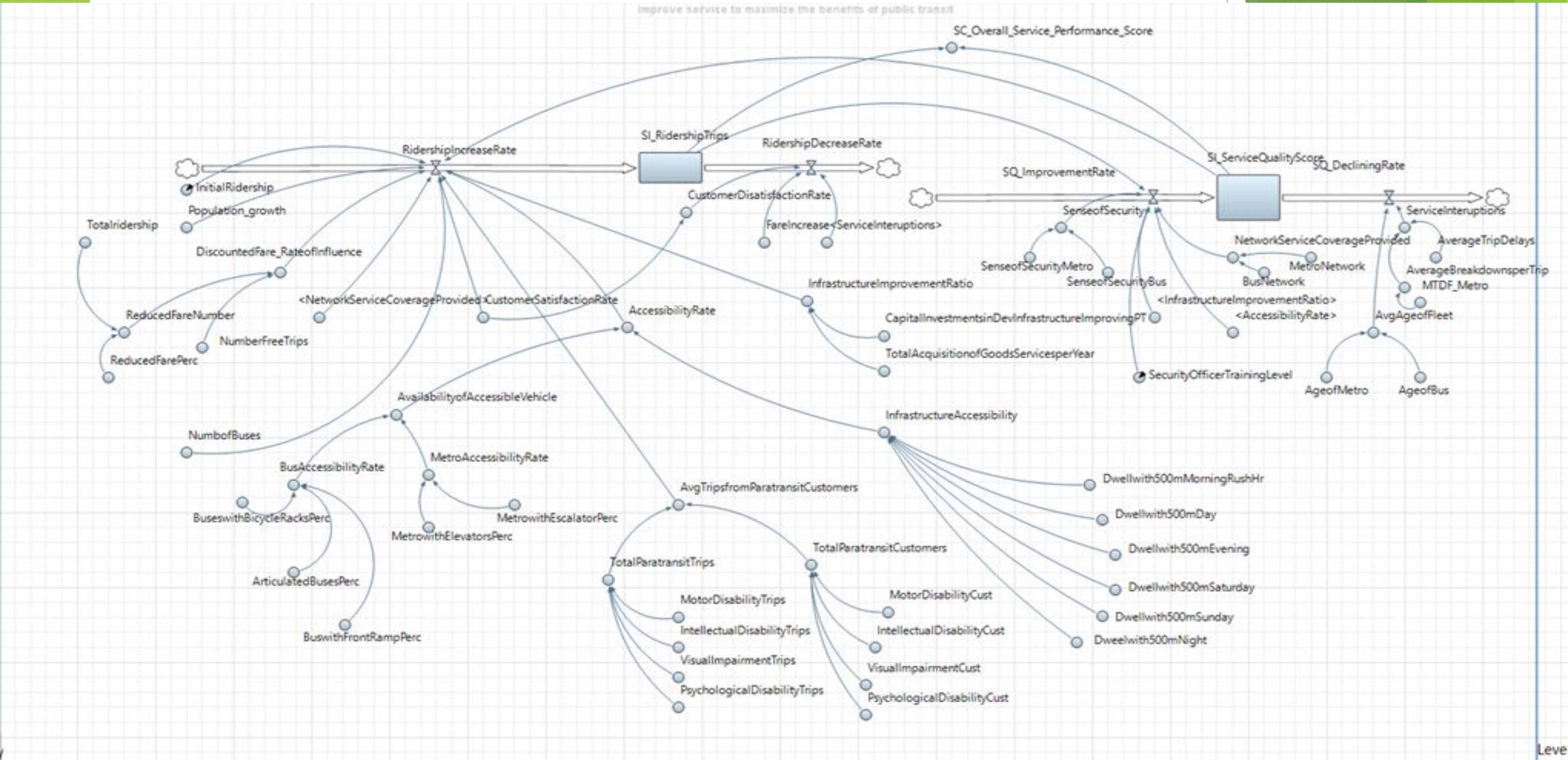
Model Benefits

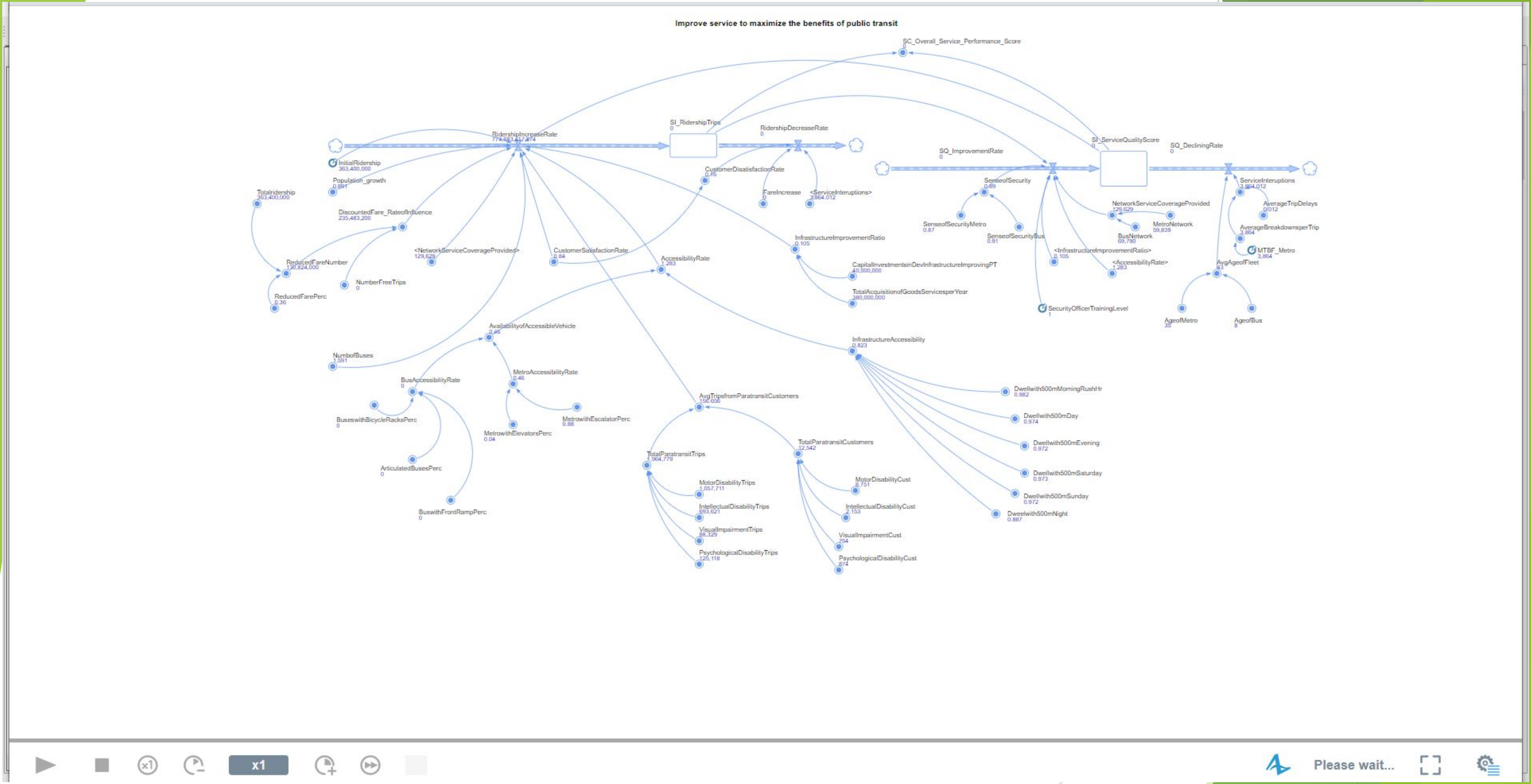
- Understand the dynamics between service quality and ridership
- Predict future trends in ridership and service quality
- Make data-driven decisions for system optimization
- Enhance social sustainability through affordability and accessibility

AvgTripsfromParatransitCustomers
TotalParatransitTrips
TotalParatransitCustomers
MotorDisabilityTrips
IntellectualDisabilityTrips
VisualImpairmentTrips
PsychologicalDisabilityTrips
MotorDisabilityCust
IntellectualDisabilityCust
VisualImpairmentCust
PsychologicalDisabilityCust


AccessibilityRate
MetroAccessibilityRate
AvailabilityofAccessibleVehicle
InfrastructureAccessibility
Dwellwith500mMorningRushHr
Dwellwith500mDay
Dwellwith500mEvening
Dwellwith500mSaturday
Dwellwith500mSunday
Dweelwith500mNight
MetrowithEscalatorPerc
MetrowithElevatorsPerc
BusAccessibilityRate
BuswithFrontRampPerc
BuseswithBicycleRacksPerc
ArticulatedBusesPerc

Implementation




Improve service to maximize the benefits of public transit
SC_Overall_Service_Performance_Score
SI_RidershipTrips
RidershipIncreaseRate
RidershipDecreaseRate
SI_ServiceQualityScore
SQ_ImprovementRate
SQ_DecliningRate
InitialRidership
Population_growth
Totalridership
DiscountedFare_RateofInfluence
ReducedFareNumber
ReducedFarePerc
NumberFreeTrips
<NetworkServiceCoverageProvided>
CustomerSatisfactionRate
CustomerDisatisfactionRate
FareIncrease
<ServiceInteruptions>
AccessibilityRate
InfrastructureImprovementRatio
CapitalInvestmentsinDevInfrastructureImprovingPT
TotalAcquisitionofGoodsServicesperYear
SenseofSecurity
SenseofSecurityMetro
SenseofSecurityBus
NetworkServiceCoverageProvided
MetroNetwork
BusNetwork
<InfrastructureImprovementRatio>
<AccessibilityRate>
SecurityOfficerTrainingLevel
ServiceInteruptions
AverageTripDelays
AverageBreakdownsperTrip
MTBF_Metro
AvgAgeofFleet
AgeofMetro
AgeofBus
AvailabilityofAccessibleVehicle
NumbofBuses
BusAccessibilityRate
MetroAccessibilityRate
BuseswithBicycleRacksPerc
ArticulatedBusesPerc
BuswithFrontRampPerc
MetrowithElevatorsPerc
MetrowithEscalatorPerc
InfrastructureAccessibility
Dwellwith500mMorningRushHr
Dwellwith500mDay
Dwellwith500mEvening
Dwellwith500mSaturday
Dwellwith500mSunday
Dweelwith500mNight
AvgTripsfromParatransitCustomers
TotalParatransitTrips
TotalParatransitCustomers
MotorDisabilityTrips
IntellectualDisabilityTrips
VisualImpairmentTrips
PsychologicalDisabilityTrips
MotorDisabilityCust
IntellectualDisabilityCust
VisualImpairmentCust
PsychologicalDisabilityCust
x1
Please wait...

Using linear regression, the tested Inflow rate and outflow rate of ridership level and service quality level are mentioned below:

Ridership Increase Rate = (Population growth x -56470000) + (Network Service Coverage Provided x 1806.5578) + (Infrastructure Improvement Ratio x -21750000) + Initial Ridership + (Customer Satisfaction Rate x 219200000) + (Accessibility Rate x -114900000) + (Discounted Fare Rate of Influence x -0.1916) + (SI Service Quality Score x 47690000) + (Number of Buses x -143700) + (Average Trips from Paratransit Customers x -374600) + 525400000

Ridership Decrease Rate = (Customer Dissatisfaction Rate x -107800000) + (Fare Increase x 351400000) + (Service interruptions x -381000000) + 399100000

Service Quality Improvement Rate = (Sense of Security x 13.5264) + (Accessibility Rate x 0.4941) + Security Officer Training Level + (Network Service Coverage Provided x 0.000005797) + (Infrastructure Improvement Ratio x -0.5282) + (SI Ridership Trips x 0.0000000007788) + -13.8509

Service Quality Declining Rate = (Average Age of Fleet x 0.1310) + (Service Interruptions x 32.1900) + -6.0412

Then, another algorithm (Ridge regression) is used to test it again.

Using ridge regression, the tested Inflow rate and outflow rate of ridership level and service quality level are mentioned below:

Ridership Increase Rate = (Population growth x -2961082.903265464) + (Network Service Coverage Provided x 3964623.043734427) + (Infrastructure Improvement Ratio x 3043965.9452915816)+ Initial Ridership + (Customer Satisfaction Rate x 285177.6661953458) + (Accessibility Rate x 1902041.2240823647)+ (Discounted Fare Rate of Influence x 4925824.7209089445) + (SI Service Quality Score x 2662485.2886600737) + (Number of Buses*2123833.910029024) + (Average Trips from Para transit Customers x -1147113.1980347312) + 393148208.636197

Ridership Decrease Rate = (Customer Dissatisfaction Rate x -4760698.105800799) + (Fare Increase x 10348287.315796513) + (Service interruptions x -3125059.3947411813) + 391786237.4749965

(SenseofSecurity x 0.07882208967083519) + (Accessibility Rate x 0.08737008149756291) + (Network Service Coverage Provided x 0.05903564460948984) + (Infrastructure Improvement Ratio x 0.05104743950421533) + (SI_RidershipTrips x 0.045355233539337125) + 0.3921025675527193 + Security Officer Training Level

Service Quality Declining Rate = (Average Age of Fleet x 0.1310) + (Service Interruptions x 32.1900) + -6.0412

Event Updation Element

- We developed a code that is designed to dynamically update and retrieve various transportation-related statistics for a given year, initially set to 2006.
- getValueFromTable, to access values from pre-defined tables corresponding to different variables
- Each dynamic variable has a dedicated method that invokes this helper method to fetch the relevant value.
- The updateYear method increments the current_year and traces/logs updated values for all dynamic variables, thus simulating a year-by-year update of these statistics.
- The main function demonstrates the incrementing process.
- This approach ensures that the variables are kept current and reflect the latest available data.

Verification and Validation

Methods Verification:

Model Inspection
Structural Verification
a.Correlation Analysis
b.Regression Analysis
Dimensional Verification

Methods Validation:

Baseline Testing
Sensitivity Analysis
Predictive Analysis

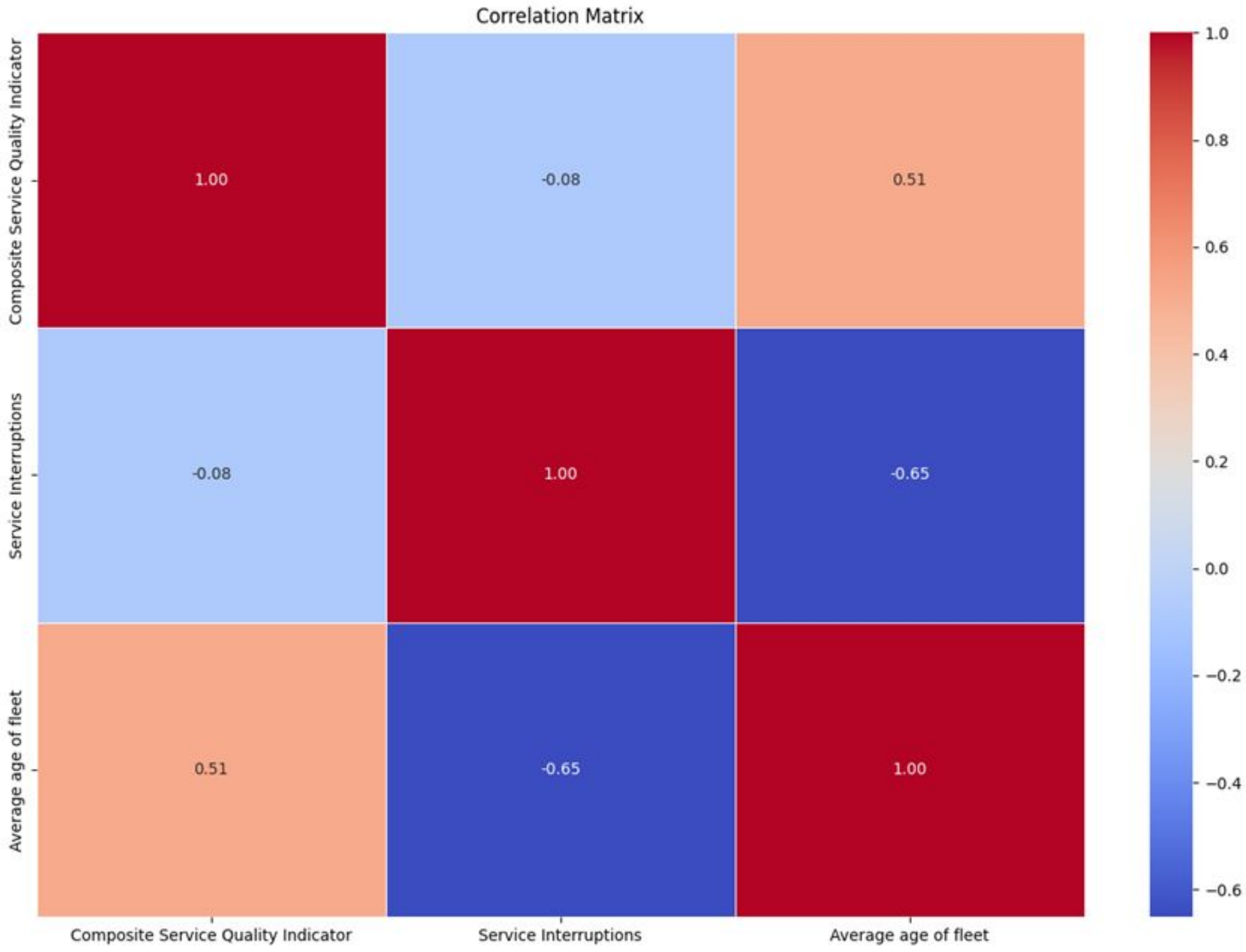
Verification and Validation

Verification:

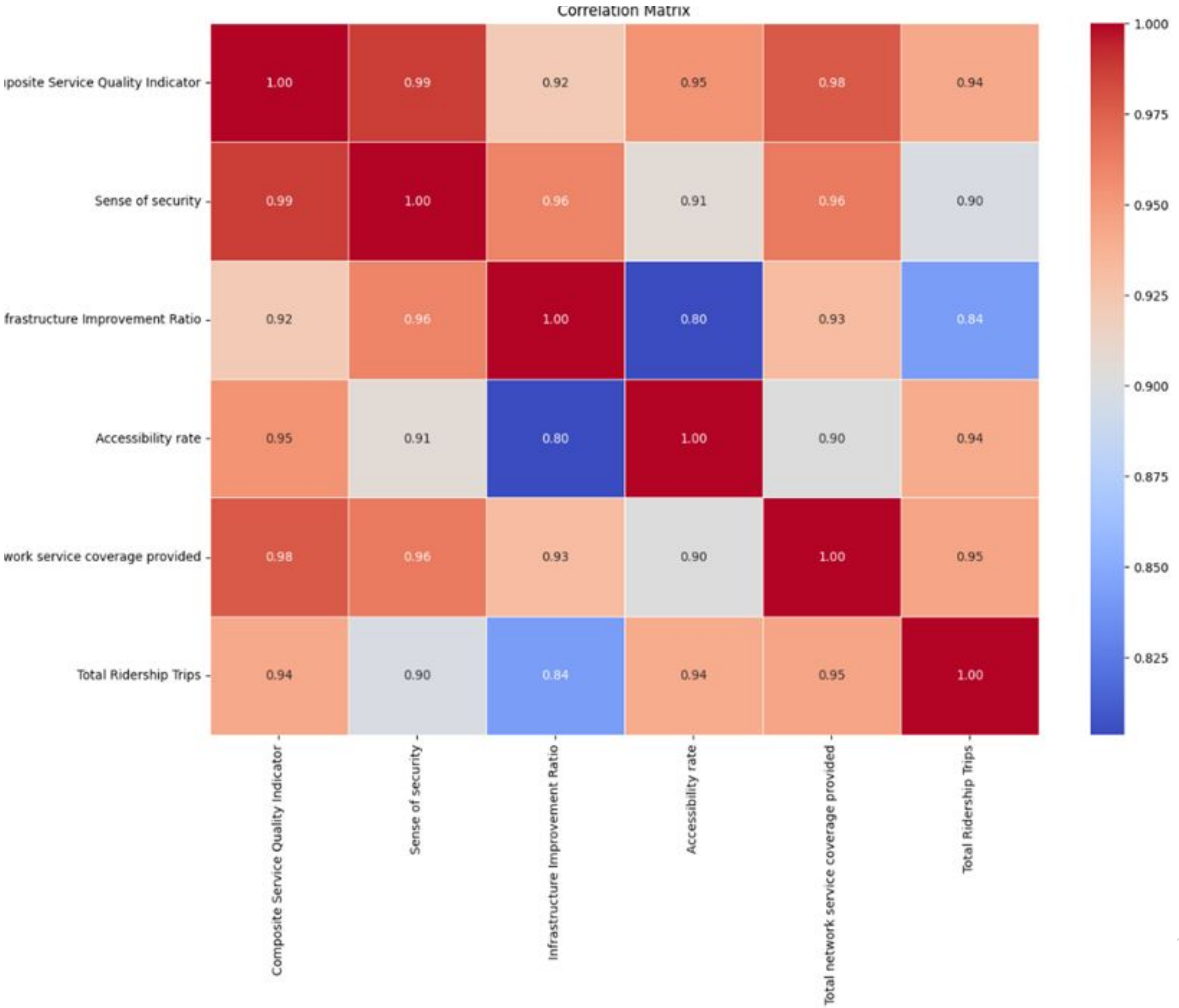
Model Inspection -Data Cleaning
Reduced data redundancy by processes such as linear interpolation, assumption of missing values, researching and averaging out

Dimensional Verification
Checking variables with same measurement (for instance, ratio, percentage) etc and compared with a baseline data. eg, population growth rate as a percentage).

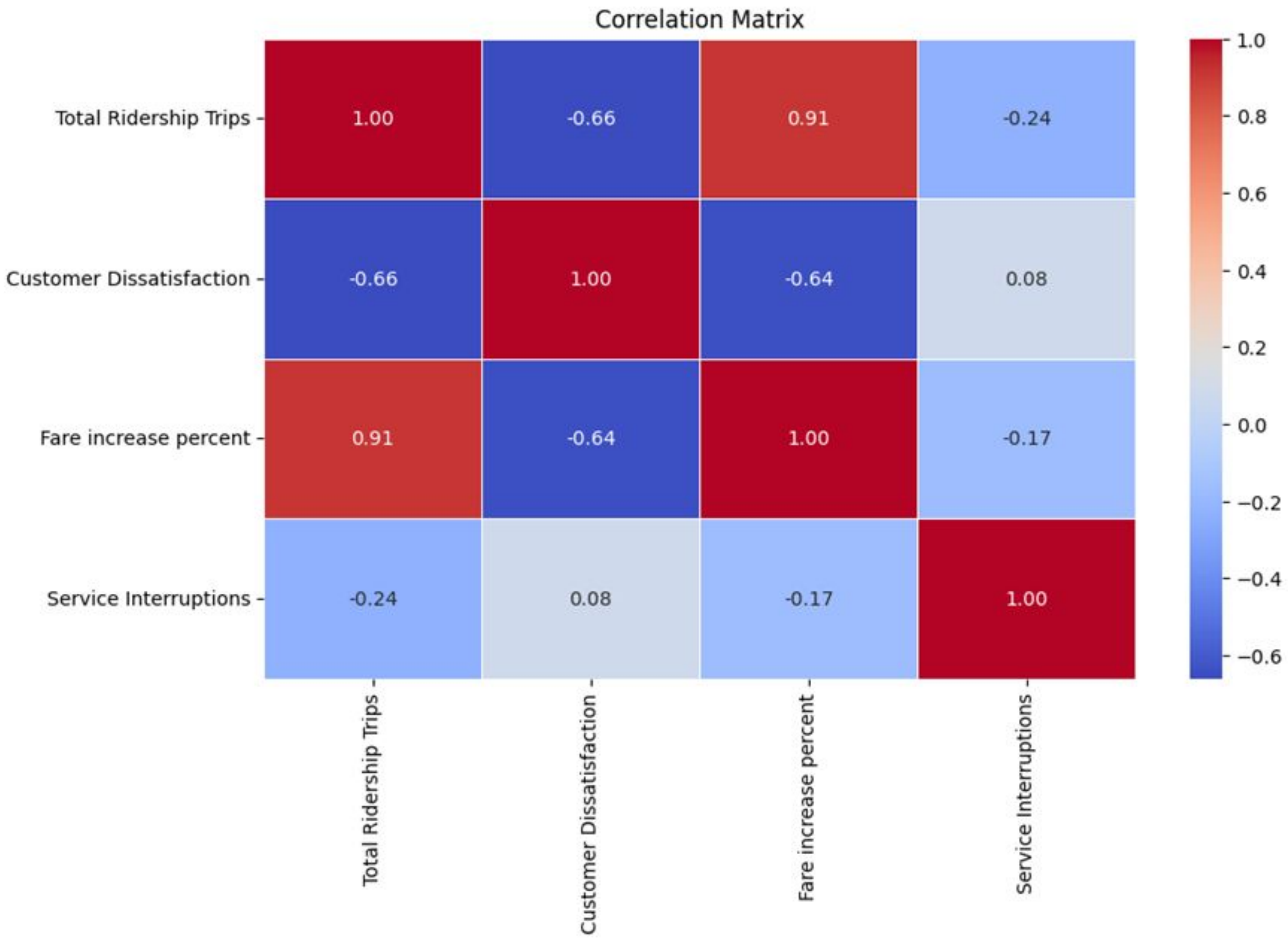
Correlation Analysis



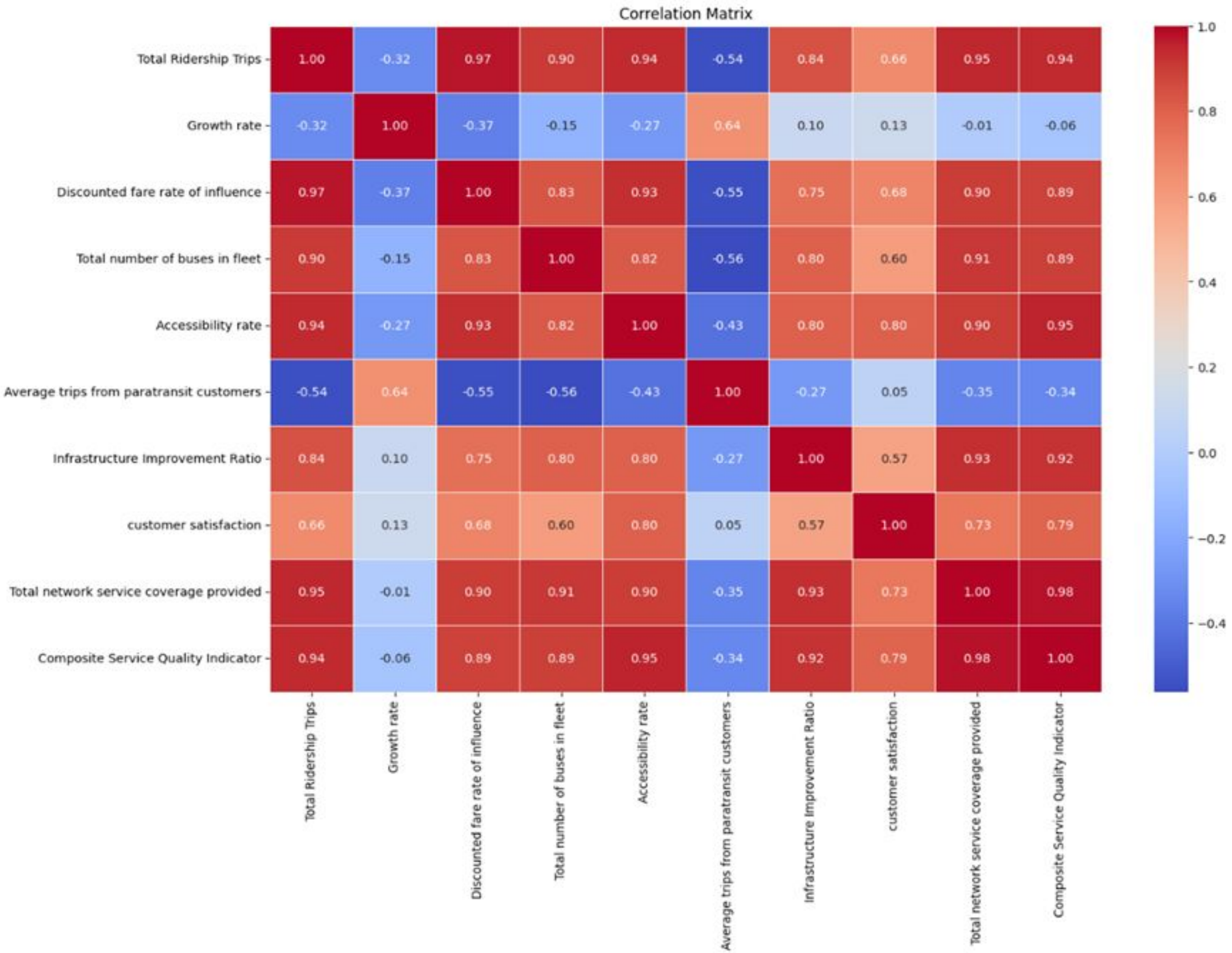
Correlation Analysis



Correlation Analysis



Correlation Analysis



Regression Analysis

```
                                   OLS Regression Results
==============================================================================
Dep. Variable:     Total Ridership Trips   R-squared:                       1.000
Model:                               OLS   Adj. R-squared:                   -inf
Method:                    Least Squares   F-statistic:                       nan
Date:                   Mon, 24 Jun 2024   Prob (F-statistic):                nan
Time:                           02:11:49   Log-Likelihood:                -26.525
No. Observations:                      9   AIC:                             71.05
Df Residuals:                          0   BIC:                             72.82
Df Model:                              8
Covariance Type:               nonrobust
===================================================================================================
                                             coef    std err          t      P>|t|      [0.025      0.975]
---------------------------------------------------------------------------------------------------
const                                   1.431e+08        inf          0        nan        nan        nan
Growth rate                            -7.803e+07        inf         -0        nan        nan        nan
Discounted fare rate of influence         -0.6269        inf         -0        nan        nan        nan
Total number of buses in fleet         -1.608e+05        inf         -0        nan        nan        nan
Availability of Accessible Vehicle      -1.41e+08        inf         -0        nan        nan        nan
Infrastructure accessibility            1.458e+08        inf          0        nan        nan        nan
Accessibility rate                      4.847e+06        inf          0        nan        nan        nan
Average trips from paratransit customers -5.967e+05      inf         -0        nan        nan        nan
Infrastructure Improvement Ratio          2.27e+07       inf          0        nan        nan        nan
customer satisfaction                   5.048e+08        inf          0        nan        nan        nan
Total network service coverage provided  2818.7365       inf          0        nan        nan        nan
==============================================================================
Omnibus:                        0.251   Durbin-Watson:                   2.321
Prob(Omnibus):                  0.882   Jarque-Bera (JB):                0.393
Skew:                           0.009   Prob(JB):                        0.821
Kurtosis:                       1.976   Cond. No.                     1.64e+11
==============================================================================
```

Regression Analysis

```
                            OLS Regression Results
==============================================================================
Dep. Variable:     Total Ridership Trips   R-squared:                       0.850
Model:                               OLS   Adj. R-squared:                  0.759
Method:                    Least Squares   F-statistic:                     9.415
Date:                   Mon, 24 Jun 2024   Prob (F-statistic):             0.0169
Time:                           02:12:17   Log-Likelihood:                -155.32
No. Observations:                      9   AIC:                             318.6
Df Residuals:                          5   BIC:                             319.4
Df Model:                              3
Covariance Type:               nonrobust
=============================================================================================
                              coef    std err          t      P>|t|      [0.025      0.975]
---------------------------------------------------------------------------------------------
const                    3.987e+08   3.17e+07     12.569      0.000    3.17e+08     4.8e+08
Customer Dissatisfaction -1.077e+08   1.87e+08     -0.577      0.589   -5.88e+08    3.72e+08
Fare increase percent    3.524e+08   9.85e+07      3.576      0.016    9.91e+07    6.06e+08
% of Trips with Delays  -3.726e+08   7.73e+08     -0.482      0.650   -2.36e+09    1.61e+09
==============================================================================
Omnibus:                        1.083   Durbin-Watson:                   1.552
Prob(Omnibus):                  0.582   Jarque-Bera (JB):                0.775
Skew:                          -0.445   Prob(JB):                        0.679
Kurtosis:                       1.871   Cond. No.                         231.
==============================================================================
```

Regression Analysis

OLS Regression Results

Dep. Variable:	Composite Service Quality Indicator	R-squared:	0.999
Model:	OLS	Adj. R-squared:	0.998
Method:	Least Squares	F-statistic:	902.0
Date:	Mon, 24 Jun 2024	Prob (F-statistic):	3.68e-06
Time:	02:31:00	Log-Likelihood:	28.039
No. Observations:	9	AIC:	-46.08
Df Residuals:	4	BIC:	-45.09
Df Model:	4		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	-13.1623	1.655	-7.952	0.001	-17.758	-8.567
Sense of security	12.7979	2.070	6.183	0.003	7.052	18.544
Infrastructure Improvement Ratio	-0.4875	0.242	-2.015	0.114	-1.159	0.184
Accessibility rate	0.5740	0.127	4.530	0.011	0.222	0.926
Total network service coverage provided	6.76e-06	1.65e-06	4.105	0.015	2.19e-06	1.13e-05

Omnibus:	1.782	Durbin-Watson:	2.752
Prob(Omnibus):	0.410	Jarque-Bera (JB):	0.776
Skew:	-0.150	Prob(JB):	0.678
Kurtosis:	1.593	Cond. No.	7.63e+07

Regression Analysis

```
                                    OLS Regression Results
===============================================================================================
Dep. Variable:     Composite Service Quality Indicator   R-squared:                       0.384
Model:                                             OLS   Adj. R-squared:                  0.179
Method:                                  Least Squares   F-statistic:                     1.872
Date:                                 Mon, 24 Jun 2024   Prob (F-statistic):              0.233
Time:                                         02:35:18   Log-Likelihood:               -0.40471
No. Observations:                                    9   AIC:                             6.809
Df Residuals:                                        6   BIC:                             7.401
Df Model:                                            2
Covariance Type:                             nonrobust
==========================================================================================
                            coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------------------
const                    -6.0559      3.378     -1.793      0.123     -14.322       2.210
% of Trips with Delays   33.2654     30.348      1.096      0.315     -40.994     107.525
Average age of fleet      0.1315      0.068      1.927      0.102      -0.036       0.299
==============================================================================
Omnibus:                        0.001   Durbin-Watson:                   0.846
Prob(Omnibus):                  1.000   Jarque-Bera (JB):                0.206
Skew:                          -0.001   Prob(JB):                        0.902
Kurtosis:                       2.259   Cond. No.                     1.35e+04
==============================================================================
```

Ridge Regression Analysis

```
Mean Squared Error: 0.13760391346167514
R-squared: 0.21452499289648852
Intercept: 0.43805364371300083
Coefficient for Service Interruptions: 0.11082642771960971
Coefficient for Average age of fleet: 0.1911197342938665
```

```
Mean Squared Error: 158067782606815.03
R-squared: 0.7366634192306288
Intercept: 391786237.4749965
Coefficient for Customer Dissatisfaction: -4760698.105800799
Coefficient for Fare increase percent: 10348287.315796513
Coefficient for Service Interruptions: -3125059.3947411813
```

```
Mean Squared Error: 19179327563374.437
R-squared: 0.9968047767490639
Intercept: 393148208.636197
Coefficient for Growth rate: -2961082.903265464
Coefficient for Discounted fare rate of influence: 4925824.7209089445
Coefficient for Total number of buses in fleet: 2123833.910029024
Coefficient for Accessibility rate: 1902041.2240823647
Coefficient for Average trips from paratransit customers: -1147113.1980347312
Coefficient for Infrastructure Improvement Ratio: 3043965.9452915816
Coefficient for customer satisfaction: 285177.6661953458
Coefficient for Total network service coverage provided: 3964623.043734427
Coefficient for Composite Service Quality Indicator: 2662485.2886600737
```

```
Mean Squared Error: 0.003956080757542365
R-squared: 0.9774177748077048
Intercept: 0.3921025675527193
Coefficient for Sense of security: 0.07882208967083519
Coefficient for Infrastructure Improvement Ratio: 0.05104743950421533
Coefficient for Accessibility rate: 0.08737008149756291
Coefficient for Total network service coverage provided: 0.05903564460948984
Coefficient for Total Ridership Trips: 0.045355233539337125
```

Verification and Validation

Validation

Predictive Analysis

Comparing actual data with predicted data and see how the model behaves

Sensitivity Analysis

Changing the values of outliers to create a new model and see how the model behaves

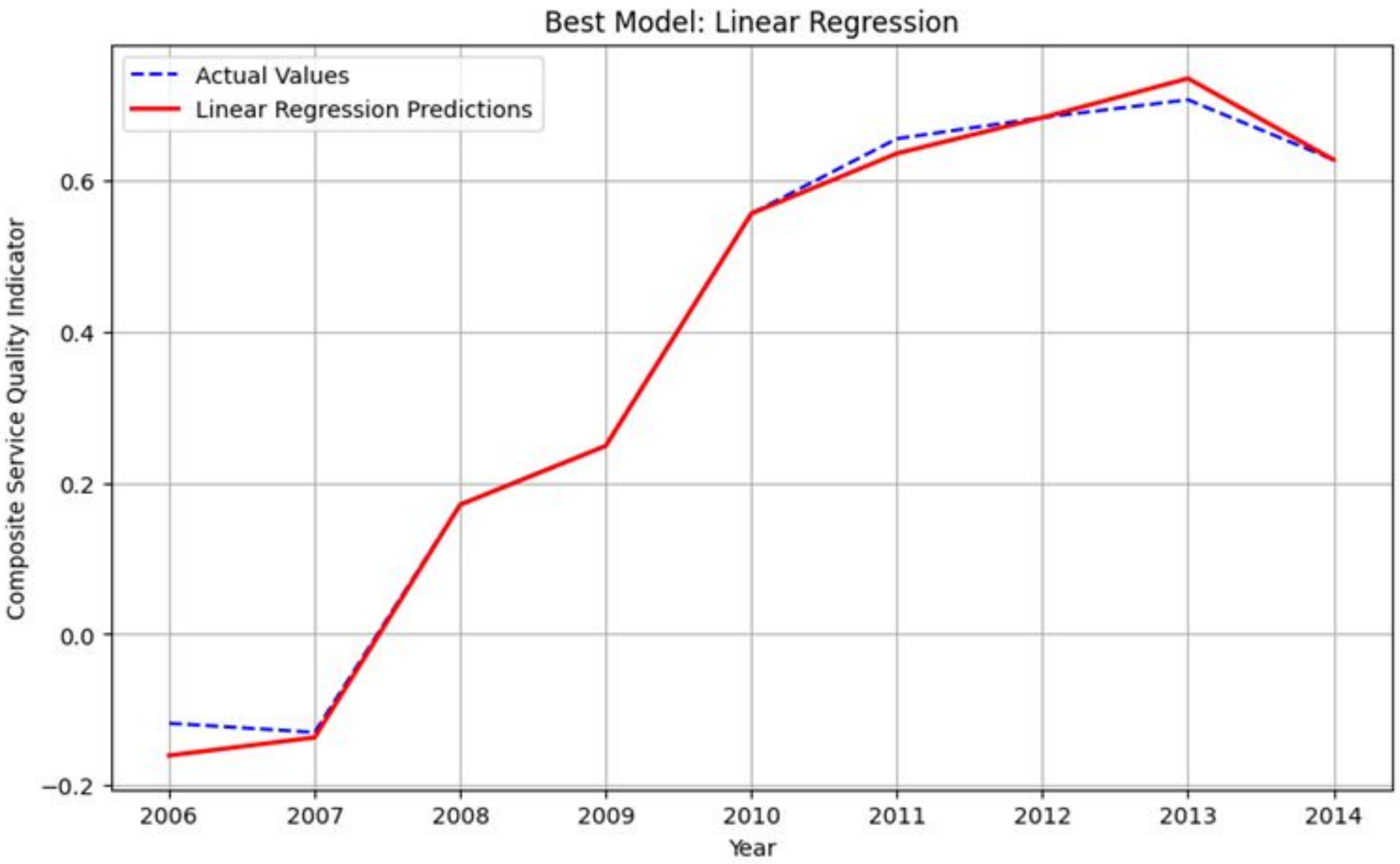
For instance, Ridership data for initial year

By comparing the baseline results with future simulation outcomes, we were able to identify the impact of different variables and interventions on the overall system performance.

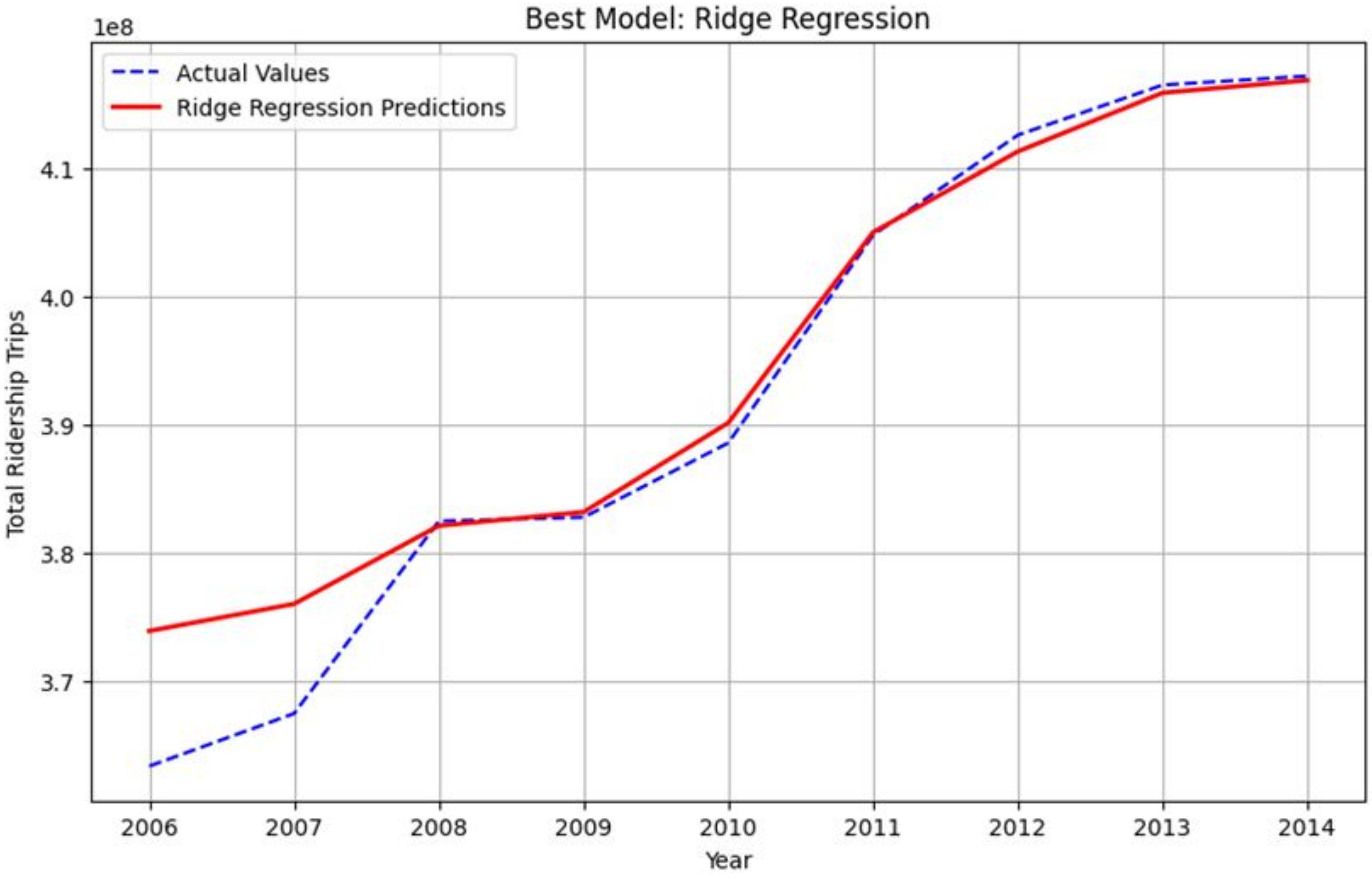
Predictive Validation

```
Predicted values and errors for the test data:
Linear Regression Predictions: [ 0.73542126 -0.1366888   0.63611742 -0.16059699]
Linear Regression Error: 0.024317115738519208
Ridge Regression Predictions: [ 0.76661471 -0.14089135  0.59571248 -0.19588179]
Ridge Regression Error: 0.052088551138390574
SVR Predictions: [0.53683413 0.44960652 0.53039889 0.45649831]
SVR Error: 0.36235748889962 21
Random Forest Predictions: [0.62083766 0.25286714 0.60407931 0.24004019]
Random Forest Error: 0.21963712760979653
```

```
Predicted values and errors for the test data:
Linear Regression Predictions: [4.17090219e+08 3.77376338e+08 4.05654175e+08 3.74559336e+08]
Linear Regression Error: 5620017.024271101
Ridge Regression Predictions: [4.15890033e+08 3.76046519e+08 4.05020635e+08 3.73936980e+08]
Ridge Regression Error: 4978525.385139182
SVR Predictions: [3.88600001e+08 3.88600000e+08 3.88600001e+08 3.88600000e+08]
SVR Error: 22599999.557607055
Random Forest Predictions: [4.08959e+08 3.86739e+08 4.04642e+08 3.86525e+08]
Random Forest Error: 12515750.0
```



Best Model: Linear Regression
Actual Values
Linear Regression Predictions
Composite Service Quality Indicator
0.6
0.4
0.2
0.0
−0.2
2006
2007
2008
2009
2010
2011
2012
2013
2014
Year


Best Model: Ridge Regression
1e8
Actual Values
Ridge Regression Predictions
4.1
4.0
3.9
3.8
3.7
Total Ridership Trips
2006
2007
2008
2009
2010
2011
2012
2013
2014
Year

Future Prospects

- Optimisation of the system in system dynamics by understanding the influential factors.
- State transformations from one state to another when a parameter is invoked using the switch function. eg, Security training level during the years can be monitored.
- Incorporating Environmental factors-population density, walkability, urban design factors, level of carbon emissions affecting the social parameters etc.
- Integrate more variables like staff training level, public perception level, marketing effectiveness and attrition.
- Creating agents in the system dynamics model that can entirely change the pattern and analyse the behaviour of the system. Eg, agent can be a person's travel behaviour over the system.

References

- Investigating carbon footprint reduction potential of public transportation in United States: A system dynamics approach, https://www.sciencedirect.com/science/article/abs/pii/S0959652616307284
- https://blog.fagstein.com/2013/12/27/stm-rate-hikes-2008-2014/
- https://donnees.montreal.ca/dataset/?q=stm+
- https://www.anylogic.com/resources/case-studies/
- Annual Report STM 2006-2014
- https://www12.statcan.gc.ca/census-recensement/2021/as-sa/fogs-spg/page.cfm?topic=2&lang=e&dguid=2021S0503462
- https://www.stm.info/en/press/news/2019/update-on-stm-hybrid-buses---efficient--reliable-and-environmentally-friendly-vehicles
- https://www.stm.info/sites/default/files/a-ra2008.pdf
- https://www.stm.info/en/about/financial_and_corporate_information/sustainable-development/annual-sustainable-development

- THANK YOU -