System Dynamics Investigation of the Impact of a Multi-School Site on the Local Community

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Abstract:

The operation of schools affects local communities to a large extent. Traffic congestion, traffic safety issues and air pollution problems at school drop-off and pick-up times have many negative impacts on traffic throughout the area, seriously affecting the safety and smooth flow of roads in front of and around schools. This phenomenon is particularly prevalent in areas with multiple school sites. In many parts of the city, traffic congestion around multiple school sites has become a social problem that cannot be ignored.

This project takes the traffic problem around multiple school sites in Cardiff as an entry point to study the impact of building multiple schools on campus-style sites on the local community from different perspectives and dimensions, to analyze the potential safety hazards associated with the operation of multiple school sites, especially traffic problems. Use system dynamics to create causal loop diagrams and stock and flow diagrams to obtain ways to mitigate the problems around multiple school sites by studying different policies.

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1. Introduction

For the vast majority of cities around the world, pupil transport to and from school and commuter transport is an important part of travel for urban residents. School-related traffic congestion and the risk such congestion poses to the safety of pupils, teachers, parents, residents, and motorists in and around schools is a major issue for communities in the UK and abroad. As a result, traffic issues around schools have been of great concern to managers and ordinary residents of local communities. Recently there has been a growing focus of attention and research on the commuting of primary and secondary school pupils. Concerns include the health and safety of children, traffic congestion and the impact of children going to school on the community. It is well known that there are large numbers of pupils and parents arriving and departing from school in a short period of time during school and dismissal hours, with a high concentration of traffic. This creates regular congestion and a high probability of traffic disruption, increasing the likelihood of traffic accidents around the school, which can put pupils at risk. At the same time, traffic congestion increases vehicle emissions and contributes to air pollution with high levels of nitrogen oxides, which can have a negative impact on the health of pupils and local residents.

This is particularly the case in multi-school areas. Multi-school areas are often communities of multiple secondary or primary schools, some a short distance apart, and more often in close proximity to each other, making a small city of schools. Having multiple schools in a small area means that a large number of pupils travel to and from the area on a daily basis. Due to the large number of pupils and the density of schools, the impact on the local community of pupils going to and from school each day in a multi-site area will be much greater than that of an ordinary individual school.

It is evident that the complex, chaotic traffic caused by multiple school sites to local communities must be addressed and mitigated for the health and safety of local residents and pupils.

1.1 Key Points of Research

The most obvious cause of traffic congestion around schools is vehicles, and the biggest source of these vehicles is parents dropping off and picking up their children from school. The proportion of children who drive to school in the UK is estimated to be around one third. Many pupils have parents who drive them to school in the morning, which can lead to long queues of cars on the roads and junctions outside the school. During key school times - usually between 8.30-9.00am and 2.15-3.30pm - the roads around primary and secondary schools can become clogged with parents dropping off and picking up their children. This can slow down people driving to work from their respective neighborhoods. This can lead to commuters being stuck in traffic jams for long periods of time, making them late for work (Keith Chong 2020). This, coupled with the fact that the proportion of children who drive to school has increased significantly in recent years, often causes serious traffic congestion problems. As a result, more and more parents and residents are complaining about how traffic and road conditions are linked to the potential dangers faced by schoolchildren, and this is becoming a real issue for local community leaders. Not only does this create potentially dangerous areas for children, but it also interferes with the smooth flow of traffic in the area. In summary, traffic congestion will be the first point of analysis in this paper, which will be followed up with an analysis using system dynamics and an examination of other impacts caused by traffic congestion.

Traffic accidents are a problem that needs attention in every country in the world. Each year, nearly 1.17 million people worldwide die in traffic accidents. Sixty-five percent of those killed are pedestrians, and 35 percent of those pedestrians are children. This high percentage of children is due in large part to their lack of understanding of traffic hazards because pupils not always readily aware of the dangers of road traffic and take the necessary precautions. This issue will be analyzed in this paper as a second key point of research.

In terms of health and safety, in addition to the above-mentioned traffic jams and the potential for more accidents, congested traffic also leads to high levels of exhaust emissions, and for the large numbers of pupils who congregate here, they inhale large amounts of nitrogen dioxide every working day, which has a significant impact on their health as time goes on. Many doctors have shown that children are particularly vulnerable to the effects of air pollution, that damage to the lungs in early life is irreversible and that there is a clear link between children breathing dirty air and chronic chest problems later in life. This phenomenon will therefore be analyzed as a third research point and ways of alleviating the situation will be investigated.

1.2 The Aim

The study will use system dynamics to investigate the impact of a multi-campus on surrounding residents and pupils. The investigation will focus on the safety and accessibility of the multi-campus and its surrounding area. Using the three key points previously mentioned, namely traffic congestion, air pollution and traffic safety. The survey will focus on primary, middle, and high school pupils and will investigate the impact of the multi-campus on these pupils. The areas where the three schools, Riverbank School, Cantonian High School, and Woodlands High School, located in Cardiff, UK, are located will serve as the primary study example. A causal loop diagram and a stock and flow diagram will be created to further identify the potential impact and chain of relationships between key points. A data model will then be created from the chain of relationships and associated reliable data. Experiments will be conducted on the basis of this model. The results of the experiment will be analyzed in the context of the local situation in Cardiff and the current existing situation in other similar areas of the UK. This will lead to effective recommendations to reduce the negative impact of multi-district on pupils and the surrounding community.

1.3 The Objective

Several hypothetical objectives have been set for the project as shown below. These objectives will be used as the main research direction and route in the subsequent content. In the final evaluation section, the project will be concluded and reflected upon according to the extent to which the objectives have been achieved.

1. Study the local transport around schools in Cardiff or other similar areas of the UK.
2. Obtain the current transport situation of UK pupils to school based on official UK data.
3. Analyze the main negative impacts of traffic congestion on pupils.
4. Examine the potential relationships that exist between the three key factors.
5. Further use reliable data to create stock and flow diagrams and quantify them based on causal loop diagrams.
6. Identify effective ways to mitigate the negative impacts of multi-school site districts on pupils and the surrounding community through quantitative modeling.
7. The validity of the methodology for determining the final experimental results in the context of reality.

2.Research on Multi-School Site and Pupil

2.1 Transport around Cardiff's local schools

Cardiff, the capital of Wales, has a wide range of educational resources. Cardiff has many schools in all areas of the city, including some special schools for pupils with special needs. These multi-site areas are either large or small. The multi-school site of Riverbank School, Cantonian high School and Woodlands High School are located on the western edge of Cardiff. This type of multi-campus site is the main example of study in this dissertation. It is local policy that all three schools will be relocated to the same site in the future, where they will also share the same entrance, which will inevitably have a significant impact on local traffic, especially during weekday school hours and after school hours.

Cantonian High School is an English medium 11–18-year-old community school maintained by the Cardiff Local Authority. It is located in Fairwater and serves the surrounding area of west Cardiff, Wales. There are currently over 800 pupils enrolled. The school is still growing, and Cardiff City Council is planning to completely rebuild Cantonian High School, expand the capacity of the high school and provide a specialist resource base for people with ASC (21st Century Schools Consultation Document 2021).

Cantonian high school is a large site and there are two special schools to be built on the site in the future. The multi-school site is surrounded by a number of residential areas and the roads are narrow. The main road in front of the main entrance is Fairwater Road, which is almost the only road leading to the main entrance, but it is also a small road in width. Many of the roads around the school, including Fairwater Road, have very limited capacity. Most of these roads are only theoretically two-way, but due to the residential areas nearby, cars are often parked on both sides of the road, making it difficult for two cars to pass at the same time. Many of these roads are used by pupils on their way to school, so this will not result in a very smooth flow of traffic around the school. As a result, the high volume of traffic during and after school hours makes the road's capacity very limited. In the future there will be many special needs pupils coming to school and they will often need to travel in carriers (Childcare and parenting 2021). At that time there will be a large number of taxis, private cars, minibuses, and coaches in front of the school. In these circumstances, it is easy to imagine that the traffic around the area where Cantonian High School is located is likely to become very congested during and after school hours. Beside it there is a bus stop and that's a tight corner for bus to turn which will Probably let accident rate become very high here.

In addition to Cantonian high school, Riverbank School and Woodlands High School, both special education schools and located in the same area, have similar traffic problems. In addition to these two schools, the area is also home to Ty Gwyn School and Trelai Primary School, which is also a special education school. These schools are located in the same area and are also surrounded by residential areas. As with the multi-site area where Cantonian high school is located, traffic congestion at school and after school causes problems for the pupils and the surrounding residents. This poses a further challenge to local traffic. According to field surveys, local residents report that once school starts in the morning, a large number of taxis and other vehicles will gather in the area. The resulting traffic congestion can make it difficult to even leave one's house, let alone drive up and commute. This happens almost every weekday and the congestion often starts at 9am and continues until 9.30am or 10am.

2.2 Pupils' health

According to a survey of UK pupils, more and more of them are choosing to drive to and from school. According to official statistics, for the majority of pupils in the UK, travelling to school by private car remains the main mode of transport to school. In particular, nearly half of primary school pupils go to school by car. The proportion of pupils travelling to school by car has continued to rise in recent years. At the same time, the proportion of pupils walking and cycling to school has been falling. According to government survey data on travel, the percentage of pupils in England walking to school dropped from 53 percent to about 50 percent in 2017. In addition, the data shows that more and more people are choosing to drive to short destinations, which are less than two miles away. The decrease in walking as well as the increase in driving has led to a significant increase in air pollution as well as obesity rates.

In the UK, nearly a third of children aged 2-15 are overweight or obese and as many as 42%

of children do less than half the recommended number of hours of physical activity each day. Today's children are simply not getting enough exercise, and this is compounded by the fact that the proportion of children walking and cycling to school has fallen in England since 1995. Meanwhile, the dominance of motorized vehicles continues to grow, with up to a quarter of cars on the road during the morning rush hour.

In addition, a 2017 survey by The Guardian and Greenpeace found that over 2,000 nurseries and schools are in areas where nitrogen dioxide levels exceed the EU legal limit: the main cause being car exhaust. This is worrying because children's lungs are still developing and they are therefore most vulnerable to toxic particles, as the recent link between tragic child deaths and air pollution has shown. New research shows that 65% of parents of UK children aged 4-11 are concerned about the impact of air pollution on their child's health - a 17% increase on 2018 figures. 40% are particularly worried about the level of air pollution around their child's school or on the school run (Emissions of air pollutants in the UK – Nitrogen oxides (NOx) 2021). Concerns were much higher among London parents, with 78% concerned about the health effects and 68% worried about the level of air pollution around their school (Matthew Taylor 2018). These parents' concerns are legitimate, as many medical studies have shown that children's lungs are more susceptible to air pollution than adults because their bodies are growing.

Despite growing concerns about the impact of air pollution on the health of young people, the proportion of parents driving their children to school rather than walking or cycling is still on the rise. This is because there are two interrelated issues - the first being too many cars on the roads around schools, which directly affects the second - the low number of children walking and cycling. The predominance of cars in school runs leads to parents and careers being concerned about road safety. This in turn discourages them from getting their children to walk and cycle to school and leads to an unhealthy environment. It is clear that we need fewer cars on the roads to reduce safety concerns and improve the quality of the air we breathe. We also need to translate these journeys into more children walking and cycling. Not only is it a great way to help children meet the recommended daily hours of physical activity, but it has also been found to help prepare children for school days by waking them up and making them more eager to learn. Walking and cycling also gives children better access to the natural environment rather than being stuck in the car.

2.3 Traffic safety for pupils

Globally, road traffic accidents are the leading cause of death for children and young people aged 5-29 years. In the five-year period from 2013 to 2017, 4,090 young people aged 17-19 were killed or seriously injured in road traffic accidents in the UK.

Insurance industry data shows that over 1,000 children are injured on local roads around UK schools every month, with the highest number of collisions occurring in London, which accounts for 13% of child casualties nationally and 22% of collisions overall (Angela Harrison

2013). According to the Office for National Statistics, there were 115,333 casualties of all degrees in reported road traffic crashes in 2020. 2020 UK road casualties reported by age group and gender show 4,140 road casualties for girls under 16, compared to 6,317 for boys in the same category in 2020 (Health Status of Children, 2021). This suggests that the safety of pupils on the roads should not be underestimated.
The vast majority of pupil-related traffic accidents occur around secondary and primary schools, where large numbers of pupils and parents tend to gather at the start and end of the school day. In these extremely crowded and chaotic conditions, a traffic accident can often have very serious consequences, as has been demonstrated in various countries and regions. On 21 September 2021, a woman and child were struck by a car near a primary school in Bath at around 3.30pm. The crash occurred between Redland Park Road and St Michael's Junior Church School (Imogen McGuckin 2021). On the other hand, at around 7.30am on 23 September 2021, a serious car accident occurred in front of a primary school in Pingdingshan, Henan Province, China. An SUV ploughed into the crowd, knocking down a number of electric cars and involving two pupils under the SUV. At least four people were injured as a result of the accident, including three pupils and a parent. The intersection where the accident occurred is only one hundred meters from the entrance to the West Campus of Zhanhe District Experimental Primary School (张崇曜. 2021). From these similar accidents from around the world, it is easy to see that the vicinity of schools is a high incidence of traffic accidents, with most accidents resulting in injuries and deaths of pupils occurring in such locations.

For these reasons, parents' concerns about the dangers of traffic may lead to more parents driving their children to school, thus increasing traffic congestion. On the other hand, traffic congestion may lead to more child pedestrian accidents, and reversing cars may block the view of children crossing the road to school, which in turn increases the incidence of traffic accidents and makes more parents choose to drive their children to school, creating a vicious circle.

2.4 Related Research

This project is based on the study of multiple school sites, where the local community is affected by the social system, including traffic congestion and environmental pollution caused by the operation of schools, which are problems of urban transport operations and which, with the development of the times, have gradually become one of the main problems faced by the managers of large and medium-sized cities at home and abroad, becoming a major constraint on the development or operation of cities. It has become a major constraint on the development or operation of cities. I will discuss the research and literature that has been conducted in various regions to gain more insight into the methods and recommendations for optimizing urban traffic operations.

There is currently a wealth of research on local traffic congestion issues around the world. In terms of investigating urban traffic congestion, Taylor argues that the causes of congestion are highly correlated with the local city's economy, that urban traffic congestion occurs as a result of rapid urban economic development, and that managing congestion requires regulation of local macroeconomic policies. McKnight and Vucic argue that the increase in the number of private cars is the primary cause of urban congestion, and therefore the strategies given for urban Small Kenneth's solution to congestion in London, UK, is to increase the cost of travel, and Small Kenneth argues that the use of economic instruments, such as changes in pricing or rules for transport, can be used to reduce congestion. Marion says that the most important solution to all types of traffic problems is to adjust the control and allocation of spatial resources, to move commercial areas to the suburbs and to encourage high-density building development around metro stations and bus stops. These studies can indeed help in the long or short term in combating urban congestion, but the optimization strategies proposed by these and other studies on urban congestion are oriented towards the whole city or even the region and are a global approach. In contrast, this project is concerned with the traffic and environment of the local school community, which is a multi-school site, and requires a local approach. However, there are commonalities between this project and the previous studies in terms of traffic congestion, and we can provide ideas for optimizing traffic in local areas based on the methods of congestion mitigation mentioned above.

For example, the Safe Routes to School project in the USA implemented a series of road engineering measures to encourage children to walk and cycle to and from school, including installing more speed feedback devices, widening roads, and creating new pavements to optimize the traffic environment between the school and the community. There is also the Korean School Perimeter Safety Improvement Project, which optimizes road safety within a 300m radius of the school by creating a dedicated protected footpath around the school and prohibiting people from parking at the main school entrance. These are all schemes set up in response to traffic congestion and safety in localized areas such as schools and are highly relevant to the research objectives of this project and can be used as important references, but as such localized approaches are heavily dependent on local realities, the local Cardiff school context needs to be considered before determining the adoption of these measures.

By studying the various relevant studies above, this project has a clearer idea and a reliable reference solution to take the research into the impacts of multiple school sites in Cardiff further.

3. Research approach

Identifying the impact of multiple school sites on the traffic and health of the surrounding community is a complex social research problem, and this impact is the result of a combination of multiple issues and conflicts, and a complex approach to governance. Different countries and regions have made different solutions to this situation, and many of these policies have had some effect in mitigating the impact of traffic in that community from the school. However. Without attention to the key causes of congestion around schools and the process by which it develops, it is impossible to truly recognize the objective laws involved and, in such cases, the measures adopted, although they may alleviate the community's problems to a certain extent, will inevitably end up deviating significantly from the desired goal. Many multi-school areas still have a significant negative impact on the surrounding community during peak commuting times, and local air pollution and commuting efficiency are never significantly optimized. Therefore, a systematic analysis of this situation using system dynamics is needed to derive a tailored approach that is relevant to the actual situation of the local community. This study will find a suitable solution by collecting real local data, creating causality and stock and flow diagrams, and using simulations to determine the actual impact of multiple school sites on the community.

3.1 System Dynamics

System dynamics is a comprehensive discipline that analyses information and feedback and is primarily used to identify and solve system problems. System Dynamics uses both qualitative and quantitative methods to deal with complex problems, with systematic reasoning as its main idea. Based on my experience of studying system dynamics, I have divided the modelling process of system dynamics into three parts: study, investigation, and research. The main object of study in system dynamics is systems. By system, I mean a complex of interacting units, and many social problems belong to systems, including socio-economic systems, ecosystems, etc. As such, system dynamics is suitable for solving four types of problems.

1. long-term problems: because system dynamics places emphasis on causality and emphasizes that the dynamic structure and feedback mechanisms of a system determine its behaviors and properties, long-term simulation experiments can be conducted.
2. Studies in the absence of data: Many studies are difficult to quantify due to a lack of data or data, but system dynamics is insensitive to parameters due to the presence of multiple feedbacks, and as long as the parameters are within reasonable limits, the results or laws derived will have a high degree of reliability.
3. complex non-linear problems: system dynamics is well suited for solving problems where it is difficult to create conventional equations and is a good way to deal with complex systems with non-linear relationships.
4. Problems requiring analysis through realistic scenarios: System dynamics can be used to analyze the results of a problem under different scenarios when the problem is highly relevant to the local situation.

3.1.1 Modelling

The development of system dynamics is due in large part to the need to manage systems in modern society, and as such it places emphasis on real-world situations without relying heavily on assumptions, and information derived from actual observations is the basis for modelling system dynamics. In this way, system dynamics is able to gain an understanding of the future behavior of systems. Therefore, by studying the ideas of system dynamics, I have divided the process of modelling system dynamics into four main parts. The first step in the modelling process of system dynamics is to clarify the research problem, which is the most important step, to analyze what the object of the problem is and to determine what purpose is ultimately to be achieved by using system dynamics to build the model. A reliable model will only be concerned with factors that are strongly related to the problem itself and will not be an overly large and complex model. A model that is too complex is not conducive to solving real world problems. A secondary part of the modelling process is the creation of causality diagrams, on which system dynamics is largely based. Causality plays a key role in the early stages of building a model. It provides a visual representation of the basic structure of the model. In a system, every two variables can form a relationship. Where, if the occurrence of variable A causes a change in variable B, then A is the cause and B is the effect and A and B form a causal relationship. If variable B increases as variable A increases, they are positively causal. Conversely, they are negatively causal. The line from cause to effect is the causal chain.

If there are multiple variables in the system, and there is a causal relationship between the variables, and a change in the initial variable in this causal chain can be passed on to the last variable, and a change in the last variable can cause a change in the initial variable, then this loop becomes a causal loop. The positivity of a causal loop can be obtained by counting the number of negative causal links in the loop; if the number of negative causal links is even then the loop is positive, if the number is odd then the loop is negative.

The third step in building the model is to create a stock and flow diagram of the system, referred to as a system flow diagram. System flow diagrams are built on top of causal loop diagrams to clarify the forms and patterns of feedback in the system and to provide a more visual representation of the logical relationships in the system. The four key elements of a system flow diagram are state variables, rate variables, auxiliary variables, and constants. In common social systems, the two most important elements are state variables and rate variables. The state variable represents accumulation and provides key information for studying the characteristics of the system. The rate variable, on the other hand, represents the time variation of the stock, where the difference between the rate variable of inflows and the rate variable of outflows accumulates over time to eventually produce the stock.

The fourth step is to establish the data equation. This is a quantitative process that transforms the system model into a mathematical model based on data equations. In this way, the original conceptual thinking is transformed into a practical, quantitative model. Once the data equations have been created, the model can then be simulated on a computer to identify the patterns that are inherent in it, and thus find a way to solve the initial problem. The final step is to put the model to the test. The testing process can be a dialectical and falsification process. System dynamics models are designed to solve real-world problems, but real-world systems are complex, and the models created are bound to contain more or less assumptions or idealized data. So, the model cannot perfectly reflect reality and we need to test the model and analyze the results in the context of the reality.

3.1.2 Application

Social systems are complex and varied, with the transport, environmental and economic systems of society being highly interrelated. These systems can be included in social system models, and therefore system dynamics is well suited to the study of the potential relationships between elements within social systems and the mechanisms of interaction. System dynamics has been used to great effect in the study of regional or urban economic development models, as exemplified by the famous Western model of urban system dynamics. This model reveals the mechanisms underlying the development, decline and recovery of Western countries and cities. In addition, system dynamics is a highly versatile discipline used in a wide range of fields such as business management, urban planning, environmental and agricultural development, and construction engineering, and its applications are becoming increasingly widespread as the world develops.

3.2 Approach Selection

Of the computer simulation language software currently available specifically for system dynamics, the two most commonly used are Vensim and Anylogic.

Vensim is a simulation tool with a very user-friendly interface and is widely used because it is very powerful and can run large models with thousands of equations, such as the National Model of the U.S. Vensim is a visual modelling tool with which dynamical system models can be conceptualized, simulated, analyzed, and optimized. Vensim PLE provides a very easy to use modelling based on causal chains, state variables and flow diagrams. Vensim uses arrows to connect variables, relationships between system variables are established as causal connections and the equation editor helps to easily build complete simulation models. The model can be analyzed by creating processes, checking causal relationships, using variables, and including feedback loops for the variables. Once a stimulable model has been built, Vensim allows the behavior of the model to be studied globally. Vensim offers a variety of analysis methods for the model built. Vensim allows structural analysis of the model, including cause number analysis, result tree analysis and feedback loop analysis, and data set analysis, including data values of variables over time and graphical analysis. In addition, Vensim also allows for model validity checks to determine the reasonableness of the model, so that the parameters or structure of the model can be adjusted accordingly.

Another more powerful software is Anylogic, which supports object-oriented modelling and hierarchical modelling and has all the advantages of the object-oriented system dynamics modelling approach, where complex models can be defined in a hierarchical manner and objects show only interface variables as inputs and outputs. In addition, frequently used system dynamics models can be saved as library objects and reused within a model or across different models. AnyLogic users can benefit greatly from advantages such as model export, cloud model execution, complex animations, and interactivity with other software tools. In addition, AnyLogic is the only tool that allows the combination of system dynamics model components with model components developed on the basis of intelligent bodies and discrete events. This can be combined in different ways; for example, a consumer market can be modelled using system dynamics and a supply chain using an intelligent body-based approach, and by combining them, the consumer market can drive the supply chain.

All in all, as a first-time learner of system dynamics, I was very satisfied with Vensim's simple and intuitive interface and the way it operates. I was able to learn how to build causal loop diagrams quickly with Vensim, and I think Vensim is perfectly capable of creating causal loop diagrams and system flow diagrams. and Vensim's work is done, as it is difficult to perform system flow diagram runs and computation of the data. So once the model and associated equations have been determined, it is time to run it using the powerful Anylogic, which is needed for the testing of the model and the implementation of the data visualization. In summary, in the subsequent work of this project, the causality and system flow diagrams will be built using Vensim, and after the mathematical equations have been designed, the simulation experiments will be carried out using Anylogic.

4.Design Of Causal Loop Diagrams (CLDs)

The multiple school sites and the pupils in general have been described in Chapter 2 of this paper but trying to figure out the impact of multiple school sites requires modelling from a systems perspective, as this is a complex systemic problem that is non-linear, multivariate and has multiple feedbacks. If the impact of multiple school sites on a community is to be studied through modelling, the general idea of modelling and the individual elements within the overall system need to be identified. Elements are categorized into critical and secondary elements based on whether they have a direct impact on the community. The causal relationships and loops between the elements are analyzed and therefore a causality diagram is constructed. This section will describe the design process and philosophy based on the design ideas of the model.

4.1 Modelling objectives

1. To analyze the various aspects of a multi-school site that affect the community, to sort out the relationships and mechanisms of action between elements within the community system around the school, and to identify the dynamic feedback structures and mechanisms within the system.
2. to identify quantitative relationships between the model structure and variables based on appropriate simplifications of the school and community system.
3. to run the model using data relating to schools and surrounding communities in the Cardiff area and other similar areas of the UK to demonstrate dynamically the functioning of a multi-school site community in Cardiff.

4. in order to enable the model to be used with different areas, a variety of variables were included that could be scaled to make it valid when studying other cities or areas.
5. to provide reliable recommendations for the operation of the Cardiff Multiple School Site based on the simulation results of the model.

4.2 Prerequisites and Assumptions

4.2.1 Prerequisites

1. the scope is as narrow as possible. If the purpose of the study can still be achieved without a certain variable, then that variable should be excluded from the system for the sake of brevity and clarity.
2. As this project uses system dynamics to study a specific problem rather than a particular system, the model will be constructed to consider all variables that are conducive to studying the effects caused by multiple school sites, and therefore give a reliable and specific solution.
3. to increase the credibility of the model, all causal relationships in the model should be based on the literature or be derived from well-known common knowledge.
4. A perfect system should be highly integrated and include not only the transport system of the school and the surrounding community, but also its associated social and environmental subsystems.

4.2.2 Assumptions

There are a variety of impacts of multiple school sites on pupils and surrounding residents but given that many of these impacts are small or not suitable for application to systemic modelling, the following assumptions are made to facilitate modelling.
1. Motor vehicles are predominantly cars and buses.
2. local public transport is dominated by buses
3. most pupils and parents enter the school through the main entrance and there is only one main entrance to the school.
4. Environmental pollution is expressed in terms of emissions of nitrogen oxides, which are the most harmful to humans.
5. Special needs pupils are predominantly disabled.
6. Motor vehicles are not allowed on the safe walking and safe cycling paths.
7. Businesses in the vicinity of the school are predominantly small and medium-sized enterprises.
8. The duration of the school day and the duration of the school day are within one hour.
9. Pupils' preferences for transport to school are constantly changing depending on the outside world.
10. the time required for pupils to travel to school is less than one hour.

4.3 Modelling routes

When I first began to design the model, I consulted a wide range of literature on urban transport and management concepts and, based on the thinking used in these studies, I eventually designed a causal loop diagram with a macro-city as the subject of study. The original model is shown in Figure 1. It contains many macro factors such as urban economy, transport subsidies and urban management policies. As for the school factor I considered a large number of variables from different primary and secondary schools, universities, and other higher education institutions, which can be seen to include many variables about higher education. This original model was too macro in that it did not show the impact of a specific multiple school site, but rather the macro-level functioning of a city with multiple educational institutions. After some guidance from my supervisor, I thought again about the title of this project and the content of the research, and I realized that the object of my research should be a local object such as the community where the multiple school sites are located, and that I needed to design a model for this local object, the details and rationale for which I have already mentioned in the relevant research section of Chapter 2 of this paper. Although this original model is not applicable to this project, it is not a complete failure and some of the causal relationships and elements of it can be carried forward to the new model, such as traffic congestion, air pollution and vehicle trips and the causal relationships between them, which can be identified as the core points of this project's research. This can be used as the core for the construction of the new model. So, building on the original model, I started to design another model for specific problems and local objects.

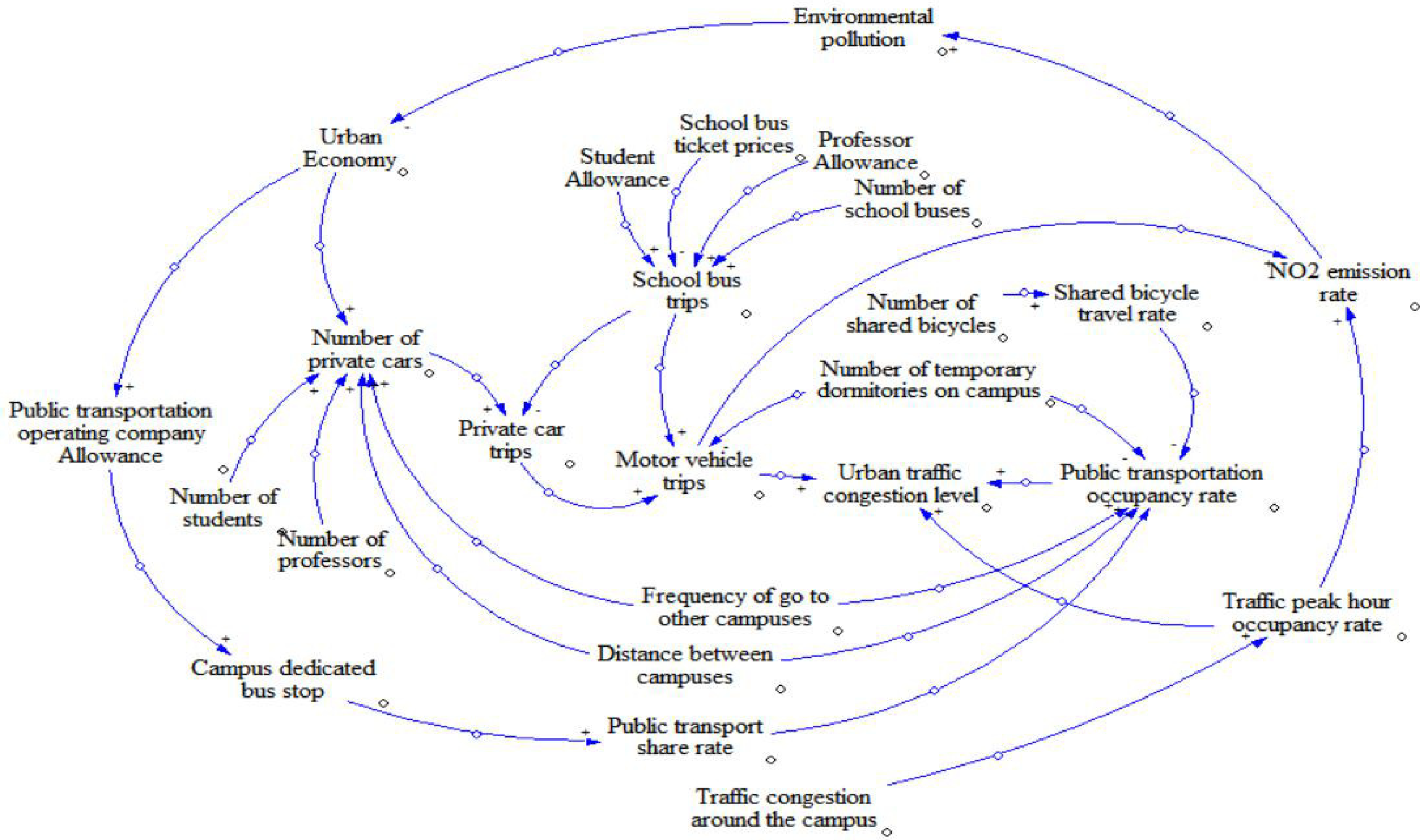

Figure 1: The original model

With the experience of the original model, I began to gradually work on the construction of the new model. Firstly, the creation of a causal loop diagram considers the association between the school and the community, i.e., the transport system. As mentioned in Chapter 2, Cantonian high School, Riverbank School and Woodlands High School are the three schools that will be relocated to the same site, and this was the subject of my study. The results of the survey are described in Chapter 2 under 'Local school transport'. Once I had the details of the multiple sites in Cardiff, I also needed to find out about local school policies, which I knew very little about as I am not a local, but fortunately my tutor was very helpful in this area, and I was able to find out about Cardiff's education policies such as admissions regulations. In addition, I collected official research and data on youth transport and safety in the UK and summarized it to get a preliminary picture of the current transport situation of pupils in the UK. After all these preparations, I built the basis of the model, as shown in Figure 2.

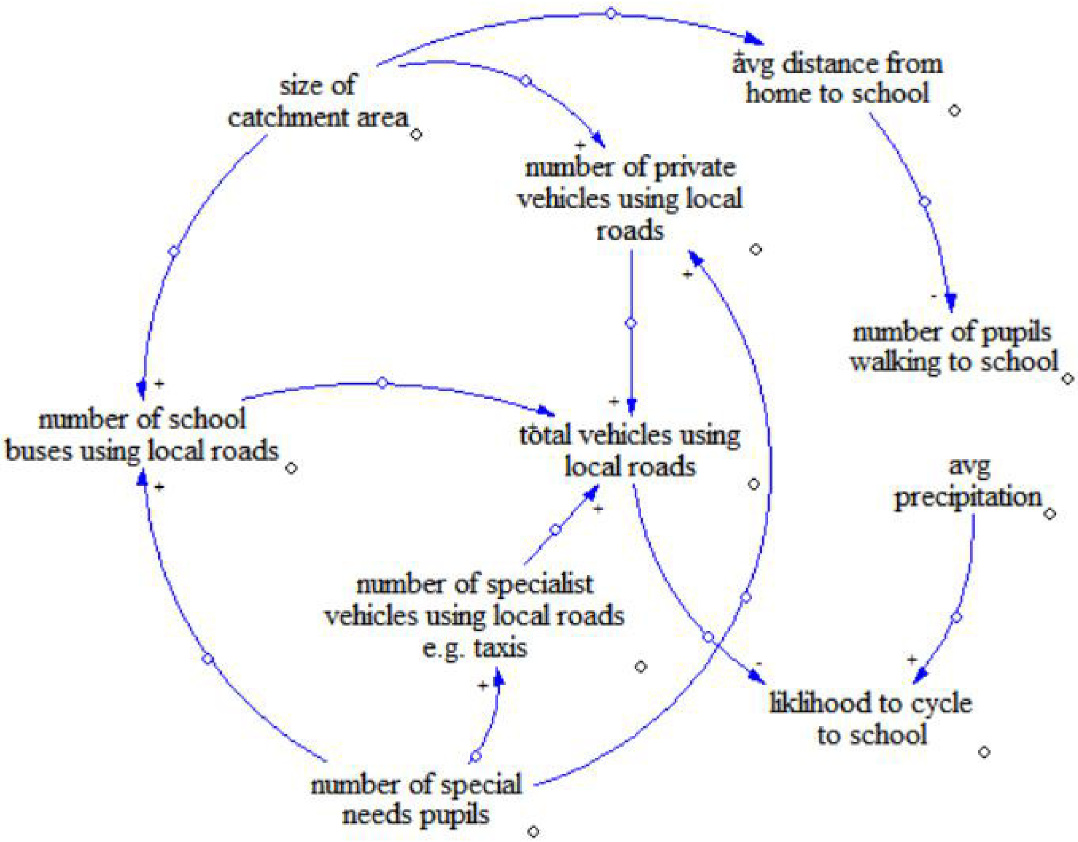

Figure 2: The basis of the model

In the model, the total number of vehicles on local roads is calculated through three types of vehicles: school buses, private cars, and special person vehicles. The main vehicles used by the general pupil population to get to school are school buses and private cars. In addition, special needs pupils with mobility problems use special needs vehicles and other private vehicles as their main mode of transport to school and the UK government therefore provides a special service for these pupils in England and Wales. transport for a child with special educational needs and disabilities, 2021). Therefore, multiple school sites containing special schools will inevitably have more traffic, and special pupils will have a greater impact on the system as a whole and will need to be included in the model. The size of a school district is a key determinant of the number of pupils in a school, according to the admissions policy, and a larger district means more pupils, and then more pupils will drive to school. A larger district also means that the average distance from home to school will be greater, and according to a survey of pupil travel preferences, on average, the further away a pupil's home is from school, especially if it is more than one mile away, the more likely they are to choose to travel by car (Elizabeth J Wilson 2010). These two reasons therefore suggest that the larger the school district, the more vehicles there will be to get to school. More cars will inevitably lead to more congestion on the roads, and congested traffic will have a significant negative impact on pupils' willingness to cycle to school (Sustrans 2020). On the other hand, rainy days can make the roads slippery, which can also discourage pupils from cycling. These two aspects are the main reasons that affect the likelihood of cycling to school.

Thus, the basis of the model has been built. The next step was to add other subsystems and additional elements to this to make it a complete model, including elements such as air pollution, school policies and traffic accident problems. The final causality diagram is shown in Figure 3.

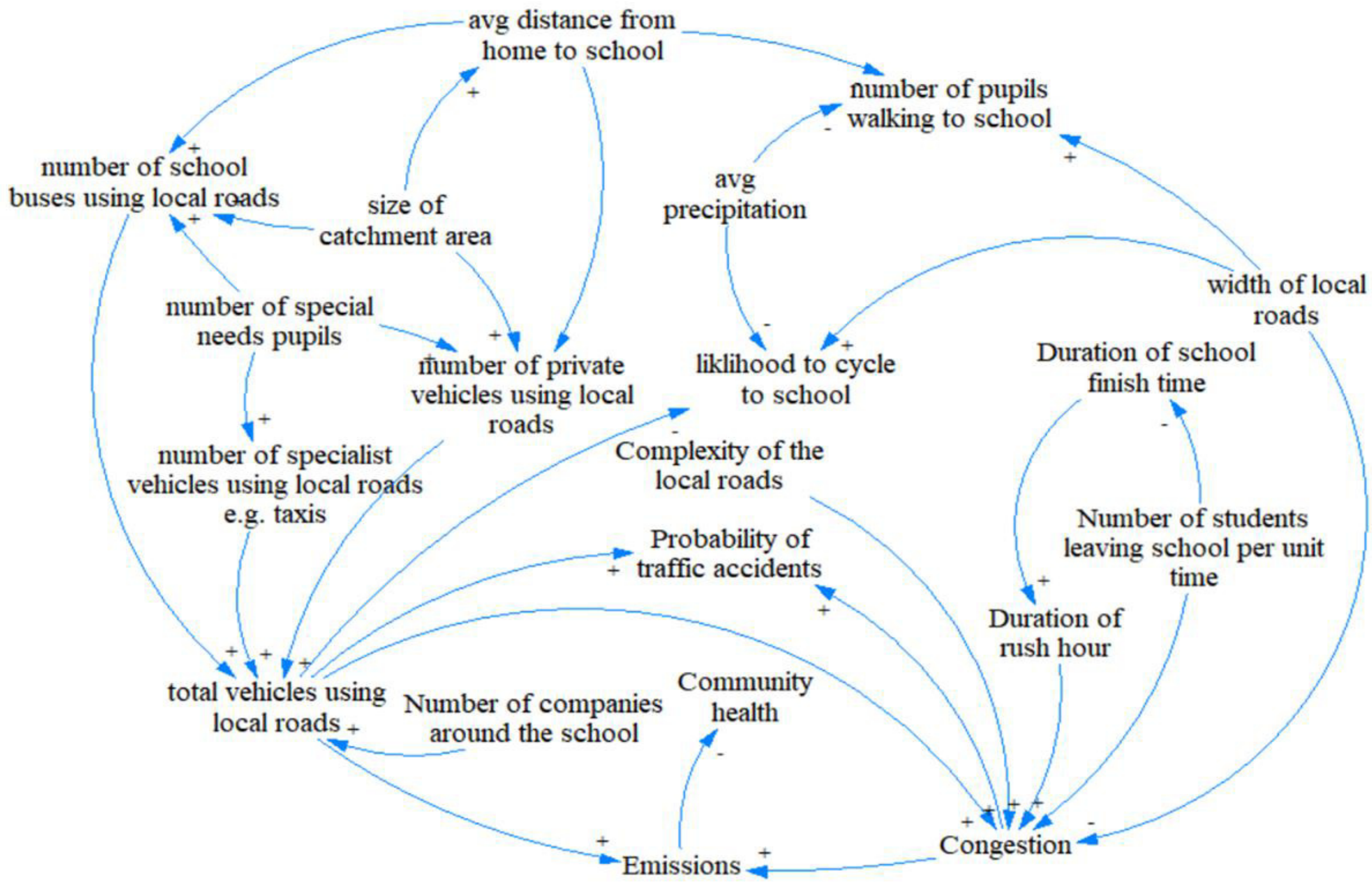

Figure 3: The final causal loop diagram

The final causal loop diagram has three themes, traffic congestion, air pollution and traffic accident rates. The specific causes are mentioned in section 1.2. Some details about the design are described below.

One element that can be seen added to the total number of vehicles on the road is the number of companies around the school. This is because the number of vehicles on the roads around pupils is influenced not only by the number of pupils commuting to and from school, but also by the number of people commuting to work. The greater the number of companies and businesses around a school, the greater the number of commuter vehicles on the local roads. Therefore, when considering the composition of road vehicles, the number of companies in the vicinity needs to be included. The increase in the number of vehicles and the congestion problems this causes can lead to increased air pollution. The next element of air pollution is included in the system, with tailpipe emissions being measured in terms of nitrogen oxides and the health criteria of the community being expressed in terms of the probability of the respiratory system of young people being affected. Similarly, the probability of traffic accidents was added to the system as a variable. The school policy is an interesting part of the system, as it can be seen that the school direction duration, peak traffic periods, congestion and the number of pupils leaving school per unit time form a loop. Adjusting the number of pupils leaving per unit time is a key part of this, too large or too small a variable will increase congestion and so a middle ground needs to be found, which is one of the issues that many school directors are considering in order to reduce congestion around their schools. In addition, road width is a very important aspect of the system, as it directly affects the number of pupils cycling and walking to school and the level of traffic congestion.

Taken together, the causal loop diagram is very simple and theoretical. It is intended to provide a more visual representation of the way in which multiple school sites affect a community and is also intended to be more easily applied to schools in different areas. Once the causal loop diagram was completed, all specific information about the model, the design rationale and references are recorded in Appendix A in order to demonstrate that the variables and causal relationships are supported by the evidence.

5. Stock and Flow Diagram

Stock and flow diagrams are the key to modelling system dynamics. The causal loop diagram was completed in Chapter 4 and provides the guidance and basis for the construction of the stock and flow diagram in this chapter. As mentioned earlier, the key to the model focuses on three main elements, including traffic congestion, air pollution and traffic accidents, which will further serve as the main points of the stock and flow diagram. This is to ensure uniformity of thinking throughout the study. In addition, the elements of the flow inventory diagram need to be incorporated into the mathematical equations and therefore be prepared for quantification, with some of the more theoretical variables being modified for quantification purposes. In this section, I describe in detail the process of designing a flow inventory diagram using Anylogic, which, as mentioned in Chapter 3, is more powerful than Vensim and is required to support the testing of the model and the implementation of the data visualization.

5.1 Assumptions

1. Public transport is counted in the daily traffic volume and no additional calculations are made.
2. Pupils travel to school in four main ways: driving, walking, cycling, and using public transport.
3. NOx emissions are averaged equally for all vehicles.
4. the proportion of pupils who travel to school by public transport is constant at 12%, which is the proportion of the UK population that commutes by public transport.
5. Daily traffic volumes are based on the average traffic volumes on local roads around schools in Cardiff as provided by the UK Government.
6. the viability of walking and cycling to school is only related to constant factors in the environment, including rainfall, road width, number of safe roads, etc. and is not related to dynamic factors such as traffic volumes.

5.2 Model design

The complete stock and flow diagram is shown in Figure 4.

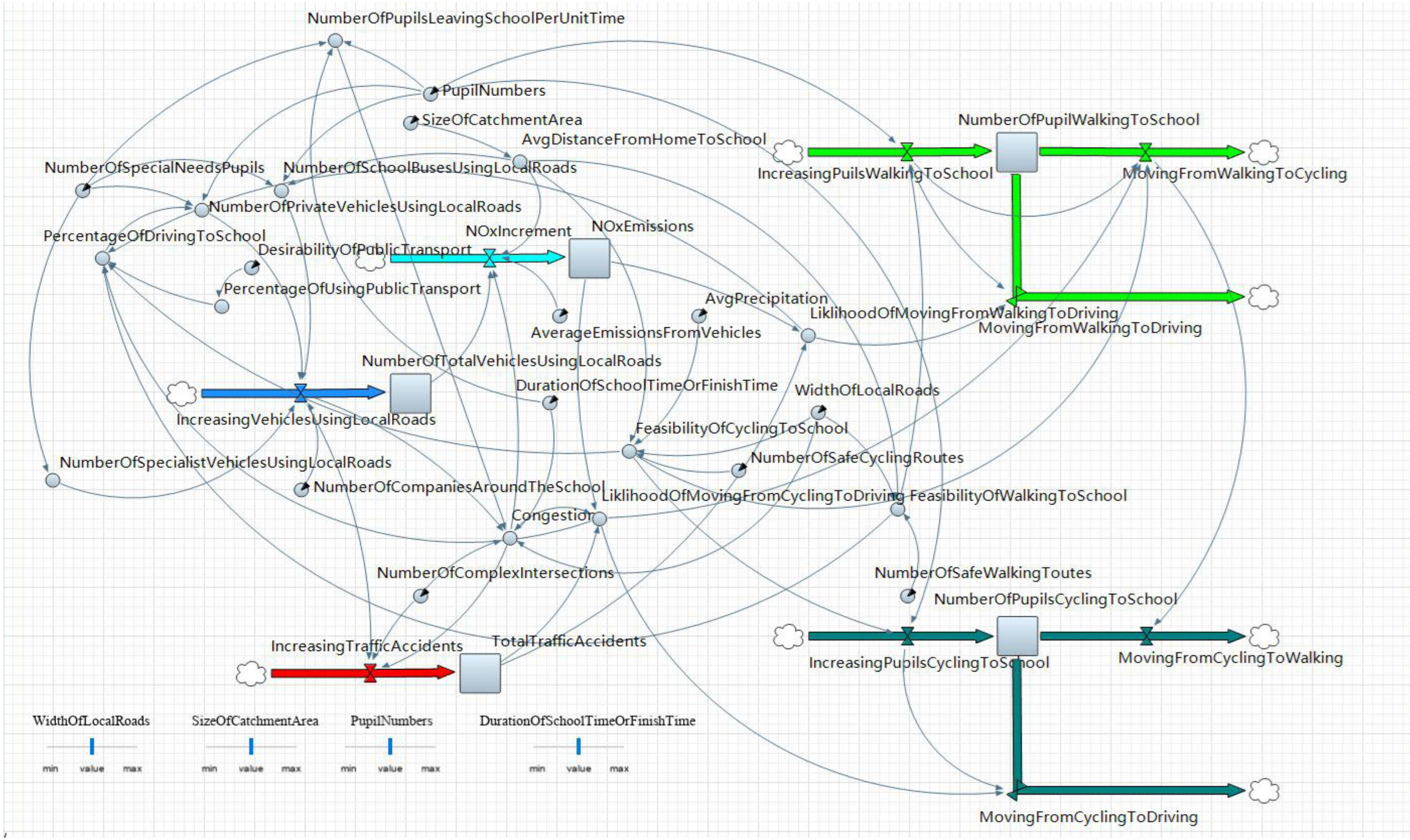

Figure 4: stock and flow diagram

Based on the causal loop diagram, flows, stocks, and additional factors that facilitate quantification have been added. Increasing Traffic Accident, NOx Increment and Increasing Vehicles Using Local Roads as flows. Total Traffic Accidents, NOx Increment and Number Of Total Vehicles Using Local Roads as stocks. These are all important indicators of the impact of multiple school sites on communities. The travel impact on pupils caused by these indicators is nothing more than a change in the mode of transport. This change is what the model needs to focus on representing. Therefore, in addition to the information underlying the causal loop diagram, the model considers how to show the change in the mode of transport of pupils to school. In order to do this, a number of special factors were added to the model, including walking to cycling, walking to driving, cycling to walking and cycling to driving, which were used as flows. The total number of pupils walking to school and the total number of pupils cycling to school were then used as stocks.

In addition, relevant factors that contribute to quantification are essential in order to calculate the quantitative value of the changes in these factors. So, two factors have been added to the model which are Likelihood of Moving From Walking To Driving and Likelihood Of Moving From Cycling To Driving. These two factors are designed to quantify the change in the proportion of pupils who change their mode of transport to school. As mentioned in the assumptions, there are four main ways for pupils to get to school - driving, walking, cycling, and using public transport. Of the four quantities, the proportion of pupils who take the bus is constant, and we can use these two factors to calculate the other three quantities. In this way, the relationship between several modes of transport can be obtained. Taking the number of pupils walking to school as an example, this stock is influenced by three main flows, with the incremental number of pupils walking to school increasing the stock and the number of pupils switching from walking to driving and cycling decreasing it. This design enables connections to be made between the three different ways in which pupils travel to school. The relationship between these factors can be used to give a clear picture of the impact of multiple school sites on the way pupils attend school.

Once the quantification is complete it is time to start designing the mathematical equations. It is worth mentioning that since Anylogic is based on java, the software uses the logic and rules of java. Therefore, when designing mathematical equations, it is necessary to follow the "if else" rule. Some of the factors in this project are complex due to the number of variables involved. For example, in the case of congestion, it can be difficult to write its equation using the 'if else' statement. This can be solved by splitting the equation into multiple 'if else' statements and nesting all of them at the end. Although this approach, based on multiple nesting, can be applied to almost every equation, it is bound to make the equation look very complex and make subsequent modifications difficult, so it is best to consider how to structure the equation for the 'if else' rule when initially designing it.

Once the flows, stocks, initial values, quantification, and equations are all completed, the entire model is built. The elements of the entire model can be divided into three levels. Firstly, there are the three basic elements of traffic congestion, air pollution and traffic accidents. The second is the proportion of pupils travelling to school by each mode of transport. Thirdly, there are the secondary factors that affect the primary factors, many of which are designed to have variable values in order to facilitate experimentation and testing. The multiple levels of factors work together to form a complex system. In the next section a series of experiments will be conducted through this system.

In order to complete the stock and flow diagram, a large amount of literature and research needs to be collected and studied. Most of them are from a variety of disciplines and fields. As with the causal loop diagram in Chapter 4, to demonstrate that the variables and causal relationships of the stock and flow diagram are supported by evidence, all specific information about the model, the design rationale and references are recorded in Appendix B.

5.3 Simulation

Now that the stock and flow diagram has been built, it is time to start the simulation. Anylogic's simulation system is based on the eclipse platform and the java language based development system allows it to be integrated with a wider range of systems and to take advantage of java's rich ready-made algorithms. The operating interface of the simulation is straightforward and easy to use. The operation bar is located at the bottom of the view and can be used to change the speed of the simulation, including functions such as start, stop, and speed up. Sliders can be added to variables with variable values, so that the values of these variables can be easily changed via the sliders. To view the simulation results for each variable, a graph can be added. Once the simulation has started, the data in the graph will change as the simulation progresses.

You can see that four sliders have been added to the Figure 4. They are the variables that have a large impact on the system, which are the width of the road, Size of Catchment Area, number of pupils, and the duration of school dismissal or attendance. These variables can be changed while the simulation is in progress as a way of seeing the immediate impact of the variables on the overall system.

6. Result & Discussion

The most important function of system dynamics is the simulation experiment, i.e., changing the values of some key variables in the model and analyzing the effect of such measures on the results of other variables in the model. In this section, a series of 'what-if' experiments are conducted on a completed stock and flow diagram. The policies used in the experiments are drawn from programs that have been adopted or considered by schools or other institutions around the world. The results of these experiments are then used in conjunction with real-life school situations to discuss which measures would be beneficial in ameliorating the negative effects of multiple school sites on the surrounding community.

6.1 No policy for intervention

The system dynamics model was first used to predict the future impact of multiple school sites on the local community while keeping the trend of multiple school sites constant. The simulation results are shown in following figure.

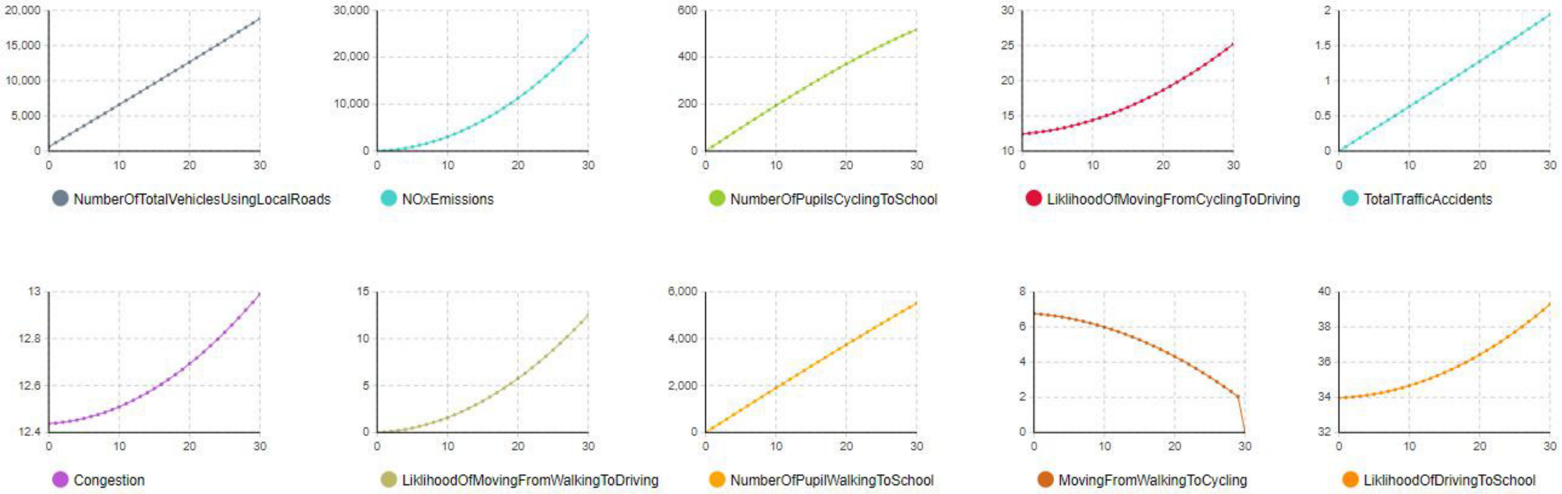

Figure 5: No Policy graphs output

The simulation results show that the number of pupils driving to school will continue to increase at an increasing rate without changing any of the variables in the system dynamics model. At the same time NOx emissions and traffic congestion levels follow almost the same trend. It can be seen that the increase in emissions and congestion makes it more likely that pupils will drive to and from school. The increase in the number of pupils driving will in turn increase congestion and emissions again, creating a vicious circle. This causes the total number of traffic accidents and the total number of vehicles on the road to appear to be at a constant rate, although they are also increasing due to the current small amount of change. The number of pupils switching from walking to cycling is decreasing and decreasing at an increasing rate.

6.2 Free School Bus Policy

Under the UK's free school transport policy, all pupils aged 5 to 16 who attend a suitable school in their neighborhood, including those under 8 years of age who are more than 2 miles from school and those over 8 years of age who are more than 3 miles from school, will be able to travel on a free school transport (Free school transport, 2021) due to the cost of public transport and the time released from work to take their children to school. As the cost of public transport and the need to take children to work is a burden for most families, free school transport would theoretically solve the problem for more than 50% of pupils who need to travel to school by car or private car. Therefore, the proportion of pupils travelling to school by private car and public transport is reduced by 50% in the system dynamics model under the assumption that the free school bus policy is adopted. These reduced numbers of pupils would be counted towards the number of pupils travelling by school bus. Due to the changes to the mathematical equations involving the variables, the results of this section cannot be presented directly using Anylogic Cloud, so the resulting data is exported via Anylogic Cloud and presented via Excel charts.

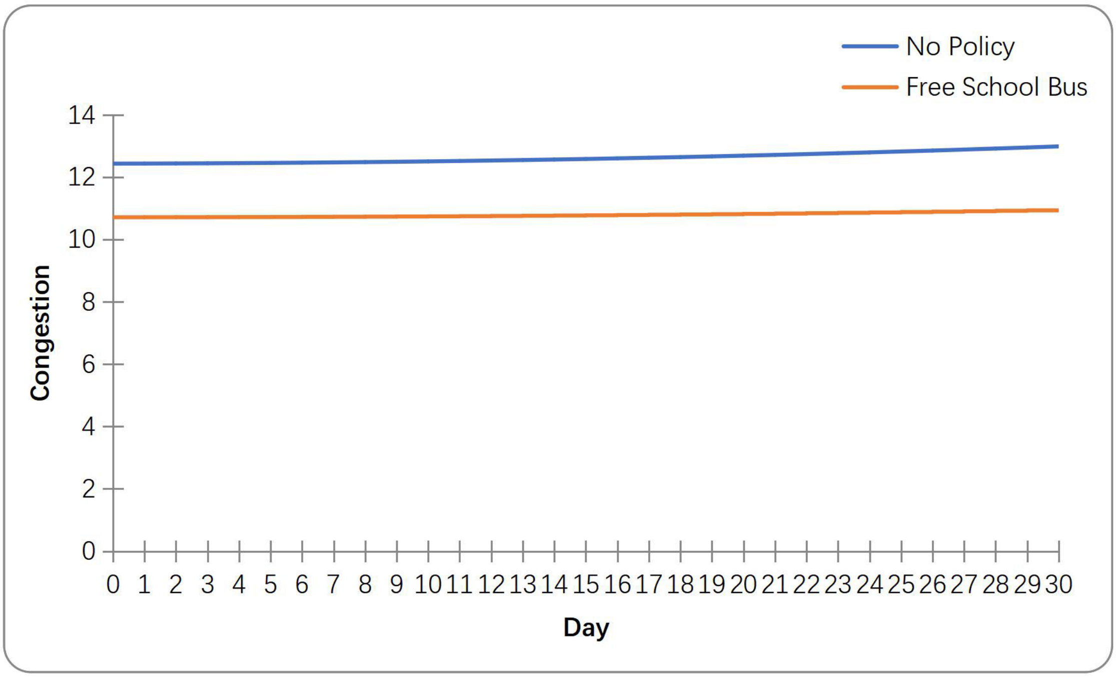

Figure 6: Free School Bus Policy "Congestion" graph output

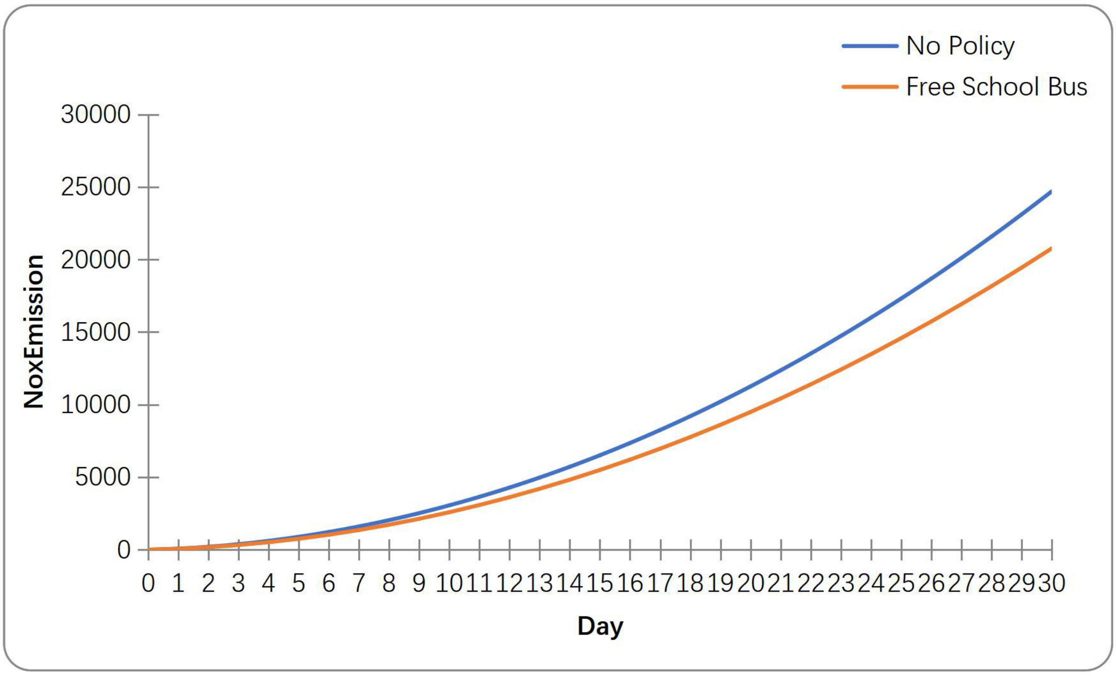

Figure 7: Free School Bus Policy “NOx Emission” graph output

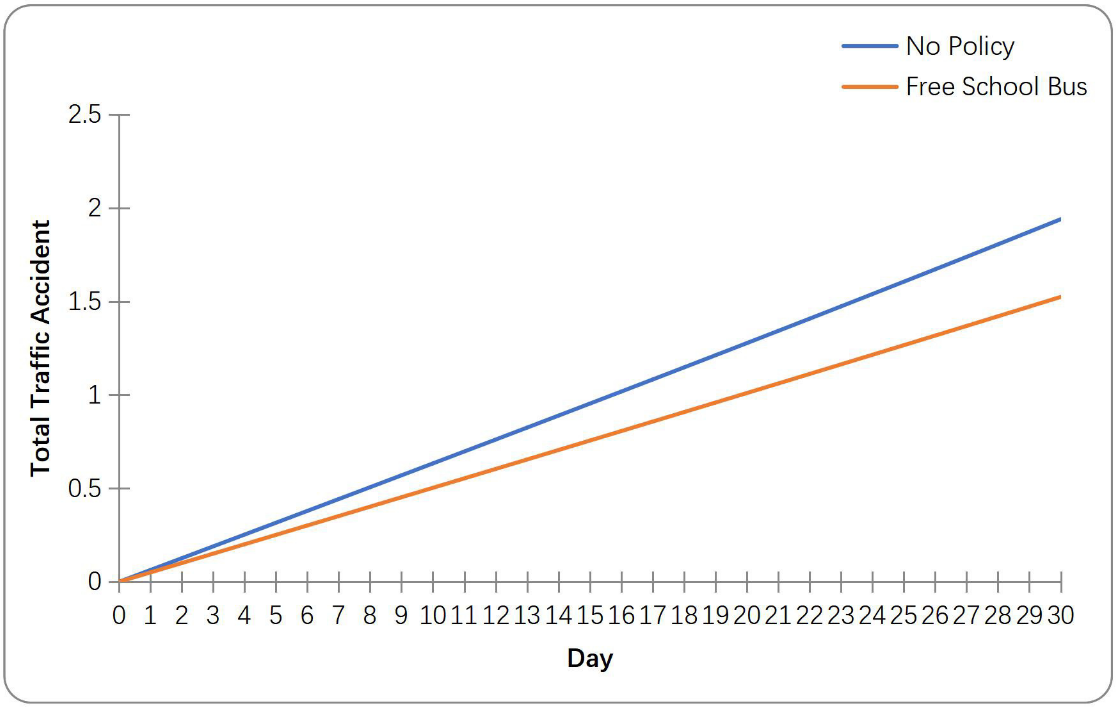

Figure 8: Free School Bus Policy "Total Traffic Accident" graph output

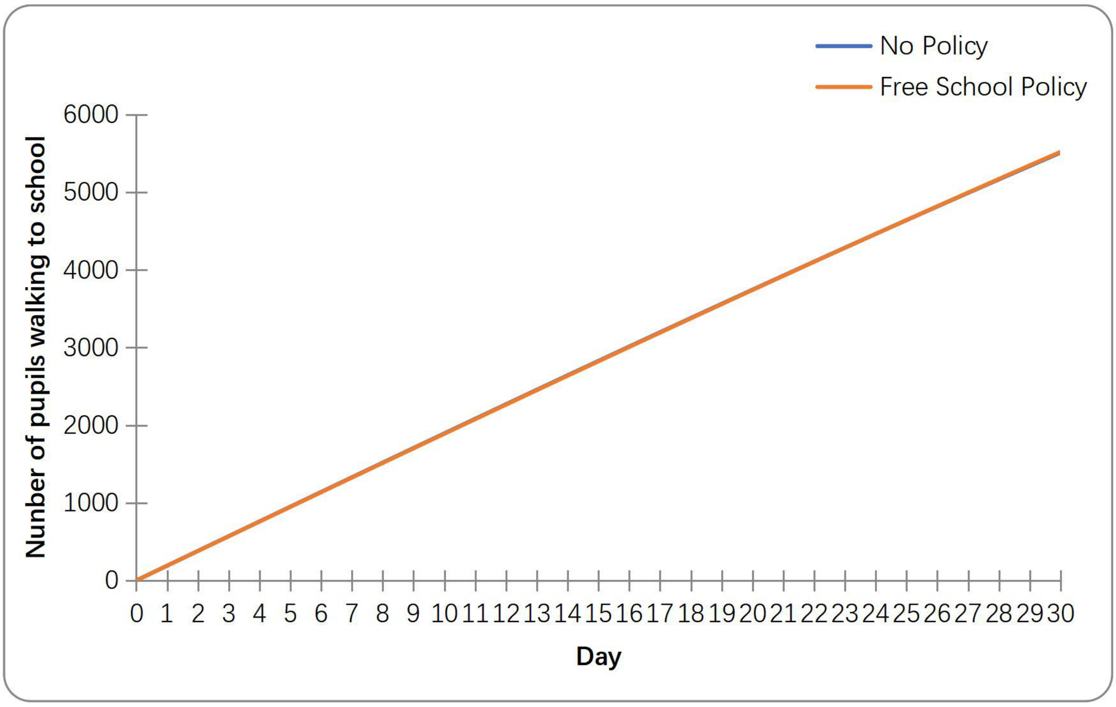

Figure 9: Free School Bus Policy "Number of pupils walking to school" graph output

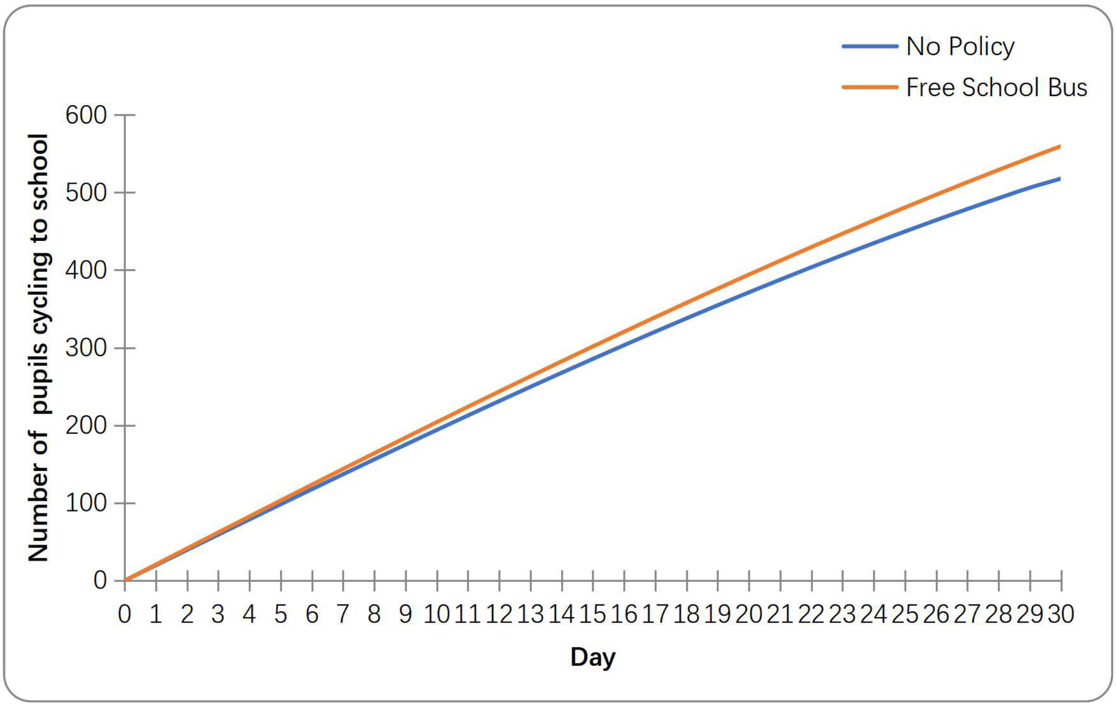

Figure 10: Free School Bus Policy "Number of pupils cycling to school" graph output

The results shown in the graph indicate that the policy has had little effect in encouraging pupils to walk and cycle to school. This is because the essence of the free school bus policy is to reduce the number of pupils travelling by private car and increase the number of pupils travelling by school bus, while pupils walking and cycling to school are not directly affected by the policy. The proportion of pupils travelling to school by car has not changed as a result of the policy. On the other hand, it is worth noting that the free school bus policy was highly effective in alleviating three key factors affecting communities: traffic congestion, air pollution and traffic accidents, with significant reductions in all three indicators. Such results are in line with the expectations of the experiment and the policy can be considered quite successful in terms of the starting point of this project. However, the cost of the policy is also significant, especially in terms of getting all pupils in need onto free school buses.

6.3 Safe Roads Policy

Many of the responses to school traffic congestion aim to reduce the number of children travelling to school by private car. Not only do these programs reduce traffic congestion, they are also an environmentally friendly scheme to encourage physical activity among children, the benefits of which far outweigh the benefits of reducing traffic congestion. Many countries and regions have demonstrated through practical experience that creating safe roads between school and home can go a long way towards increasing the motivation of pupils to walk and cycle. The multiple benefits of such a scheme almost perfectly address the three main points mentioned in section 1.2 of this project. However, the cost of the policy is also relatively high. Given that most safe roads can be used for both walking and cycling, the creation of a safe road is seen as an increase in both safe walking roads and safe cycling roads in this experiment. The following is a comparison of the different impacts of having a safe road or not.

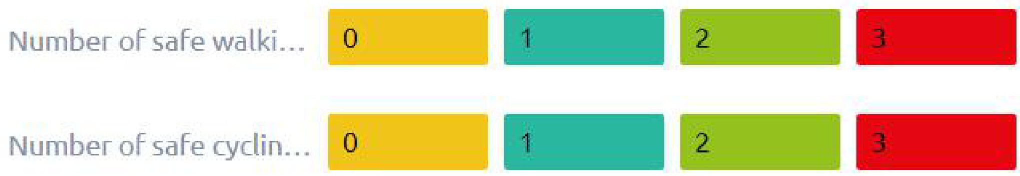

Figure 11: Safe Roads Policy input

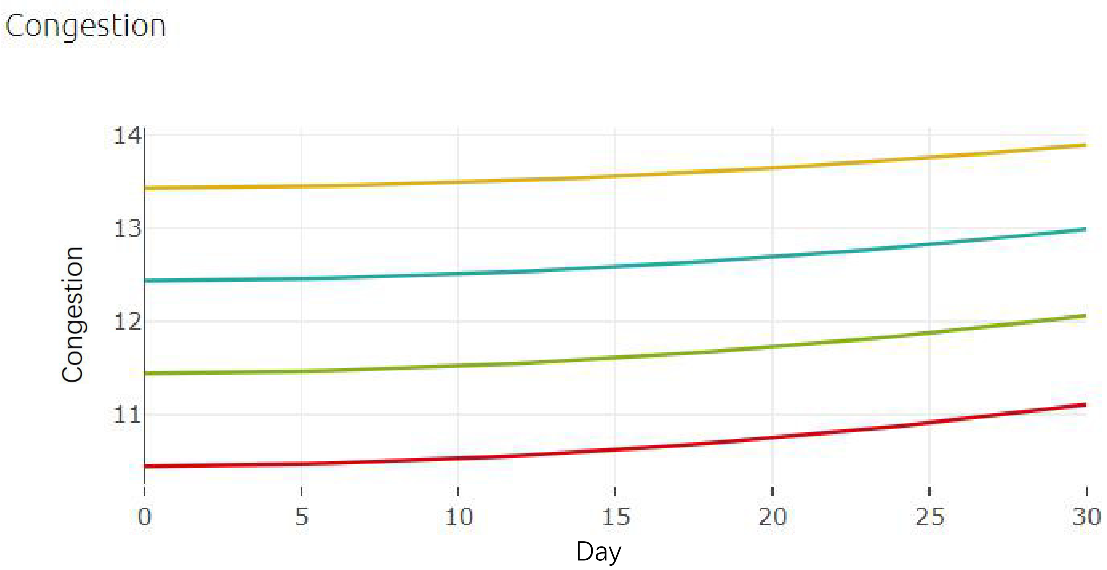

Figure 12: Safe Roads Policy "Congestion" graph output

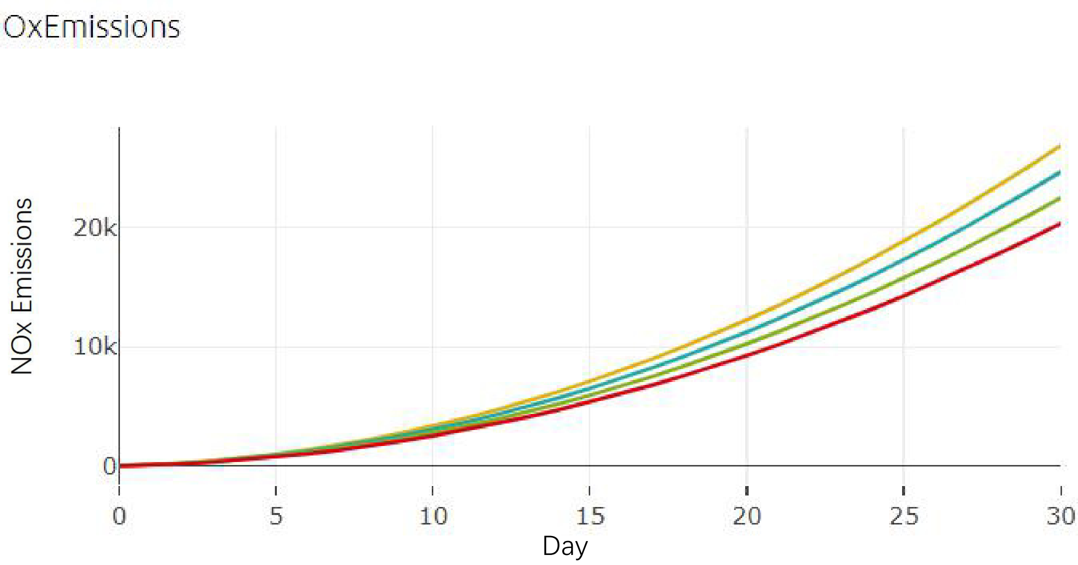

Figure 13: Safe Roads Policy "NOx Emission" graph output

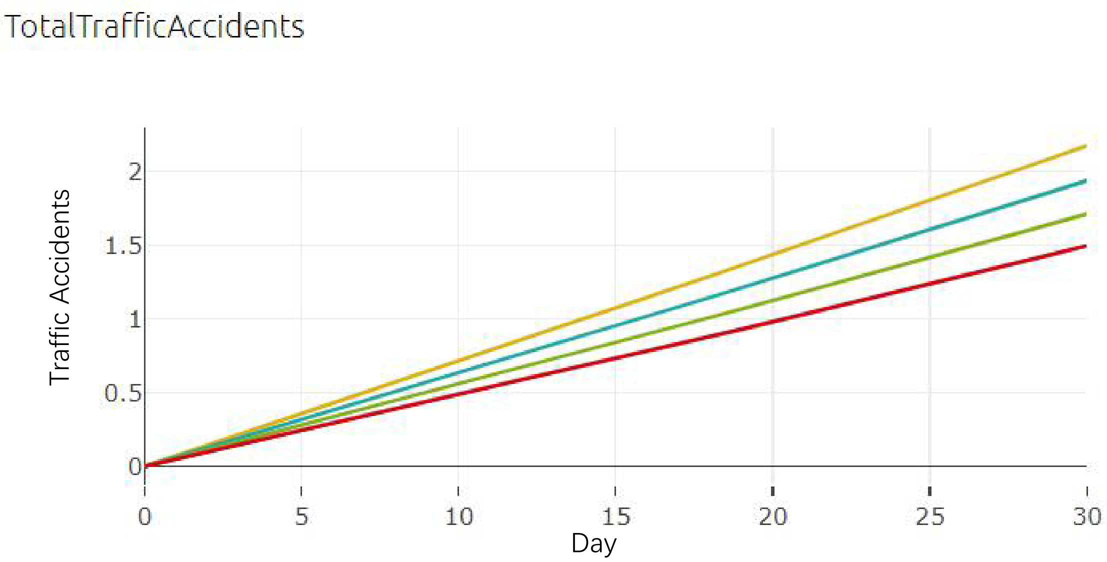

Figure 14: Safe Roads Policy "Total Traffic Accidents" graph output

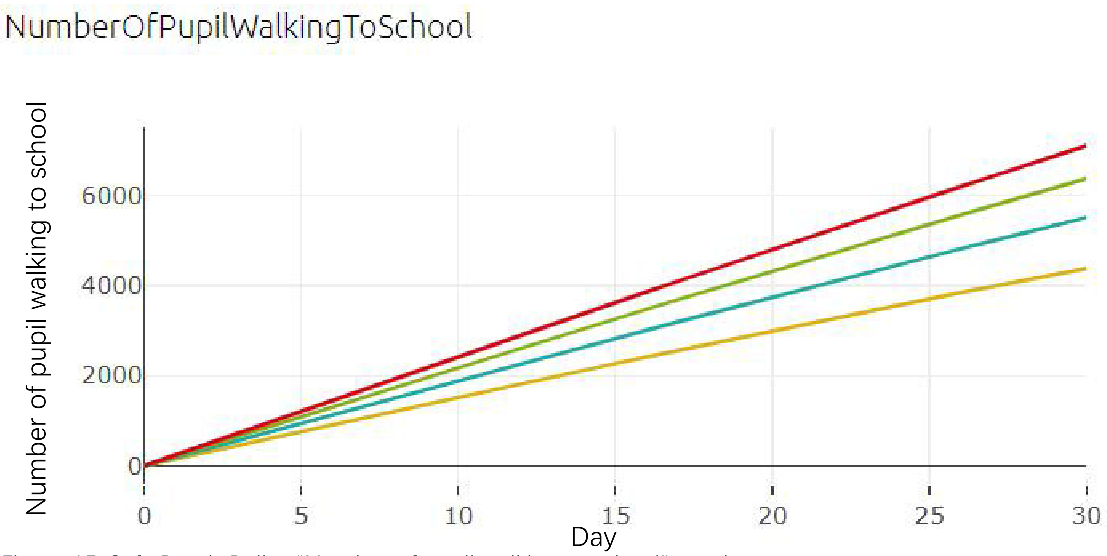

Figure 15: Safe Roads Policy "Number of pupil walking to school" graph output

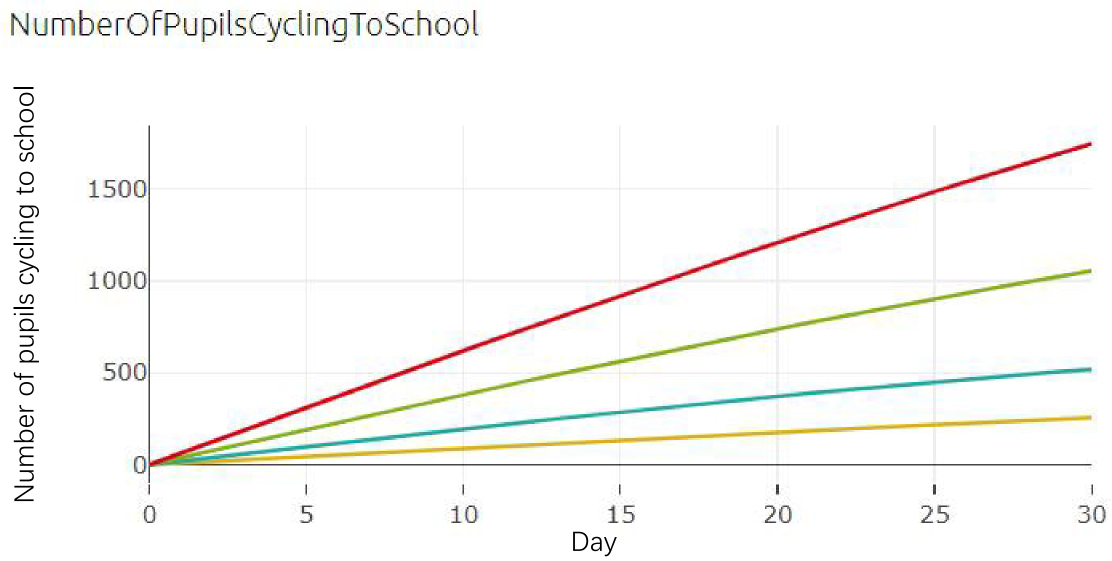

Figure 16: Safe Roads Policy "Number of pupils cycling to school" graph output

It can be seen that having a safe road has a significant impact on the way pupils travel, which is the same as expected from the experiment, as the variable directly affected by a safe road is the feasibility of getting to school and cycling. The total number of pupils walking to school increased by approximately 20% from no safe road to a safe road, while the total number of pupils cycling to school increased even more significantly, by almost 160%, as the feasibility of cycling to school was more heavily influenced by safe roads in the model. As safe roads increase, the rate of increase in pupils walking to school decreases, while the rate of increase in pupils cycling to school continues to increase significantly, so the benefits of having safe cycling roads are highest. The increase in the number of pupils walking and cycling to school and the relative decrease in the number of pupils travelling to school by car results in lower traffic volumes and therefore lower values for the three elements of congestion, air pollution and traffic accidents, with each decrease being about the same as the increase in safe roads. From a practical point of view, the introduction of safe roads increases the willingness of pupils to walk and cycle, which has a very positive impact on their health, and also has a beneficial effect on congestion, air pollution and traffic accident rates. The difficulty in implementing this policy in reality is that not all schools and multiple school sites are in a position to provide safe roads. Firstly, many schools in city centers are often surrounded by busy shopping areas and there is no suitable location for additional safe roads, only schools in residential areas or away from busy urban areas are in a position to provide safe roads. Secondly, there are considerable financial and time costs associated with the creation of safe roads.

6.4 Pupil Splitting Policy

Dividing pupils into different periods according to their grade level can prevent congestion caused by the large number of pupils and parents' cars concentrated in front of the school (Anders Ljungberg 2009), but it is important to find the most appropriate duration considering that the duration of the commute to and from school should not be too long. In this experiment, five different durations were designed for pupils to go to and from school, which were set at 20, 30, 40, 50 and 60 minutes respectively.

Figure 17: Pupil Splitting Policy input

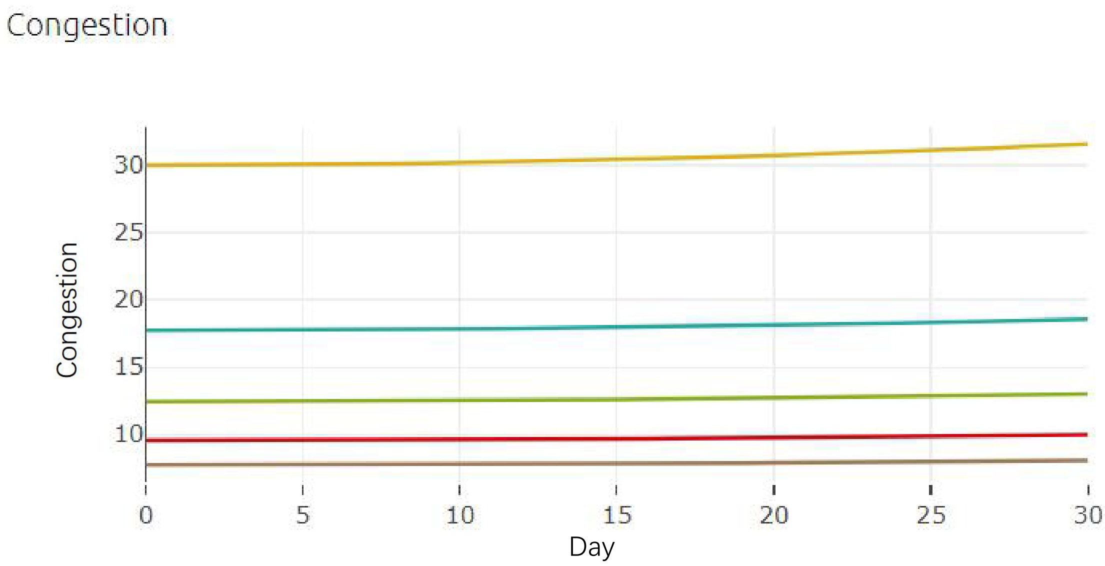

Figure 18: Pupil Splitting Policy "Congestion" graph output

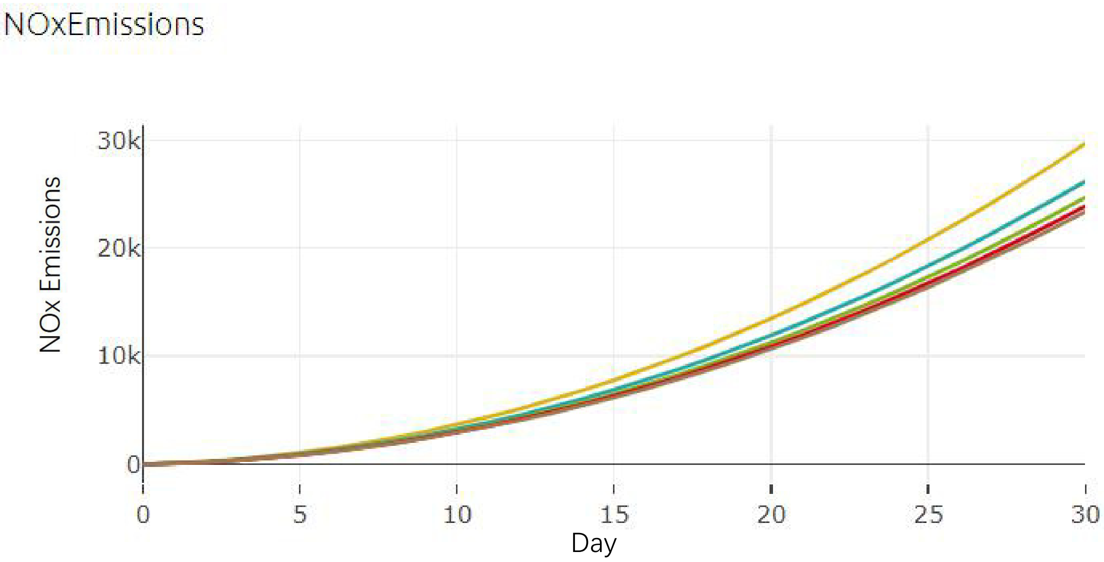

Figure 19: Pupil Splitting Policy "NOx Emission" graph output

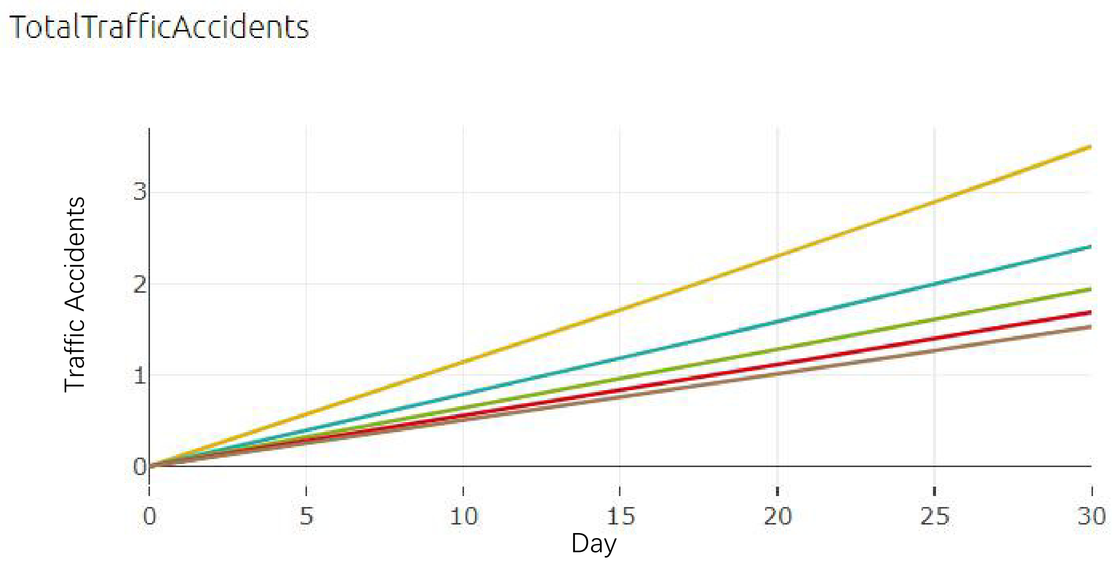

Figure 20: Pupil Splitting Policy "Total Traffic Accidents" graph output

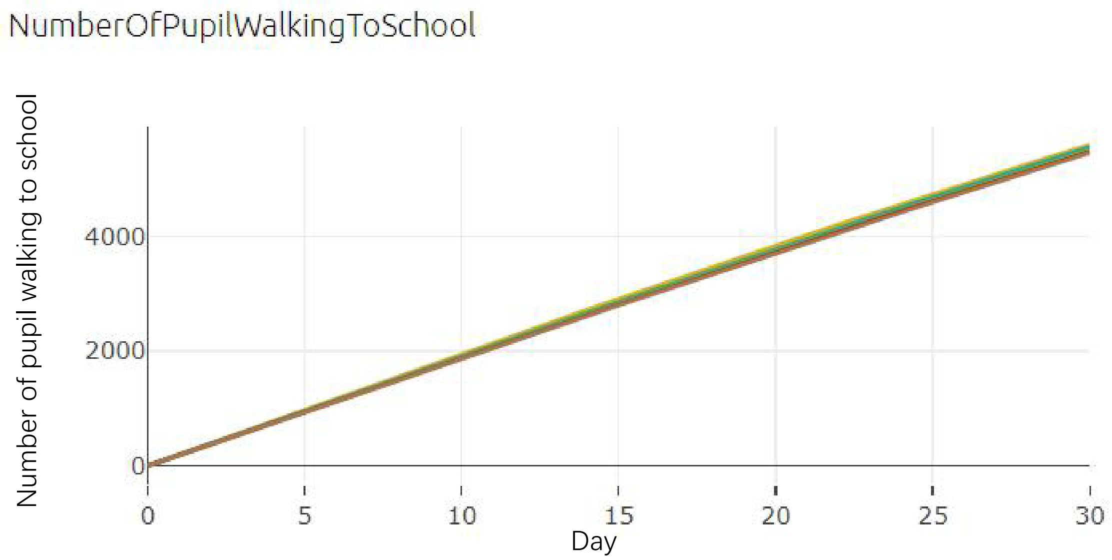

Figure 21: Pupil Splitting Policy "Number of pupil walking to school" graph output

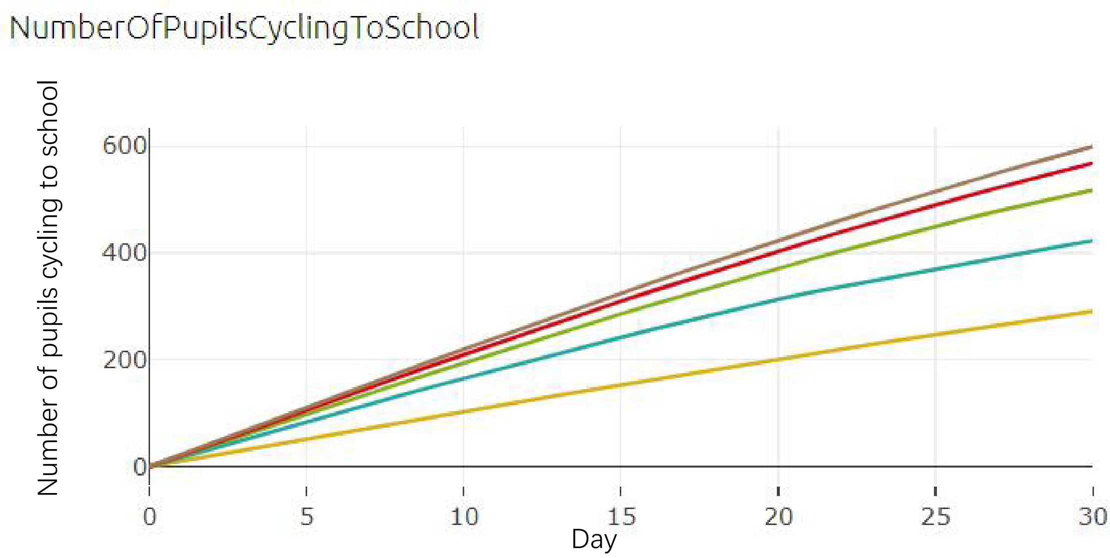

Figure 22: Pupil Splitting Policy "Number of pupils cycling to school" graph output

It is clear from the results that the duration of the school commute has a significant impact on congestion, with the more generous the duration, the lower the congestion, and the same impact on NOx emissions and traffic accident rates. However, as the duration of school commuting increases, the magnitude of the reduction in the values of these three key variables decreases, especially once the duration reaches 30 minutes or more. On the other hand, changing the duration of the commute had little effect on the willingness of pupils to walk to school, but the effect of a generous duration was significant in making more pupils want to cycle to school. While there are many benefits to increasing the duration of commuting by splitting pupils into groups, a large increase in duration is not desirable given that most schools have a policy of setting the duration of commuting to school at less than one hour or even half an hour. Therefore, in order to maximize efficiency, it is best to set the duration of the commute to and from school at 30 minutes or more. If a multi-school site includes a special school, it may be advisable to extend the duration even further.

6.5 Parking Control Policy

The Cantonian high school mentioned in section 2.1 is a typical example of a multi-school area with dense residential areas and therefore narrow roads. The roads around these schools have very limited capacity. The width of the roads is reduced by almost half because the roads are residential, and cars are often parked on both sides. The already narrow roads can make it even more difficult for two cars to pass at the same time. These roads are prone to serious congestion during and after school hours (Karuppanagounder Krishnamurthy and Venkatachalam Thamizh Arasan 2014). A policy of regulating vehicles parked on both sides of the roads in the communities surrounding the schools could potentially alleviate this problem. Most roads in residential areas are 6 meters wide and above, and the width is reduced by 2 to 3 meters when cars are parked on both sides of the road, which is the data used in this experiment.

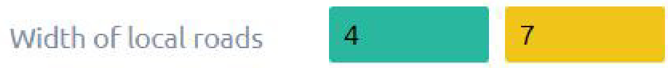

Figure 23: Parking Control Policy input

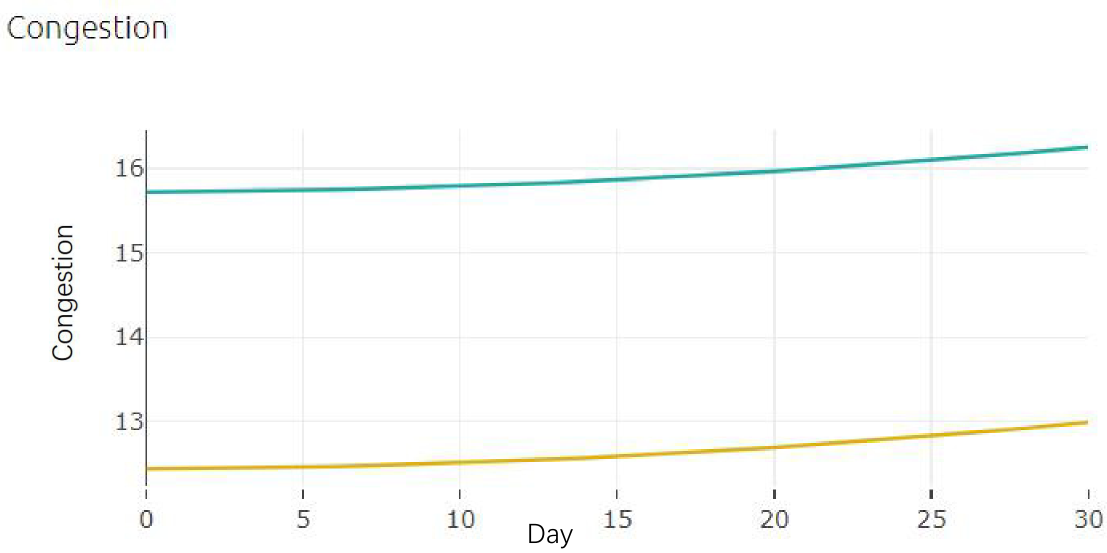

Figure 24: Parking Control Policy "Congestion" graph output

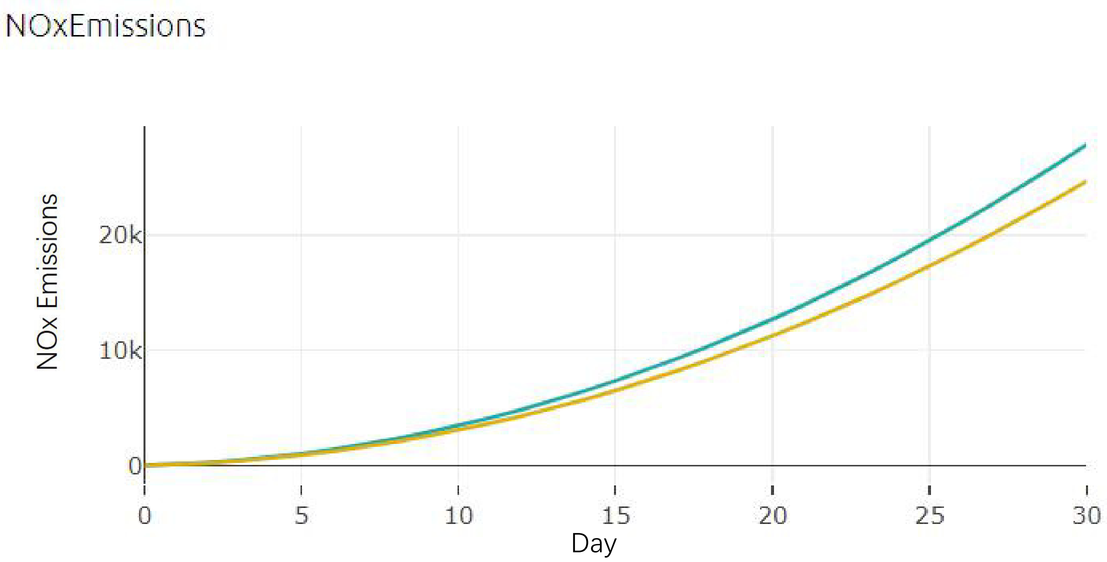

Figure 25: Parking Control Policy "NOx Emission" graph output

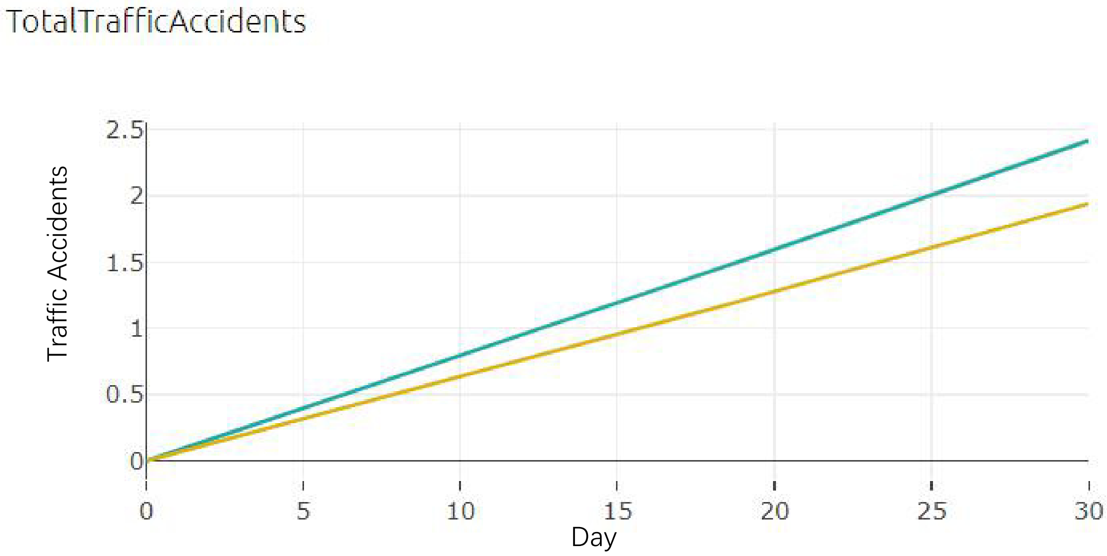

Figure 26: Parking Control Policy "Total Traffic Accidents" graph output

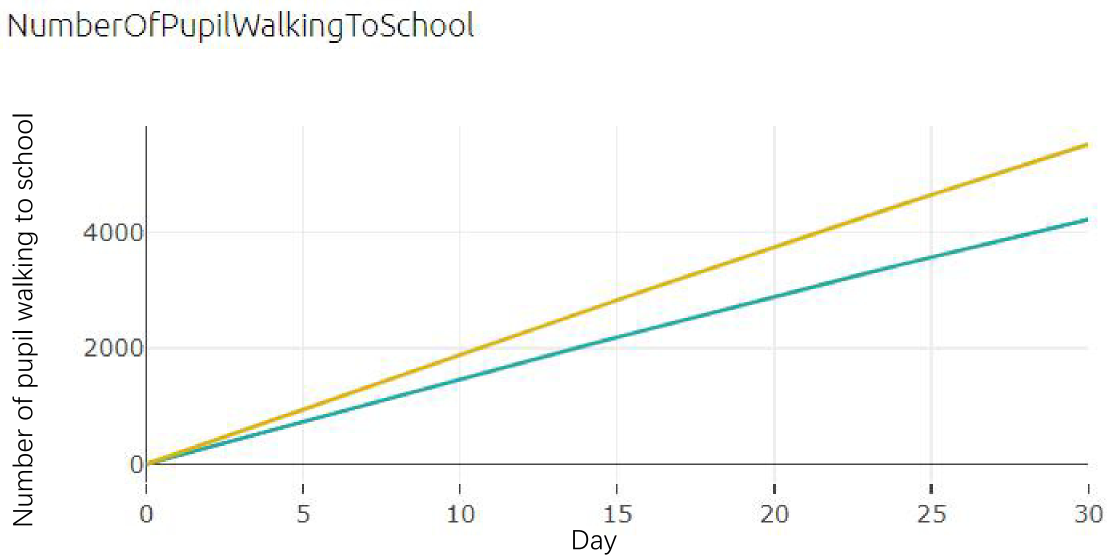

Figure 27: Parking Control Policy "Number of pupil walking to school" graph output

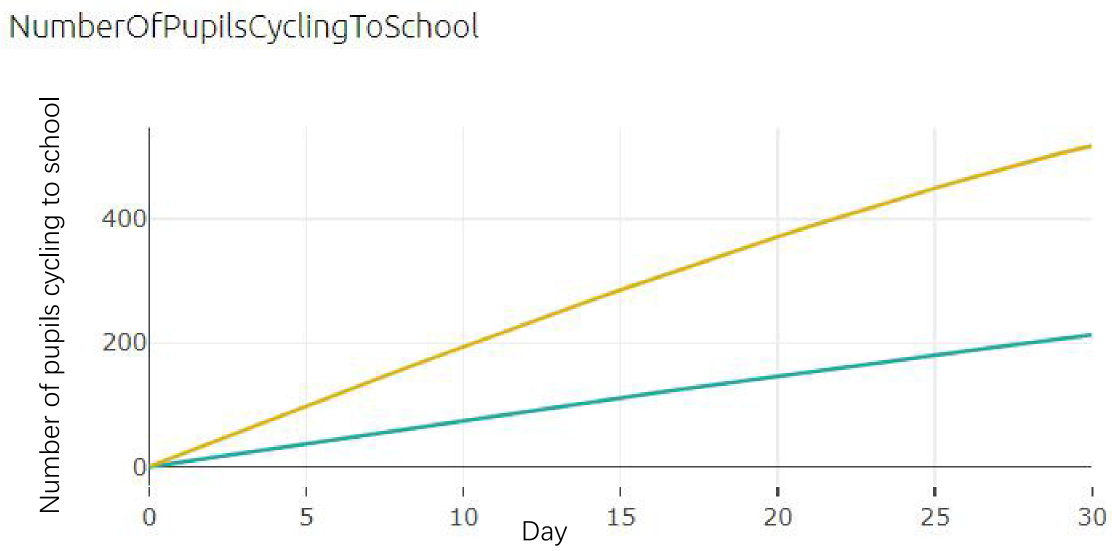

Figure 28: Parking Control Policy "Number of pupils cycling to school" graph output

The key to the parking control policy is to ensure that the width of the road is not reduced, and this policy achieves very similar or even better results than the safe road policy. In particular, parking control policies have been more effective in reducing congestion than the more costly safe roads policies. This is because the width of the road has a significant impact on congestion, which is a key influence on air pollution and traffic accidents. It follows that the width of the road has a critical impact on the community, with congestion being the core issue that multiple school sites bring to the surrounding community, and the width of the road influencing the level of congestion to a large extent, exactly as expected when the experiment was designed. Therefore, for schools and multiple school sites in residential areas, the control of vehicles parked on both sides of narrow roads is the first priority.

6.6 Footbridge Policy

Pedestrian bridges are often found in urban areas of large cities, especially at junctions in busy shopping areas. The pedestrian bridges ensure that pupils can safely cross the road without having to wait on the side of the road, thus reducing congestion and traffic accidents. In addition, the footbridges allow for the dispersal of pedestrian traffic so that pupils are not overly concentrated in their parking spaces. According to the function of the footbridge, pupils leaving the school at the same time will be divided into two groups, with half of the pupils leaving on the footbridge and the other half leaving on the usual road. The traffic congestion caused by the concentration of pupils in front of the school will therefore be reduced to half of what it would have been.

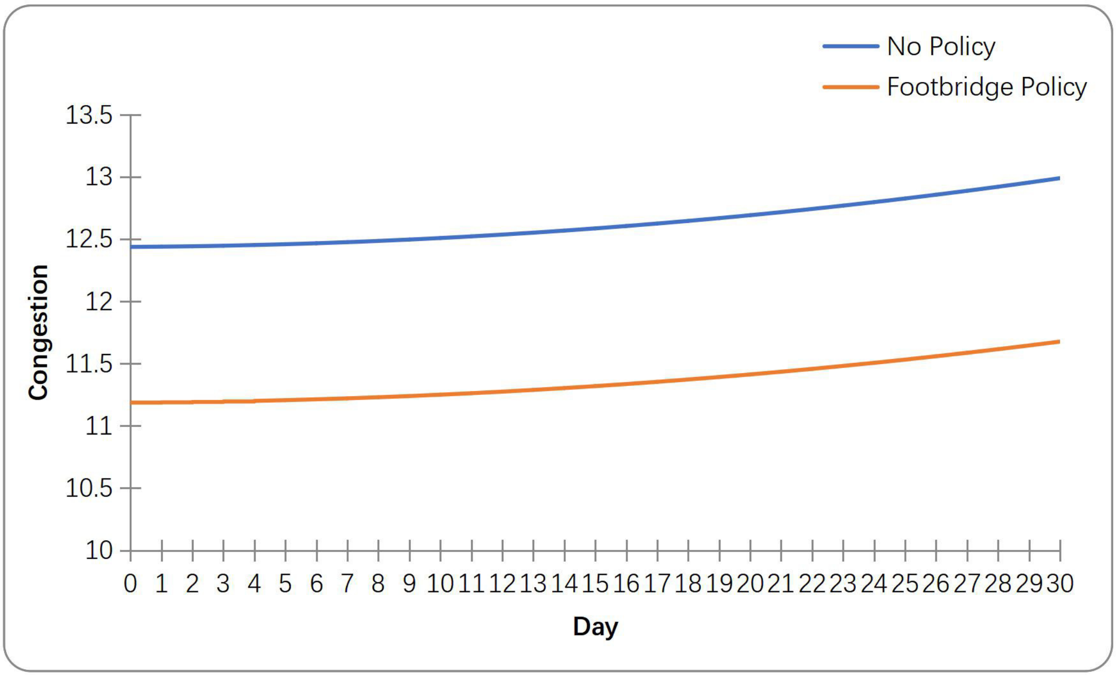

Figure 29: Footbridge Policy "Congestion" graph output

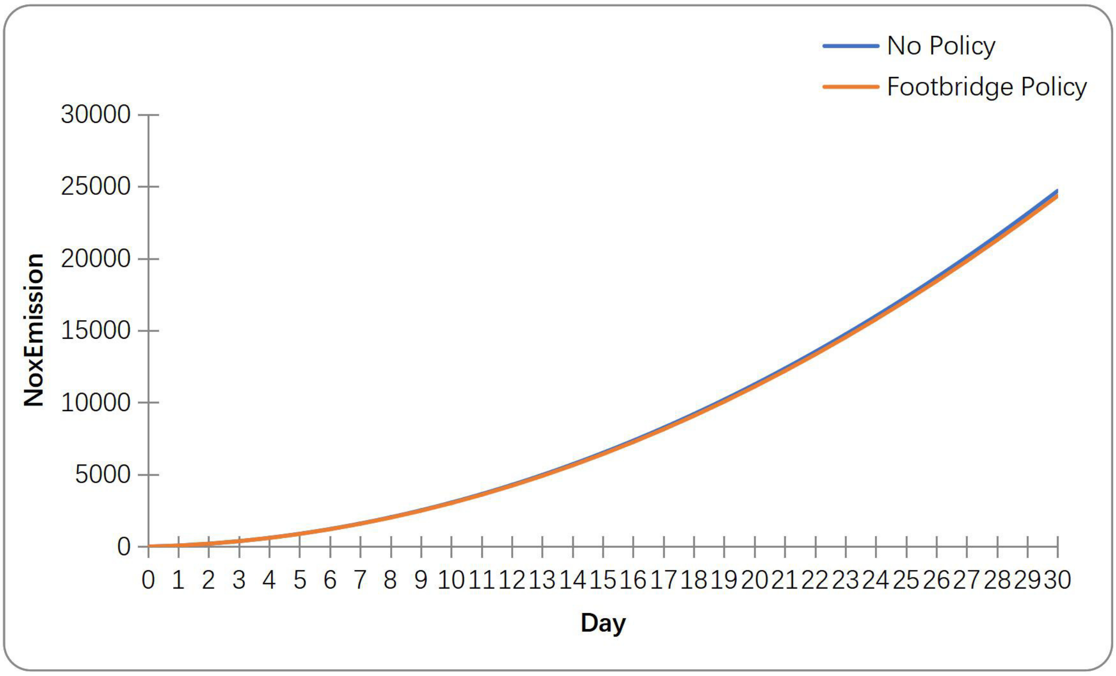

Figure 30: Footbridge Policy "NOx Emission" graph output

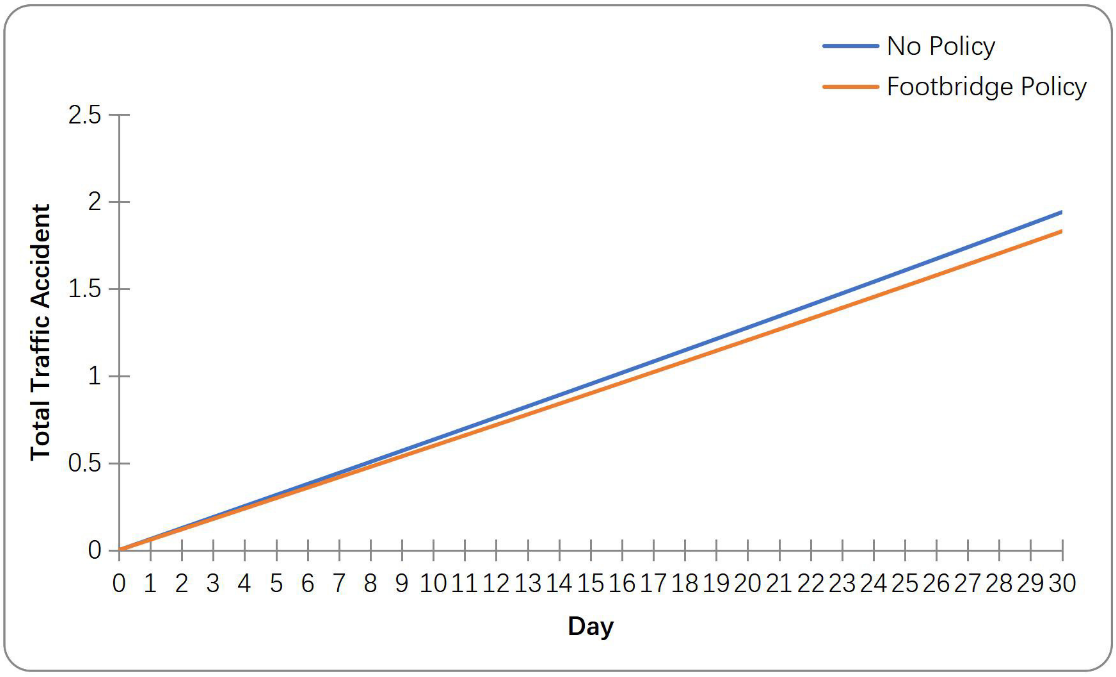

Figure 31: Footbridge Policy "Total Traffic Accident" graph output

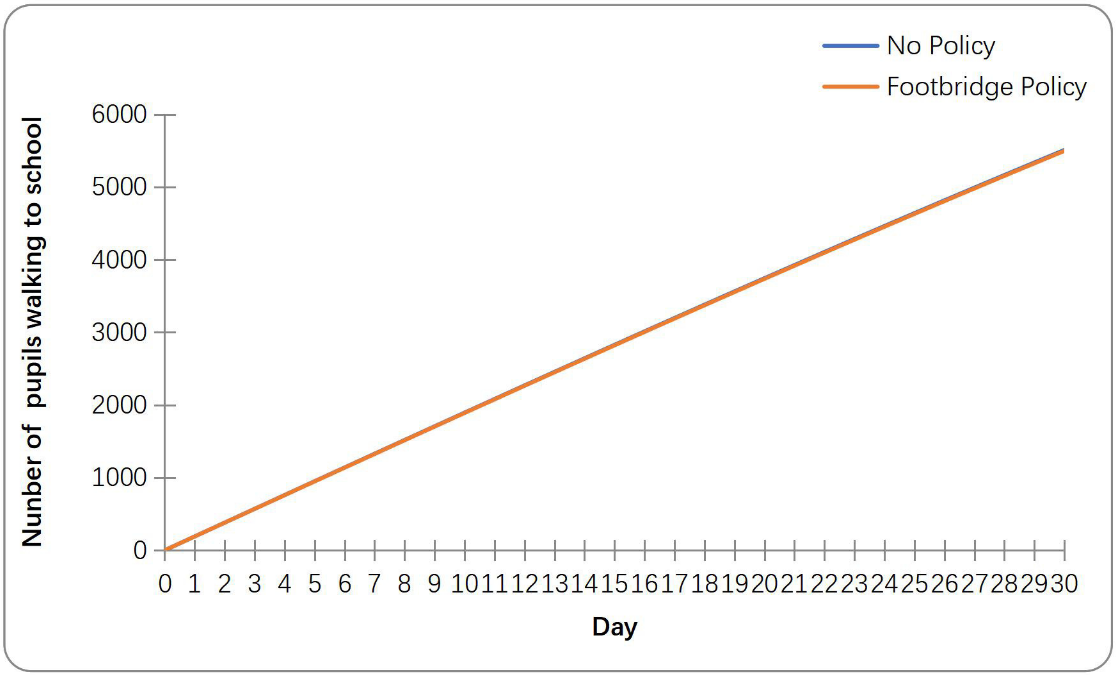

Figure 32: Footbridge Policy "Number of pupils walking to school" graph output

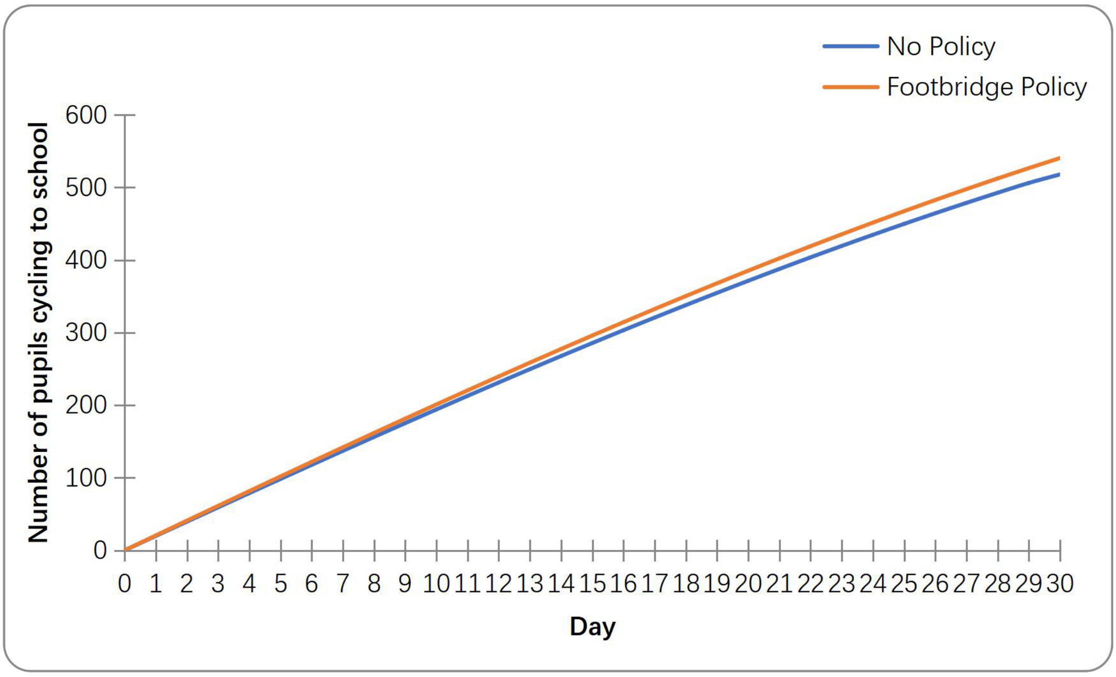

Figure 33: Footbridge Policy "Number of pupils cycling to school" graph output

Although the footbridge diverts pupils exiting the school, it has had little or no effect in improving various problems such as congestion and NOx emissions, while failing to effectively increase the number of pupils walking and cycling to school. This is related to the real role of footbridges. As traffic congestion is mainly caused by too many vehicles, pedestrians are not the main cause of congestion. So simply diverting pupils as pedestrians does not solve the congestion problem in the normal sense and therefore makes it difficult to improve other related indicators. In fact, the main purpose of the footbridge is to alleviate the impact of traffic congestion on pedestrians, for example by preventing people from crossing the road because there are too many cars on the road, rather than alleviating the traffic congestion itself.

7. Conclusion

Policy	Effects	Feasibility	Reliability
Free School Bus	It has been highly effective in alleviating three key factors affecting communities: traffic congestion, air pollution and traffic accidents, and has had little success in encouraging pupils	Free school transport is a significant expense for either the school or the local government, and its feasibility needs to be judged in the light of the specific economic situation	The data used in the experiment is conservative, with only 50% of pupils who travel to school by private car choosing to travel to school on the free school bus, and this proportion should in

	to walk and cycle to school.	of the country or region. On balance, it is difficult to achieve this policy.	fact increase considerably, making the data from this policy very reliable.
Safe Routes	There has been considerable success in encouraging pupils to walk and cycle to school, and the number of pupils cycling to school in particular has increased significantly as a result of the policy.	The requirements for achieving this policy are more stringent and require a local transport environment and economic conditions.	As this project's analysis of the impact of safe roads on the way pupils get to school is largely based on reports from schools across the UK, the data is volatile and therefore the reliability is site-specific.
Pupils in batches	The improvements in congestion, NOx emissions and traffic accidents have been significant and have been effective in encouraging pupils to cycle to school.	The vast majority of schools are in a position to implement this policy, and indeed many schools suffering from traffic congestion in their neighborhoods have implemented it.	The pupil batching policy applies to most schools and is highly reliable.
Parking control	The improvement in all factors was significant.	The policy has certain requirements for local human resources.	Consider the data sources used in the experiment. The experimental results of the policy are more reliable in areas with more residential areas in the UK mainland, but data from other countries or regions will need to be judged on a local basis.
Pedestrian bridge	Unsatisfactory improvement in all	The construction of pedestrian bridges	Although ideally footbridges would

	factors	requires a certain amount of capital, in addition to a high probability of causing disruption to local traffic in the process of construction, so the policy requires both economic conditions and a traffic environment.	only relieve congestion caused by pedestrians waiting at traffic lights, the role they play is heavily influenced by the traffic environment and therefore this policy is site-specific.

The experimental results for each of the policies proposed in this project are shown in the table above.

Based on the above analysis, these policies are divided into three categories according to priority as follows:

1. pupil batching policy, parking control policy
2. free school bus policy, safe road policy
3. pedestrian bridge policy

Concrete ways of mitigating the negative effects of multiple school sites on local communities were eventually arrived at:

Firstly, the capacity of the surrounding roads should be ensured and for those narrow roads a parking control policy needs to be implemented to prevent the width of the roads from being reduced further. At the same time, the school should be split into as many groups as is acceptable, so that the duration of the school day is as long as possible, and preferably longer for schools with special pupils. After this, if the situation still needs to be improved, free school buses can be introduced where economic conditions allow, and for reasons of pupil health, additional safe roads can be opened for pupils to travel to and from school if transport conditions are also suitable. Finally, if the rate of traffic accidents in front of or near schools remains high, the construction of footbridges could be considered.

8. Evaluation

This section will summarize and reflect on the project in terms of the extent to which the objectives set out in the first part of this project have been achieved by.

1. Study the local transport around schools in Cardiff or other similar areas of the UK.

This objective was accomplished in part 2.1 by examining Cardiff as a research example to derive the impact of multiple school sites on the surrounding area, particularly residential areas. The results obtained provided the basic idea for the design of the subsequent causal loop diagram, which can be considered as the basis of the whole project. In order to ensure the reliability of the study, I not only collected and processed relevant data during the research process, but also conducted a site visit to the Cardiff multi-school site to ascertain my own expectations of the network data

2**. Obtain the current transport situation of UK pupils to school based on official UK data.**
The experiment had to be based on reality and therefore the current mode of transport of pupils to school in the UK was one of the key data needed for the research of this project. This section was completed and is located in section 2.3 of this paper. The data in this section is crucial because the quantification of the factors in the stock and flow diagram is largely based on this data, including the proportion of pupils driving, the proportion taking public transport, and the proportion walking to school, so this objective is arguably no less important than the first one.

3. Analyze the main negative impacts of traffic congestion on pupils.
This objective is similar to the first one in that it is designed to be a casual relationship. There are many elements involved in this objective, including increased commuting time, air pollution, and traffic accidents. This objective was also successfully accomplished, and most of Chapter 2 elaborates on the negative impacts of traffic congestion on pupils. These effects also provided much help in designing causal relationships subsequently.

4. Examine the potential relationships that exist between the three key factors.
This goal was achieved in the design of the causal loop diagram, which is located in Part IV of this paper. This objective is more difficult to achieve and trying to get the potential relationship between the three key factors means completing the whole causal loop diagram. It is recursively related to the previous goals, and the first three goals need to be perfectly achieved before starting this goal. As mentioned in section 4.3, the causal loop diagram designed at the beginning was not perfect to achieve this goal from it. With the guidance of the mentor, a new causal loop diagram was created, and the new model provided a comprehensive description of the relationship between the three key factors, which led to the achievement of this goal.

5. Further use reliable data to create stock and flow diagrams and quantify them based on causal loop diagrams.
This objective was arguably the most difficult part of the entire project, as the quantification required not only the collection of a large amount of reliable data, but also the study of many relevant literature to finally obtain all the mathematical equations needed to create the stock and flow diagram. This goal took the longest time, and although the achievement of the second goal provided a lot of help for this goal, there were still many mathematical equations that had to rely on related literature in other fields to provide design ideas. Despite the difficulty, this objective was successfully achieved after spending a lot of time, and the details are located in the section on flow village maps in Chapter 5. The majority of the mathematical equations and quantitative data were derived from specific literature or government data, but some of the more variable variables were difficult to quantify due to practical reasons. These variables were eventually quantified through probabilistic as well as averaging methods, the results of which may be subject to error but do not violate the basic ideas of system dynamics. In general, the present objective was successfully achieved in general, because all data and mathematical models are very reliable in theory.

6. Identify effective ways to mitigate the negative impacts of multi-school site districts on pupils and the surrounding community through quantitative modeling.
This goal was achieved in Chapter 6 of this paper. In conjunction with the quantified model, a total of five reliable policies are proposed to mitigate the negative impacts of multiple school sites. These five policies were rigorously modified and selected. Originally, eight policies were planned for this study, and although all of these policies were helpful to varying degrees in mitigating the negative impacts of multiple school sites on pupils and the surrounding community, upon reflection, three of

them could not be represented by the flow village map created for this project because the variables in the model were not sufficient for the methods proposed for these three policies and were therefore removed.

7. The validity of the methodology for determining the final experimental results in the context of reality.

This is the final goal of this project, which is achieved in chapter 7 section. In chapter 7, the characteristics of each of the five policies were analyzed in a comparative manner by means of a table. Through a realistic perspective, the five policies were finally divided according to three dimensions of effectiveness, feasibility, and reliability, categorized according to priority, and summarized as the best way to mitigate the negative effects of multiple school sites on the surrounding community. Since this set of methods was designed based on the Cardiff area, it may be more applicable to areas or cities with traffic and community environments similar to the Cardiff area chosen for this paper, especially for multiple school sites located in dense residential areas, so there are still some geographical limitations to the effectiveness of the methods proposed in this project, depending on local conditions. Overall, the final objectives were achieved.

9. Future Work

This project investigated the impact of multiple school sites on the surrounding community through system dynamics modeling. Because the model was built based on a simplification of the system, it did not consider all the influences that affect the health of pupils and the community, such as noise pollution. In addition, more variables mean that the model for this project can study more policies, and the three additional policies mentioned previously that could not be studied may thus be possible, such as the safety light policy. Even so, the current model is still complete because the scope covered by the system dynamics model is infinite, and depending on the scenario and environment, there are always new factors worth considering that can be added to the model. There is no way to accomplish an infinite number of requirements in a limited amount of time, so I designed the model with only three important factors in mind, and it was my intention from the beginning to complete a complete and reliable model around the key factors within the time limit. Of course, there is always room for optimization, and all factors not considered can be added to the model in the future as needed.

In addition, after completing the project, I realized that I could use GIS to simulate the system dynamics model on a real map, and that a realistic simulation environment could be used to further test the effectiveness of the system dynamics model for this project. Unfortunately, there was not enough time to support the GIS experiments, as I spent more time than expected on optimizing the flow inventory maps and quantitative data. This is the regret of this project. More time would have allowed for more interesting 3D experiments with GIS, which would have made the results of this project more interesting to the reader and made the ideas of the experiments more understandable.

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Appendices

Appendix A – Justification Table for CLD

Factor	Linked to	Polarity	Justification/Assumption	Evidence
number of special needs pupils	number of private vehicles using local roads	S or +	Special needs pupils usually need special buses or private cars to travel directly from home to school.	1,020,000 results on google scholar for "transportation of special needs pupils to school"
number of special needs pupils	number of specialist vehicles using local roads	S or +		
number of special needs pupils	number of school buses using local roads	S or +		
number of special needs pupils	Number of pupils leaving school per unit time	S or +		
number of specialist vehicles using local roads e.g. taxis	vehicles using local roads increment	S or +	The increase in the number of vehicles of all types will inevitably lead to an increase in the number of vehicles on the roads. On the other hand, companies in the vicinity of the school will also increase the demand for vehicle use, resulting in an increase in the number of vehicles travelling on the roads around the school.	(Road traffic, 2021), 140,000 results on google scholar for "traffic jam problem"
number of private vehicles using local roads	vehicles using local roads increment	S or +		
number of school buses using local roads	vehicles using local roads increment	S or +		
Number of companies around the school	vehicles using local roads increment	S or +		
Increasing vehicles using local raods	number of total vehicles using local roads	S or +		
Increasing vehicles using local raods	Increasing traffic accidents	S or +	Overall, the increase in traffic volume will increase the accident rate, but the congestion will slow down traffic speeds so that the accidents that do occur are not very serious.	(Angus Eugene Retallack and Bertram Ostendorf 2019), (Chao Wang 2010)
Increasing vehicles using local raods	Congestion	S or +		

size of catchment area	avg distance from home to school	S or +	The size of catchment area is proportional to the distance pupils commute to school. Large catchment areas will increase the demand for driving to school.	(Cardiff schools 2021)
Desirability of public transport	Percentage of using public transport	S or +	Convenient public transport will make more pupils choose to travel to school by public transport	129000 results on google scholar for "desirability of public transport"
Percentage of using public transport	Percentage of driving to school	O or -	Under the assumptions of this project, the percentage of pupils who drive to school is equal to 1 minus the percentage of pupils who walk to school, bike to school, and take public transportation to school.	(Travel to school 2019)
Percentage of driving to school	number of private vehicles using local roads	S or +	The more pupils drive to school, the more traffic on the road is bound to increase.	(赵世涛 2018)
Number of total vehicles using local roads	Nox Increment	S or +	Up to 80 per cent of the NO2 concentration originates as NOx emissions from road transport.	(Emissions of air pollutants in the UK – Nitrogen oxides (NOx), 2021)
Nox Increment	Nox Emissions	S or +		
Number of complex intersections	Increasing traffic accidents	S or +	40 percent of all crashes involve intersections, the second largest category of accidents, led only by rear-end collisions. Fifty percent of serious collisions happen in intersections and some 20 percent of fatal collisions occur there.	(Autoaccident 2021)
Number of complex intersections	Congestion	S or +	The extent of traffic congestion depends heavily on intersections.	(Jingfei Yu 2013)
Increasing traffic accidents	Total traffic accidents	S or +	An increase in the volume of traffic accidents inevitably leads to an increase in the total number of traffic accidents	
Total traffic accidents	Liklihood of moving from cycling to drivng	O or -	Air pollution and safety hazards reduce the incentive for pupils to walk and bike to school.	(NAEE Web Team 2019)
Total traffic accidents	Liklihood of moving from walking to driving	O or -		
Pupils number	Number of private vehicles using local roads	S or +	The way pupils get to school can be roughly divided into driving, walking, and biking.	(Travel to school, 2019)

Pupils number	number of school buses using local roads	S or +		
Pupils number	Increasing pupils cycling to school	S or +		
Pupils number	Increasing pupils walking to school	S or +		
Pupils number	Number of pupils leaving school per unit time	S or +		
Congestion	Nox Increment	S or +	Traffic congestion often means more air pollution and traffic accidents, which will reduce the incentive for pupils to bike to school.	(Ming Lu 2016)
Congestion	Increasing traffic accidents	S or +		
Congestion	Likihood of moving from cycling to driving	O or -		
Number of pupils leaving school per unit time	Congestion	S or +	Extending or staggering pupils' school hours can help reduce school congestion.	(Anders Ljungberg 2009)
Duration of school time or finish time	Number of pupils leaving school per unit time	O or -		
Duration of school time or finish time	Congestion	O or -		
Average distance from home to school	Nox Increment	S or +	Distance greatly influences how pupils travel to school; the farther the distance from home to school, the less likely pupils are to walk or bike to school.	(Ermagun 2018), (Noreen C. McDonald 2007)
Average distance from home to school	number of school buses using local roads	S or +		
Average distance from home to school	Feasibility of cycling to school	O or -		
Average distance from home to school	Feasibility of walking to school	O or -		

Nox Emission	Likihood of moving from walking to driving	S or +	Due to the increased amount of air pollution, more and more parents are choosing to drive their pupils to school instead of having them walk or bike to school.	(Matthew Taylor 2018)
Nox Emission	Likihood of moving from cycling to driving	S or +		
Average emissions from vehicles	Nox Increment	S or +		
Likihood of moving from walking to driving	Moving from walking to driving	S or +	The increase in possibilities will inevitably lead to an increase in the total number, and the increase in the number of drives will also lead to an increase in the percentage of drives.	
Likihood of moving from walking to driving	Percentage of driving to school	O or -		
Likihood of moving from cycling to driving	Moving from cycling to driving	S or +		
Likihood of moving from cycling to driving	Percentage of driving to school	O or -		
Likihood of moving from cycling to driving	Moving from walking to cycling	S or +		
Feasibility of cycling to school	Moving from walking to cycling	S or +	The increase in viability will inevitably lead to an increase in the total amount as well as the percentage.	
Feasibility of cycling to school	Percentage of driving to school	O or -		
Feasibility of cycling to school	Increasing pupils cycling to school	S or +		
Feasibility of walking to school	Percentage of driving to school	O or -		
Feasibility of walking to school	Increasing pupils walking to school	S or +		
Average precipitation	Feasibility of cycling to school	O or -	The increase in rainfall will reduce the number of cyclists significantly.	(Kevin 2019)
Width of local roads	Feasibility of cycling to school	S or +	The capacity of a road is significantly influenced by the width of the road, so the level of congestion is closely related to the width of the local road.	(Karuppanagounder Krishnamurthy and Venkatachalam Thamizh Arasan 2014)
Width of local roads	Congestion	O or -		

Width of local roads	Feasibility of walking to school	S or +		
Number of safe walking routes	Feasibility of walking to school	S or +	Creating safe roads and additional cycling paths is a great way to encourage people to walk and bike to get around.	(Sustrans 2021)
Number of safe cycling routes	Feasibility of cycling to school	S or +		
Increasing pupils walking to school	Number of pupils walking to school	S or +	The number of pupils who walk to school determines how many pupils who walk to school will switch to biking, and vice versa.	
Increasing pupils walking to school	Moving from walking to cycling	S or +		
Increasing pupils walking to school	Moving from walking to driving	S or +		
Increasing pupils cycling to school	Number of pupils cycling to school	S or +		
Increasing pupils cycling to school	Moving from cycling to driving	S or +		
Number of pupils walking to school	Moving from walking to cycling	S or +	The number of pupils who walk to school determines how many pupils who walk to school will switch to biking, and vice versa.	
Number of pupils walking to school	Moving from walking to driving	S or +		
Number of pupils cycling to school	Moving from cycling to walking	S or +		
Number of pupils cycling to school	Moving from cycling to driving	S or +		
Moving from walking to cycling	Moving from cycling to walking	O or -	Obviously the two are in an opposite relationship	

Appendix B – Justification Table for stock and flow diagram

Factor	Model Type	Units	Initial Value	Justification	Evidence	Equation
number of private vehicles using local roads	Dynamic Variable	vehicles	N/A	calculated from the road traffic data of local road and the way of pupils travel to school	(Travel to school 2019), (Road traffic statistics 2020)	PupilNumbers*PercentageOfDrivingToSchool/100+236+NumberOfSpecialNeedsPupils/3

Increasing vehicles using local roads	Flow	vehicles	N/A	calculated from the total types of vehicles using local roads	(Road traffic statistics 2020)	NumberOfSchoolBusesUsingLocalRoads + NumberOfSpecialistVehiclesUsingLocalRoads + NumberOfPrivateVehiclesUsingLocalRoads + NumberOfCompaniesAroundTheSchool*2
number of total vehicles using local roads	Stock (level)	vehicles	N/A	calculated from Increasing vehicles using local roads flow	""	Increasing vehicles using local roads
avg distance from home to school	Dynamic Variable	Miles	N/A	calculated from the average catchment area and distance to school for 5 to 16 year olds in the 5 years from 2015 to 2019	(Travel to school 2019)	Math.pow(((SizeOfCatchmentArea)/3.14),0.5)*2*0.8
number of special needs pupils	Dynamic Variable	Pupils	403	based on the number of all special pupils in Cardiff schools	(Number of pupils at Cardiff schools (NOR) 2021)	N/A
size of catchment area	Dynamic Variable	Square miles	6	based on average school catchment area	(Amara Naveed 2017)	N/A
number of specialist vehicles using local roads	Dynamic Variable	Vehicles	N/A	calculated from school transport for special needs pupils	(Childcare and parenting 2021)	(NumberOfSpecialNeedsPupils)/30
number of school buses using local roads	Dynamic Variable	Vehicles	N/A	calculated from proportion of pupils travelling to school by school bus which is 12% and the average capacity of school buses which is 40	(Travel to school 2019)	((PupilNumbers*((AvgDistanceFromHomeToSchool)>1 ? 0.14 : 0.1))+(NumberOfSpecialNeedsPupils)/3)/40
Number of companies around the school	Dynamic Variable	Companys	20	based on average number of companys around school area in cardiff	(Merchant Savvy 2021), (Welsh Government 2019)	N/A
desirability of public transport	Dynamic Variable	Percentage of people use public transport	0.1	based on the data of average percentage of people travel by public transport in wales	(Welsh Government 2021)	N/A
Percentage of using public transport	Dynamic Variable	Percentage of Pupils use public	N/A	calculated from average percentage of pupils travel to school by public transport	(Travel to school, 2019)	(DesirabilityOfPublicTransport)*(1+0.2)

		transport				
Average emissions from vehicles	Dynamic Variable	NOx g/km	0.026	based on average emission of passenger car	(Robert Alvarez 2008)	N/A
NOx increment	Flow	NOx e	N/A	calculated from average vehicles' emission on air pollution	(Weizeng Sun 2018)	1.6*AvgDistanceFromHomeToSchool*NumberOfTotalVehiclesUsingLocalRoads*AverageEmissionsFromVehicles*(Congestion/100 +0.8)
NOx emissions	Stock (level)	NOx e	N/A	calculated from nox increment flow	(Weizeng Sun 2018)	NOx increment
Congestion	Road occupancy of vehicles	Vehicles per miles	N/A	calculated from the measures of road traffic congestion and local road capacity	(Tenzin Afrin and Nita Yodo 2020)	(IncreasingVehiclesUsingLocalRoads/143)*(1+(NumberOfComplexIntersections)*0.2)*(1+NumberOfPupilsLeavingSchoolPerUnitTime/90)*(WidthOfLocalRoads >6 ? (1-(WidthOfLocalRoads-6)/20) : (1-(WidthOfLocalRoads-6)/20)) /DurationOfSchoolTimeOrFinishTime*100 > 100 ? 100 : ((IncreasingVehiclesUsingLocalRoads/143)*(1+(NumberOfComplexIntersections)*0.2)*(1+NumberOfPupilsLeavingSchoolPerUnitTime/90)*(WidthOfLocalRoads >6 ? (1-(WidthOfLocalRoads-6)/20) : (1-(WidthOfLocalRoads-6)/20)) /DurationOfSchoolTimeOrFinishTime*100)
Number of pupils leaving school per minute	Dynamic Variable	Pupils	N/A	calculated from total number of pupils divided by efficiency of release	(Tsai, Jeff, Cranford, Joel, Lee, Jae-Joon 2004)	(PupilNumbers+NumberOfSpecialNeedsPupils)/DurationOfSchoolTimeOrFinishTime
Duration of school finish time	Dynamic Variable	Minutes	40	based on the average school policy	(Tsai, Jeff, Cranford, Joel, Lee, Jae-Joon 2004)	N/A
Number of complex	Dynamic Variable	complex intersecti	0	Default is 0	(Cardiff Council 2021)	N/A

intersections		ons				
Total traffic accidents	Stock (level)	Accidents	N/A	calculated from Increasing traffic accidents	""	Increasing traffic accidents
Increasing traffic accidents	Flow	Percentage of accidents	N/A	calculated from percentage of accidents	(Yingyu Zhang 2018)	IncreasingVehiclesUsingLocalRoads*(1+NumberOfComplexIntersections*0.000235)*(Congestion/100*10+1)*0.000047
Feasibility of cycling to school	Dynamic Variable	Percentage of Pupils	N/A	calculated from percentage of pupils cycling to school and the traffic conditions affecting cycling to school	(Laurie F.Beck and Daniel D.Nguyenb 2012), (Travel to school, 2019)	100*0.03*(AvgDistanceFromHomeToSchool>2.2 ? (1-(AvgDistanceFromHomeToSchool-2.2)/2.5) : 1)*(NumberOfSafeCyclingRoutes*0.3+0.7)*(WidthOfLocalRoads>6 ? 1 : 0.6)*(AvgPrecipitation>1200? (1-(AvgPrecipitation-1200)/1000) : 1) > 0 ? 100*0.03*(AvgDistanceFromHomeToSchool>2.2 ? (1-(AvgDistanceFromHomeToSchool-2.2)/2.5) : 1)*(NumberOfSafeCyclingRoutes*0.3+0.7)*(WidthOfLocalRoads>6 ? 1 : 0.6)*(AvgPrecipitation>1200? (1-(AvgPrecipitation-1200)/1000) : 1) : 0
avg precipitation	Dynamic Variable	mm per year	1150	based on average annual rainfall in Cardiff	(World climate guide 2021)	N/A
width of local roads	Dynamic Variable	metres	7	calculated from average width of streets in uk's standard	(Manual for Streets, 2007)	N/A
number of safe walking routes	Dynamic Variable	Routes	1	Default is 1	(Manual for Streets, 2007)	N/A
Increasing pupils walking to school	Flow	Pupils	N/A	calculated from proportion of total pupils able to walk to school	(Number of pupils at Cardiff schools (NOR) 2021)	FeasibilityOfWalkingToSchool*PupilNumbers/100
number of pupils walking to school	Stock (level)	Pupils	N/A	calculated from proportion of total pupils able to walk to school	""	Increasing pupils walking to school
moving from walking to driving	Flow	Pupils	N/A	calculated from number of pupils who changed travel mode because of rainy weather	(Sébastien Blanchette 2020)	LiklihoodOfMovingFromWalkingToDriving*IncreasingPuilsWalkingToSchool/100

moving from walking to cycling	Flow	Pupils	N/A	calculated from number of pupils who changed from walking to cycling to school	(Laurie F.Beck and Daniel D.Nguyenb 2012), (Travel to school, 2019)	IncreasingPuilsWalkingToSchool*((FeasibilityOfCyclingToSchool*(1-LiklihoodOfMovingFromCyclingToDriving/100)/100/0.03>0.75 ? ((3-(1-FeasibilityOfCyclingToSchool*(1-LiklihoodOfMovingFromCyclingToDriving/100)/100/0.03)/0.1)*0.02) : 0))
number of safe cycling routes	Dynamic Variable	Routes	1	Default is 1	(Manual for Streets, 2007)	N/A
Increasing pupils cycling to school	Flow	Pupils	N/A	calculated from proportion of total pupils able to cycle to school	(Number of pupils at Cardiff schools (NOR) 2021)	FeasibilityOfCyclingToSchool*PupilNumbers/100
moving from cycling to driving	Flow	Pupils	N/A	calculated from number of pupils who changed travel mode because of rainy weather	(Sébastien Blanchette 2020)	LiklihoodOfMovingFromCyclingToDriving*IncreasingPupilsCyclingToSchool/100
moving from cycling to walking	Flow	Pupils	N/A	calculated from number of pupils who changed from cycling to walking to school	""	moving from walking to cycling*(-1)
number of pupils cycling to school	Stock (level)	Pupils	N/A	calculated from Increasing pupils cycling to school	""	Increasing pupils cycling to school
Feasibility of walking to school	Dynamic Variable	Percentage of Pupils	N/A	calculated from percentage of pupils walking to school and the traffic conditions affecting going to school on foot	(Laurie F.Beck and Daniel D.Nguyenb 2012), (Travel to school, 2019)	44*(AvgDistanceFromHomeToSchool>4.4 ? 0.1 : (AvgDistanceFromHomeToSchool>2.2 ? (1-(AvgDistanceFromHomeToSchool-2.2)/2.5) : (1+(AvgDistanceFromHomeToSchool-2.2)/22)))*(NumberOfSafeWalkingToutes*0.2+0.7)*(WidthOfLocalRoads>6 ? 1 : 0.75)
Pupils number	Dynamic Variable	Pupils	500	The default value is 500, which can be adjusted. The range is determined by the average number of pupils in UK schools.	(Number of pupils at Cardiff schools (NOR) 2021)	N/A
Likihood of moving from walking to driving	Dynamic Variable	Percentage of Pupils	N/A	Air pollution, traffic accidents and congestion levels are the three main reasons that affect the way pupils travel to school.	(Laurie F.Beck and Daniel D.Nguyenb 2012), (Travel to school, 2019)	100*(1-(1-TotalTrafficAccidents*0.001)*(1-NOxEmissions*0.000005))

Likihood of moving from cycling to driving	Dynamic Variable	Percentage of Pupils	N/A	Air pollution, traffic accidents and congestion levels are the three main reasons that affect the way pupils travel to school.	(Laurie F.Beck and Daniel D.Nguyenb 2012), (Travel to school, 2019)	100*(1-(1-TotalTrafficAccidents*0.01)*(1-NOxEmissions*0.000005)*(1-Congestion/100))
Percentage of driving to school	Dynamic Variable	Percentage of Pupils	N/A	Since pupils' transportation to school is divided into four main categories, the percentage of pupils who go to school by car is equal to the total number minus the number of the other three categories.	(Travel to school, 2019)	88-FeasibilityOfCyclingToSchool*(1-LiklihoodOfMovingFromCyclingToDriving/100)-FeasibilityOfWalkingToSchool*(1-LiklihoodOfMovingFromWalkingToDriving/100)-PercentageOfUsingPublicTransport*100