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Implementation of School Streets Programme and Its Impact on Traffic and Air Emissions – Case Study in Leeds using SATURN

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ABSTRACT:*Air emissions from motor vehicles adversely impact public health, especially among students who are vulnerable to pollutants when commuting to/from schools located near busy roads. Various policies have been implemented to address this issue, including the School Streets programme, which restricts motor vehicle access around the school area at the beginning and end of the school day. The programme has been adopted in several cities across the UK, including Leeds, to improve the safety and air quality around school environments. The SATURN traffic model and the DEFRA Emission Factor Toolkit were used to evaluate the impact of School Streets on private vehicle route changes and air emissions at 4 school corridors in Leeds: Armley, Chapel Allerton, Weetwood, and Woodhouse. Moreover, 5 morning time-segment scenarios were simulated to analyse the effects of road closures on traffic flow and pollutant emissions. The results show that road closures successfully diverted traffic but increased congestion on alternative routes. This programme was also had potential cost-disbenefits of up to £558.7 at the end of the scenario. The emissions of 4 pollutants, namely* CO_2*,* NO_x*,* PM_{10}*, and* $PM_{2.5}$*, were found to be significantly decreased in Chapel Allerton and Weetwood schools but increased in Armley and Woodhouse schools. The study concludes that the effectiveness of the School Streets programme is highly context-dependent and recommends micro-level evaluations and integration with complementary policies within local context—such as 20-mile/h zones and park-and-stride schemes.*

KEYWORDS:Air Emissions Reduction, Traffic Simulation, Route Choice, SATURN Software, School Streets.

1) Introduction

Air pollution from road vehicles significantly impacts public health. Air pollution has detrimental effects on human physical and mental health, including cardiovascular disease affecting the lungs and heart [1], and psychological impacts such as anxiety and depression [2]. he potential for disease exposure extends beyond adults to schoolchildren, who are vulnerable to exposure to air pollution from vehicle [3]. The vulnerability to pollution exposure typically arises from commuting to and from school [4, 5], even during school hours [6]. Without proper measure, exposure to pollution threatens the physical and mental health of children throughout their development, posing a risk to respiratory diseases, cancer, and obesity [7]. Many stakeholders are working to restore private vehicles-dominated road spaces to active transportation, reflecting the positive impacts of reduced traffic flow on existing roads. Limiting vehicle traffic by reducing traffic flow by only allowing certain vehicles to use roads around schools has been shown to improve air quality and encourage pupils to use active transportation [8, 9]. Of the various programmes that can be considered, School Streets is one that is increasingly popular in elementary schools, particularly in many countries in the Americas and Europe. Simply put, schoolchildren feel safer on the roads during school hours because private vehicles are strictly restricted from using the affected roads [10]. These programmes are generally defined as restrictions on motorised vehicles from passing through the roads around schools with the aim of prioritising travel for schoolchildren during school hours [11]. Based on a similar policy in Italy circa 1989, this policy helps temporarily reduce vehicle traffic to schools, thereby increasing road safety levels [12, 13]. During the COVID-19 pandemic, this policy became increasingly popular across the Americas and Europe, as vehicle restrictions provided an opportunity for schoolchildren to switch to active transportation [14]. United Kingdom (UK) is actively implementing School Streets in hundreds of participating primary schools. Initiated in East Lothian and Edinburgh, Scotland, in 2014, the impact of School Streets was felt in the implementation of School Streets in both schools, where a significant reduction in traffic flow was recorded to increase the sense of safety in both locations [15, 16]. School Streets has also expanded to other cities in the UK, such as London, which integrated them as preventive measure to respond to the spread of the virus [11, 17]. The UK government, through the Department of Transportation, has also released a guidebook to support the implementation of this programme, including its preparation, infrastructure and evaluation [18]. By 2025, many cities in the UK implemented this program, including 17 schools across Leeds in the north of England, a twofold increase from the initial initiation of this programme in 2020 [19].A primary justification for the implementation of School Streets is the improvement of safety and the reduction of localised traffic volumes. Empirical studies have quantified this effect; research in Hackney, London, demonstrated a significant decrease in peak-hour traffic (Figure 1), particularly when automatic number-plate recognition cameras were used for enforcement [17]. Similarly, a study in Birmingham found up to 63% traffic reductions in the restricted streets when this programme implemented [20]. This reduction in vehicle volume is directly linked to measurable improvements in air quality, a critical objective given children's vulnerability to pollutants [21]. In London, Gellatly and Marner [22] identified substantial reductions in nitrogen dioxide (NO_2), with its levels predicted to fall by up to 23% during the morning peak. In another study, Abhijith et al. [6] correlated a 33% reduction in traffic volume with a greater than 30% reduction in particulate matters (PM_{10} and $PM_{2.5}$) concentrations. Despite these localised benefits, the concern for traffic displacement leads to a corresponding concern for emission displacement, whereby pollutants are merely relocated to adjacent routes [23]. This diversion may create new congestion hotspots and generate additional emissions [24].

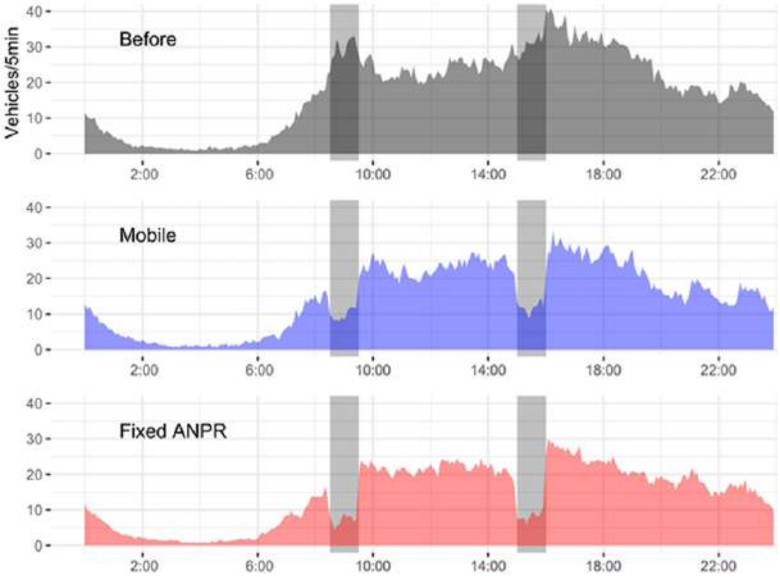


Figure 1 Average daily traffic flows before and after the application of school streets with 2 different forms of enforcement in Hackney, London, United Kingdom **[17]**

Based on the above background, this study aims to review the impact of the School Streets programme on the impact of vehicle traffic in elementary schools and its impact on reducing the number of air pollution emitters. Specifically, the authors develop a network simulation model and traffic trip matrix through SATURN that reviews changes in traffic flow patterns before and after the programme is implemented, including how changes in travel routes will occur. In addition, the authors also examine whether there is a decrease in air quality produced by vehicles passing through the streets around the school by examining the rate of air pollution produced for 4 pollutants: NO_x, $PM_{2.5}$, PM_{10}, and CO_2 in one research test cycle. It is hoped that it will be possible to determine how the School Streets simulation affects the pattern of school streets.

2) Study Area

The research location is in the metropolitan area of Leeds in West Yorkshire, England, a city with an area of 552 km^2 and a population of 822,483 in 2022. In this study, only 4 of the 17 primary schools participating in the School Streets programme will be tested in reviewing the closure of several roads. As shown in Figure 2, the schools are located in the north-west, east, south-east, and south of the city: Chapel Allerton Primary School in the ward of Chapel Allerton, Bleinheim Primary School in Woodhouse & Little London (hereinafter Woodhouse), Ireland Wood Primary School in Weetwood, and St. Bartholomew's Church of England (Voluntary Controlled) Primary School in Armley, England. These 4 schools were selected because of their proximity to major roads in Leeds, such as the school in Chapel Allerton, which is directly connected to the road leading to Harrogate, the nearest town north of Leeds, and in Armley, which connects the residential areas of Pudsey and Bradford to the city centre.

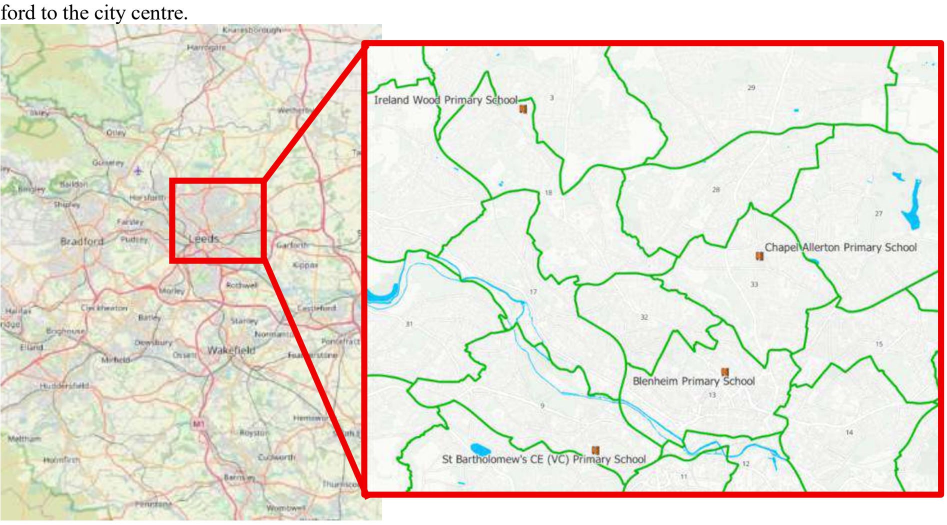


Figure 2 Location of four schools tested in Leeds

3) Methodology

This study utilises the Simulation and Assignment of Traffic to Urban Route Networks (SATURN) software package, which is based on the third stage of the four-step transport model, to evaluate the traffic network implications of School Streets [25]. This process is critical because route choice directly determines network performance, including congestion levels and travel times [25]. SATURN operates from 2 main inputs: network files (.DAT) defining the infrastructure and trip matrix files (.DAT) defining the travel demand [26]. The operational workflow of the model, as shown in Figure 3, involves the use of SATNET to convert the network data into a binary .UFN file and the MX feature to convert the trip matrix into a binary .UFM file. The SATALL process then executes the simultaneous assignment and simulation, generating .UFS binary files that contain detailed outputs. These results, including link flows, delays, queues, and average speeds, are subsequently shown and analysed using the P1X interface (Leeds P1X road network shown in Figure x) [27]. This methodology is consistent with that of previous transport studies. For example, Farda and Balijepalli [28] used this software to prove that the odd-even traffic scheme on weekends in Bandung, Indonesia, successfully reduced short-term traffic. In another study, Asadi et al. [29] used SATURN as a macrosimulation reference to build and calibrate microsimulations in other software, such as VISSIM, to evaluate the impact of autonomous vehicles on congestion and road capacity in a city.

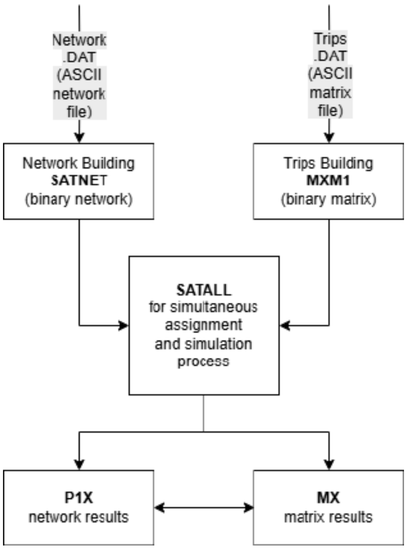


Figure 3 Operation flow of a basic SATURN network and matrix processing **[27]**

This study will use a modified SATURN model in the context of the land transport network in Leeds to review the impact of traffic changes that occur during School Streets. The modifications apply to the land transport network in Leeds (Figure 4), which is represented by lines (for road networks) and shapes (for intersection types) and a traffic journey matrix for all types of vehicles passing through.

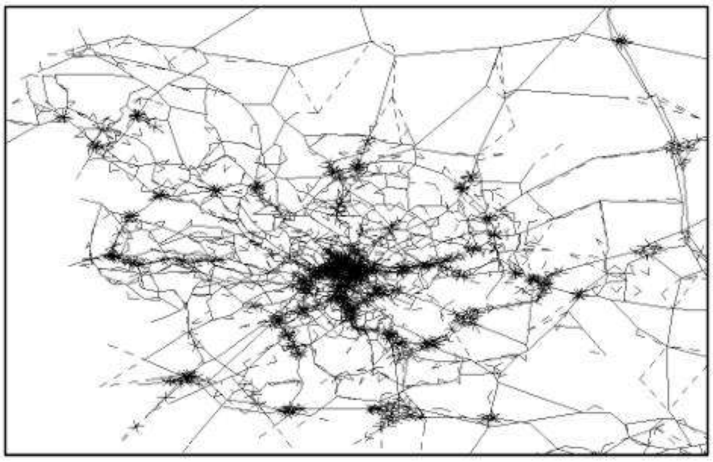


Figure 4 Leeds's SATURN network in P1X interface **[30]**

The DEFRA Emission Factor Toolkit (EFT) was used to quantify the environmental impacts of these route choice modifications based on SATURN [31]. This tool is designed to assist local authorities in the United Kingdom in assessing air quality and evaluating the environmental impacts of transport policies, such as those for School Streets. The toolkit calculates 4 tested pollutants based on a range of inputs: nitrogen oxide (NO_x), two types of particulate matter ($PM_{2.5}$ and PM_{10}), and carbon dioxide (CO_2). Key data, such as traffic flow, vehicle composition, and average speed, derived from the SATURN simulations will be fed into the EFT for this study. The resulting output, which is calculated as an emission rate (g/km), enables a direct comparison of the emissions generated by the original routes versus the diverted routes [4]. To sum up, Figure 5 summarises the technical process of the SATURN and DEFRA simulation analysis to prove the impact of School Streets on environmental emissions.

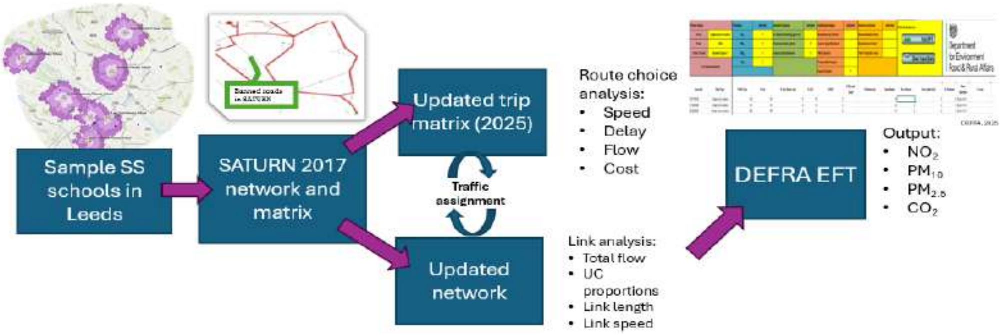


Figure 5 Research framework

This study accommodates peak morning commute traffic, given that commuter traffic to city centre of Leeds generally occurs at that time. In the SATURN network and matrix model, vehicle traffic flows are divided into 3 models representing hourly traffic flows between 7 am and 9 am. Given that the School Streets programme at these 4 schools runs after 8:30 a.m. and continues until before 10 a.m. at the remaining 2 schools, the intervention was carried out in the last 2 SATURN models (8-9 a.m. and 9-10 a.m.). Thus, 5 traffic scenarios are generated after the School Streets are operational. Appendix 1 explains which road sections are closed at the 4 schools, as well as which scenarios apply to the implementation of School Streets. The schools in Chapel Allerton and Weetwood will apply School Streets in scenarios A2 and A3, whereas only A2 will be applied at the other 2 schools. In general, Figure 6 summarises all scenarios that will be studied in this research, 2 of which include scenarios when School Streets are active.

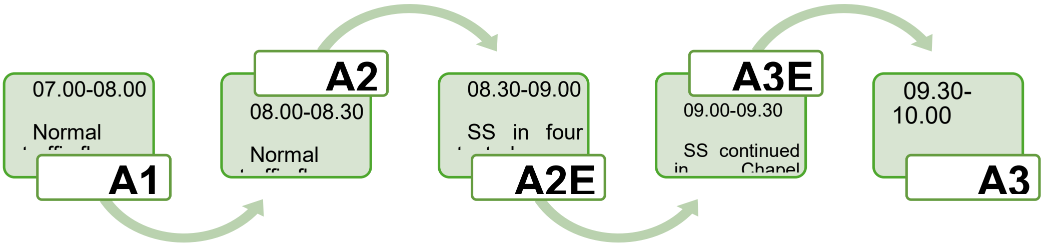
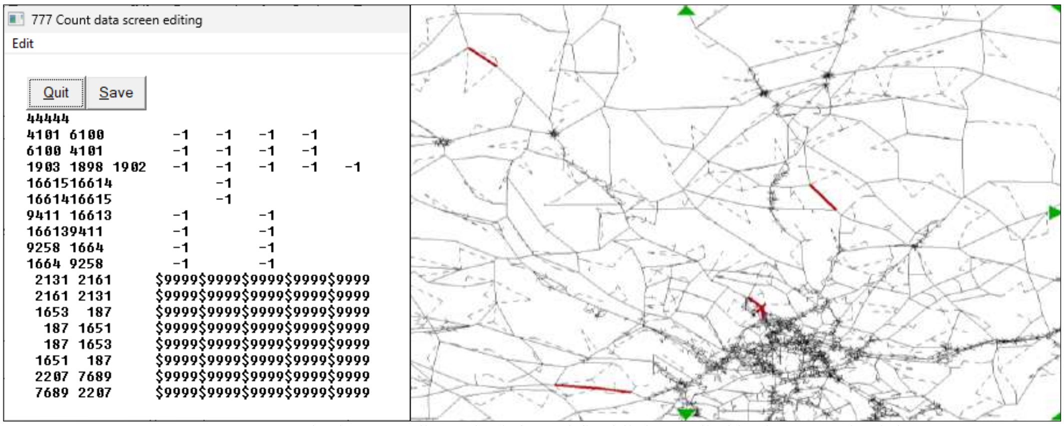


Figure 6 Five scenarios for School Streets SATURN modelling

Several **assumptions and limitations** were considered in this study. Among the 4 schools selected for the vehicle restriction test, one located in Weetwood was assumed to extend the programme beyond 9:00 a.m. For traffic transfer analysis, it was further assumed that the implementation of School Streets would coincide with the start of morning peak-hour traffic assignment rather than follow the gradual micro-level rollout. The 2025 matrix model was derived from a linear regression based on the 2017 baseline, which may not accurately reflect the current conditions. Additionally, the Leeds SATURN network lacks detailed mapping down to residential roads, limiting the analysis to the nearest major road to each school, which may not represent real-world traffic patterns. The input data for the DEFRA Emissions Factor Toolkit were rounded to avoid comma-induced calculation errors, resulting in total emissions estimates that do not reflect the actual conditions. These assumptions collectively highlight key limitations that may undermine the reliability of the study's findings.The **SATURN network and travel matrix data** to be processed were obtained based on the Leeds network model produced by Leeds City Council in collaboration with the University of Leeds in 2017. The number of trips to the Leeds matrix is based on the total number of trips in Leeds between 1993 and 2023 [32]. Through the visualisation of travel volume data in Appendix 2, it can be concluded that the travel volume in Leeds in 2025 is 0.984 times the total travel in the existing SATURN model in 2017. Then, the matrix adjustment is applied to all time scenarios simulated on the SATURN interface. The SATURN network and travel matrix data represent traffic flows in a specific one-hour scenario by default. The existing network connects intersections and activity centres in Leeds, which are numerically coded, to the main road network via straight lines. To simulate the School Streets restrictions in the last 2 scenarios, the researchers applied a road pricing-style penalty of £99.99 to all types of vehicles on the restricted road sections. This high tariff agreed with the fines issued by the local police if drivers defied the restrictions and crossed the closed road sections [33]. The restrictions then applied apply to 8 road sections at 4 schools, including the continuation of this programme after 9 a.m. in Chapel Allerton and Weetwood. Once the penalty has been successfully applied, the road network model will be repeated with a traffic matrix adjusted to 2025 conditions (result in Figure 7). The final product will be a comparison of macro traffic flows across Leeds, including an analysis of route changes and potential air emissions calculated for each school corridor.



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44444
4101 6100          -1    -1    -1    -1
6100 4101          -1    -1    -1    -1
1903 1898 1902     -1    -1    -1    -1    -1
1661516614               -1
1661416615               -1
9411 16613         -1          -1
166139411          -1          -1
9258 1664          -1          -1
1664 9258          -1          -1
 2131 2161       $9999$9999$9999$9999$9999
 2161 2131       $9999$9999$9999$9999$9999
 1653  187       $9999$9999$9999$9999$9999
  187 1651       $9999$9999$9999$9999$9999
  187 1653       $9999$9999$9999$9999$9999
 1651  187       $9999$9999$9999$9999$9999
 2207 7689       $9999$9999$9999$9999$9999
 7689 2207       $9999$9999$9999$9999$9999
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Figure 7 Fare penalty in P1X edit mode (left) and final links applied in the network (right)

A three-part analysis was conducted to test the route changes resulting from School Streets implementation: 1) changes in routes from specific origins and destinations (O-D), 2) Select Link Analysis (SLA) on closed sections, and 3) a link analysis test to assess traffic flow changes. **The O-D journey test** was conducted on 4 school corridors based on the defined Os and Ds in Table 1, targeting routes expected to cross the restricted sections. Within the P1X SATURN interface, the "forest" and "arboretum" tool menus were used to map possible routes. The arboretum details a single route, whereas the forest generates a collection of routes that users might choose by aggregating travel data. The output provided key traffic performance indicators: time (s), delay (s), distance (m), speed (kph), and cost (p). This analysis, which focused on commuter trips from the suburbs to the city centre, was vital for determining whether private vehicle route selection was disrupted.

Table 1 Tested origin and destination for route choice analysis of School Streets

Corridor	School zone	School	Origin zone	Zones represented	Destination zone	Zones represented
Chapel Allerton	-	Chapel Allerton Primary	445	St. Mattew's Church Chapel Allerton	406	ASDA Harehills
Woodhouse	317	Blenheim Primary School	709	University of Leeds's Bodington Playing Fields	179	Leeds City Museum
Weetwood	725	Ireland Wood Primary	751	Cookridge residential area	179	Leeds Civic Hall
Armley	211	St Bartholomew's Church CE (VC) Primary	226	Gamble Hill residential area	174	Leeds Civic Hall

In the **Select Link Analysis**, the preferred user routes were examined in detail by selecting road sections affected by the closures. The SLA framework identified the upstream and downstream road segments that facilitated traffic diversion. This analysis, reflecting anticipated diversions, allowed route modifications to be visualised using forest and arboretum mapping techniques. Variations in SLA locations were found to influence traffic distribution, and changes at both ends of the routes, including a complete absence of traffic at the closure points, confirmed that actual shifts in route selection occurred across the 4 test corridors.

Key traffic data were accessed for subsequent emission calculations in the link analysis impact test. The information tool in P1X was used to retrieve traffic flow data (pcu/hr) for each user classification. Traffic proportions, total flow, and average vehicle speed were derived from these data. Comparison of the main and secondary traffic scenario files (.UFS) highlighted sections with notable flow changes (Appendix 3). This comparison yielded optimal route selections and key travel metrics (i.e., time, delay, distance, speed, and cost). Traffic flow, vehicle classification ratios, and average speed were the collected data critical for processing emissions in the DEFRA EFT.

Finally, in DEFRA EFT calculation, this study utilised EFT version 13.1 (April 2025) [31], which assumed a 2025 scenario in England (excluding London), with vehicle fleet composition based on "Option 1", defining proportions of cars, taxis, LGVs, HGVs, buses, etc. The pollutants assessed were NO_x, PM_{10}, $PM_{2.5}$, and CO_2. The EFT output emission rates (g/km) in a comparative chart format, using Scenario A1 as the baseline. Input data for the EFT was derived from the link-based traffic analysis and processed in Microsoft Excel with additional gradient data from OpenStreetMap. This analysis involved aggregating total traffic flows, assigning vehicle proportions based on urban classifications (UCs), and incorporating average vehicle speeds and road segment lengths. A key methodological limitation arose from the toolkit's requirement for whole numbers, necessitating the rounding of all values to the nearest integer and introducing a degree of approximation into the study.

4) Analysis and Results

4.1) Model results and model performance

The operational impacts of the School Streets programme were evaluated using graphical and statistical outputs from the P1X interface in SATURN, focusing on the 8-10 am time-segment. Visual analysis of the network plots confirms the efficacy of the proposed method. Figure 8 shows the nullified traffic flow on the targeted road sections (indicated by the absence of green flow lines) during School Streets scenarios (A2E and A3E). This validation confirms that the high-cost penalty approach successfully replicates the intended road closures for subsequent analysis.

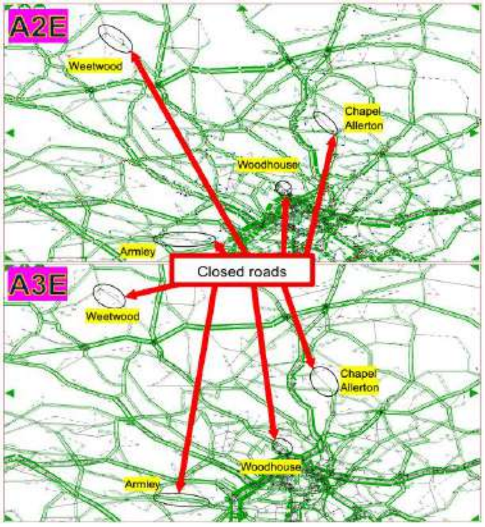
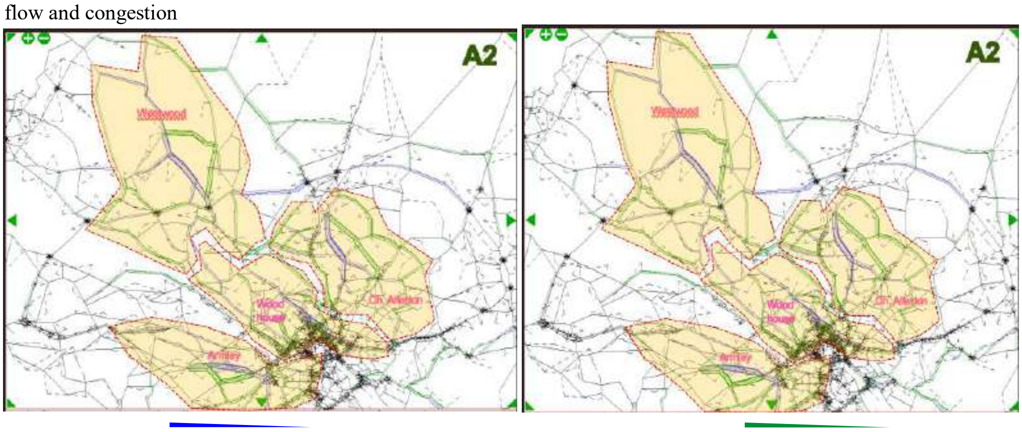


Figure 8 Nulled traffic result after School Streets implementation in scenarios A2E and A3E

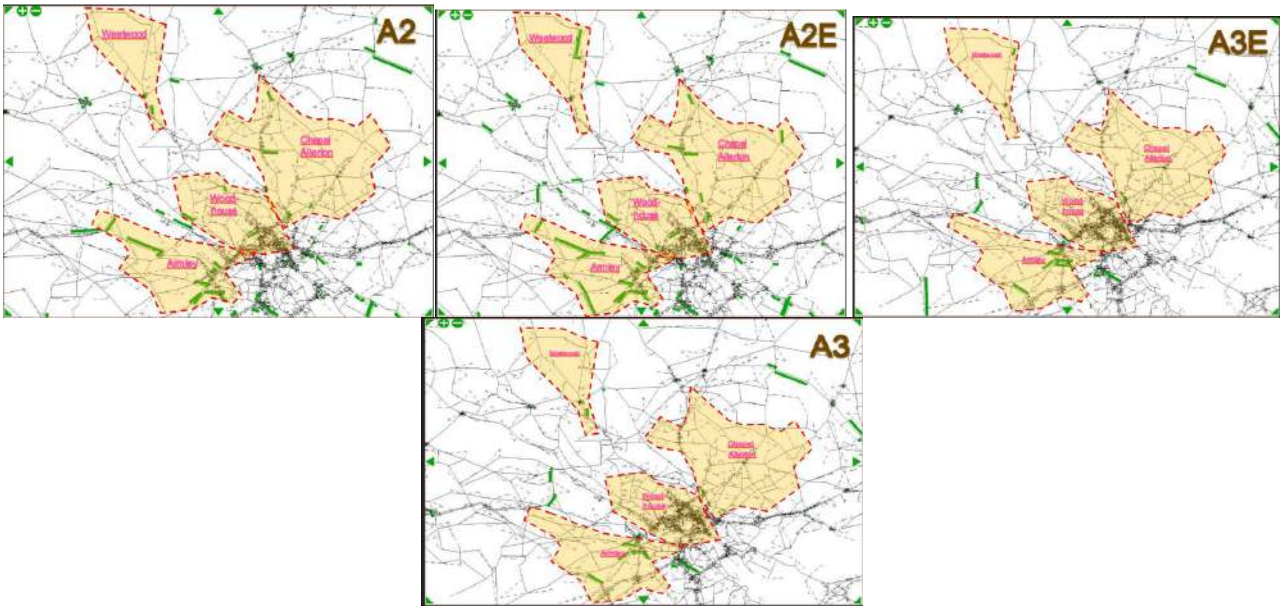
A network-wide assessment of key traffic indicators, benchmarked against the A1 (pre-peak) scenario, reveals a quantifiable degradation in network performance attributable to School Streets implementation. According to full result in Appendix 6, the model shows significant worsening of most indicators during the peak-hour A2E scenario, including increases in queuing, fuel consumption, and total network travel time, with performance degradations ranging from 1% to as high as 140% for overcapacity queues. This corresponds to a reduction of 5.79% in the overall average network speed. The post-peak A3 scenario (no interventions) showed systemic improvements as congestion naturally eased, whereas the A3E scenario (partial intervention) demonstrated poorer performance. The continuation of the scheme at 2 schools (A3E) results in network-wide savings of 7%–57% over the baseline, whereas the network without any interventions (A3) sees savings of 10%–89%, indicating a persistent, though reduced, network disbenefit caused by the active schemes.

4.2) Impact of traffic flow and congestion



Negative difference towards existing traffic flow Positive difference towards traffic flow

Figure 9 Differences in school traffic flow after street restrictions were implemented



Location with traffic congestion (with $\frac{V}{C} = 0.9$)

Figure 10 Traffic congestion result in Scenario A2-A2E and A3E-A3

Base Based on the simulation results, the implementation of School Streets successfully induces traffic redistribution away from the restricted zones. Figure 9 shows that the A2E peak-hour scenario analysis demonstrates that closing road sections near schools diverts vehicle flow to alternative routes within the network. This displacement effect is less widespread in the subsequent A3E scenario, where traffic flow changes are primarily localised to the corridors that maintain the restrictions (Weetwood and Chapel Allerton). A critical consequence of this traffic diversion is the displacement rather than elimination of network congestion. Utilising a volume-capacity ratio (VCR) threshold of 0.9 to define congestion (Figure 10), the findings indicate that the peak-hour A2E scenario generates the highest number of congestion points. Congestion is mitigated at the school sites; it concurrently intensifies on key arterial routes, particularly those serving city centre-bound traffic in the Weetwood and Armley corridors. This displaced congestion is less severe in the post-peak A3E scenario but remains demonstrably higher than in the baseline A3 scenario, where no restrictions are active.

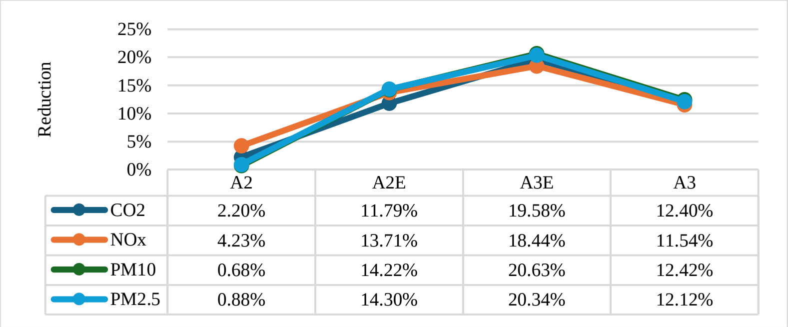
4.3) Route change results

To validate and map the changes in the travel pattern, an SLA was conducted to compare traffic flows before (A2) and during (A2E) the peak-hour intervention. The analysis examined both downstream (commuter) and upstream (reverse commute) traffic movements on routes intersecting the 4 corridors. The results confirmed that the intervention effectively redirects traffic. In the Chapel Allerton, Weetwood, and Woodhouse corridors, downstream traffic on the restricted links was substantially reduced, in some cases by over 90%, with a corresponding increase observed on clearly defined alternative routes. This finding demonstrates the clear effect of traffic displacement caused by the modelled restrictions. A significant anomaly was identified in the Armley corridor. The SLA revealed that the restricted road section does not primarily serve city centre-bound commuter traffic; rather, it functions as an inter-suburban connector. Consequently, the had a negligible impact on the dominant commuter routes to the city centre. Upstream traffic on the restricted link decreased by over 90%, and downstream flow increased. This finding underscores that the specific network function of a restricted street is a critical determinant of the resulting traffic displacement pattern.

A detailed route choice analysis was then performed, focusing on User Classification 1 (Car Commuting) for specific OD pairs. This analysis confirmed the SLA findings: the School Streets implementation measurably altered drivers' selected routes. In Chapel Allerton and Weetwood, commuters were observed rerouting onto specific detours (e.g., Gledhow Valley Road and via Horsforth). In many instances, the diversion was absolute, with 100% of the O-D matrix flow shifting to a single alternative path. As anticipated, the dominant commuter route in the Armley Corridor remained entirely unaffected by the local closure. The impact of these forced route choices on network performance for the affected O-D pairs was quantified and presented in Appendix 6. The findings indicate that the diversions impose a network disbenefit on displaced drivers. In the corridors where rerouting occurred (Chapel Allerton, Woodhouse, and Weetwood), commuters experienced quantifiable increases in travel time, travel distance, delays, and overall travel cost. Although localised benefits, such as increased average speeds on the Chapel Allerton route, were observed, the predominant outcome for displaced drivers was a degradation in journey efficiency, forcing them onto paths that were longer and more costly.In terms of cost disbenefits, School Streets risk increasing traffic travel costs during the morning traffic period in Leeds. Considering the implementation of School Streets under do-nothing and d-something conditions, it is known that at the end of the simulation there was an increase in travel distance for all vehicles in Leeds to 1,222,498.4 pcu.km, up from 1,221,785.8 pcu.km without School Streets. Assuming a vehicle operation cost for travel outside the British capital of £0.304/km and calculating the difference between the scenarios before and after School Streets were implemented [34], it is known that there will be an additional travel distance of 712.6 pcu.km for all vehicles, or equivalent to £558.7 at the end of the scenario. Thus, the potential financial loss due to this programme remains, regardless of its effectiveness in significantly reducing traffic flow around the test schools.An analysis was then conducted for 16 selected routes across the tested region (Appendix 3) to quantify the impact of traffic diversions resulting from the School Streets interventions in terms of traffic flow change. The findings confirmed that the 7 routes restricted by the interventions experienced significant decreases in traffic flow, generally exceeding 50% of their preclosure levels. Conversely, the alternative routes utilised by displaced traffic saw corresponding increases in flow, up to twice their baseline levels in some cases. As detailed in the average flow calculations in Appendix 7, the traffic displacement varied by corridor. In Weetwood, the alternative route (3B) experienced the highest average flow after implementation, as it also accommodated traffic from other residential areas. In contrast, the traffic in Chapel Allerton did not completely shift; the peak traffic flow on the alternative route remained lower than that on the main route. In Armley, the peak flow of the diverted route (4B) did not exceed that of the main restricted route (4A) at baseline (A1). The increased traffic flow on these alternative routes generally reduced their average traffic speeds.

4.4) Emission change result

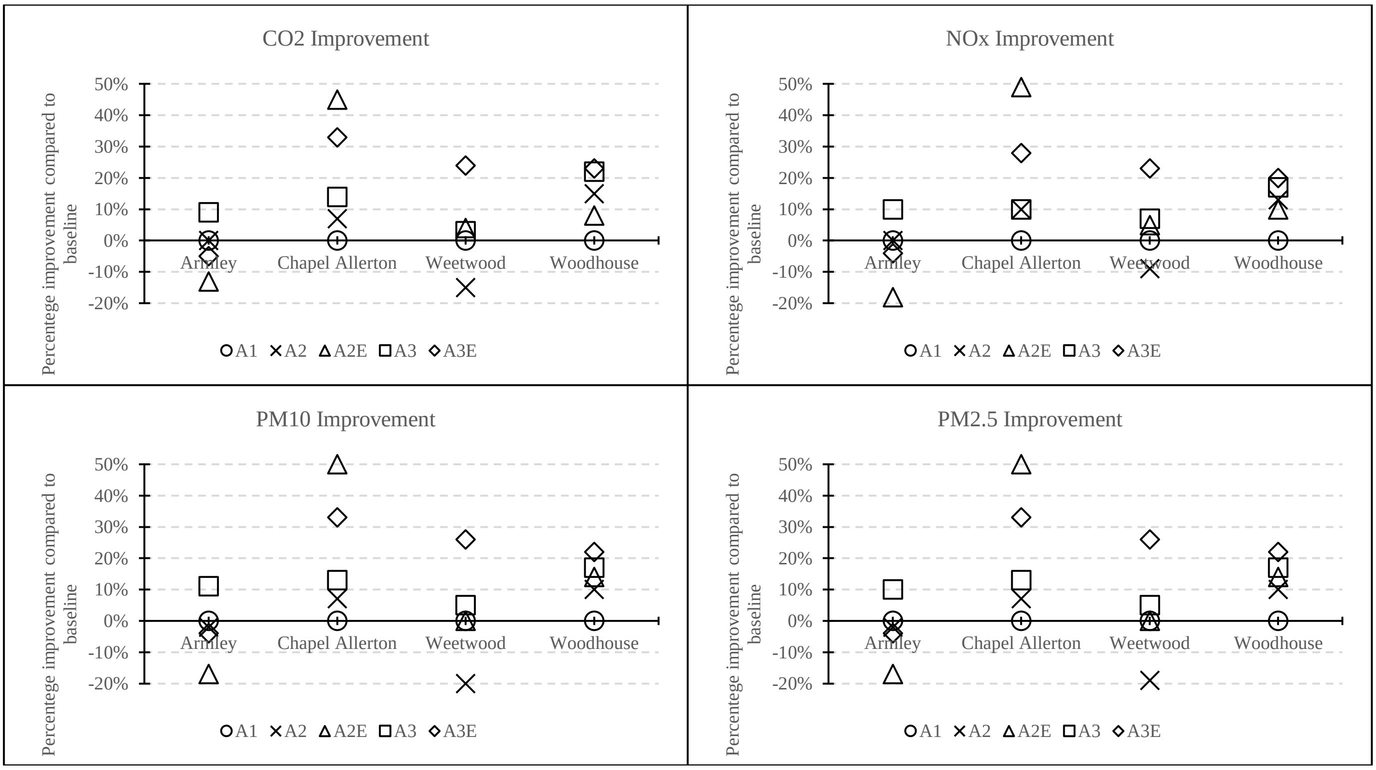
From the results of traffic performance input calculations in DEFRA EFT, comparisons of CO_2, NO_x, PM_{10}, and $PM_{2.5}$ pollutant calculations (in g/km) have been calculated for all scenarios in the 4 corridors. The traffic flow volumes, vehicle compositions (by UC), and average speed data derived from the SATURN link analysis for all test routes served as the primary inputs for the EFT model. This process yielded emission rate data, expressed in grams per kilometre (g/km), across 5 distinct temporal scenarios. As anticipated, the resultant emission levels are directly correlated with the average traffic flow volumes and average vehicle speeds modelled within each scenario.

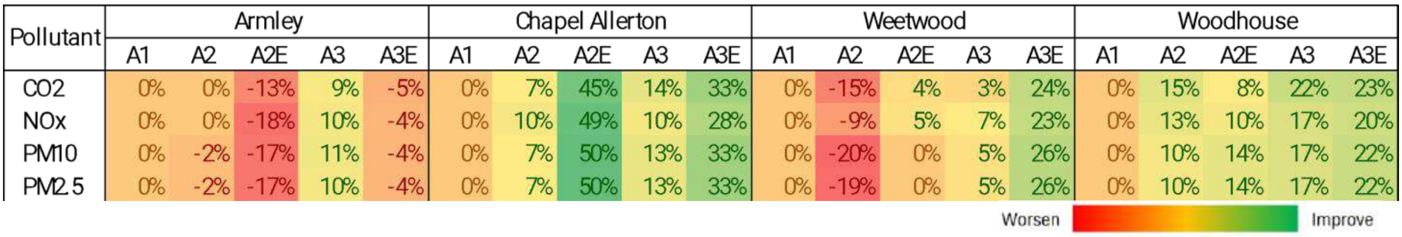


	A2	A2E	A3E	A3
CO2	2.20%	11.79%	19.58%	12.40%
NOx	4.23%	13.71%	18.44%	11.54%
PM10	0.68%	14.22%	20.63%	12.42%
PM2.5	0.88%	14.30%	20.34%	12.12%

Baseline (g/km)	CO_2	NO_x	PM_{10}	$PM_{2.5}$
Scenario A1	8,058,087.32	9,705.46	1,549.14	824.49

Figure 11 Relative in polluted emission production for all corridors after School Streets





Pollutant	Armley					Chapel Allerton					Weetwood					Woodhouse				
	A1	A2	A2E	A3	A3E	A1	A2	A2E	A3	A3E	A1	A2	A2E	A3	A3E	A1	A2	A2E	A3	A3E
CO2	0%	0%	-13%	9%	-5%	0%	7%	45%	14%	33%	0%	-15%	4%	3%	24%	0%	15%	8%	22%	23%
NOx	0%	0%	-18%	10%	-4%	0%	10%	49%	10%	28%	0%	-9%	5%	7%	23%	0%	13%	10%	17%	20%
PM10	0%	-2%	-17%	11%	-4%	0%	7%	50%	13%	33%	0%	-20%	0%	5%	26%	0%	10%	14%	17%	22%
PM2.5	0%	-2%	-17%	10%	-4%	0%	7%	50%	13%	33%	0%	-19%	0%	5%	26%	0%	10%	14%	17%	22%

Worsen — Improve

Notes:

- A1: 7-8 am, do-nothing scenario (baseline)
- A2: 8-8.30 am, peak morning without School Streets
- A2E: 8.30-9 am, peak morning with School Streets in 4 schools
- A3E: 9-9.30 am, afterpeak morning without School Streets
- A3:9.30-10 am, School Streets ended

Figure 12 Relative changes of emission by corridor, before and after School Streets, based on pre-morning peak scenario

An aggregate analysis of all corridors, presented in Figure 11, demonstrates a net positive environmental outcome from the implementation of School Streets. During the peak morning scenario (A2E), the intervention successfully reduced aggregate pollutant emissions from 11.79% to 14.3% relative to the baseline condition (A1). Notably, PM$_{2.5}$ emissions exhibited the most substantial reduction, at 14.3%. This reductive trend was not only sustained but also amplified in the post-peak A3E scenario (where interventions remained active in 2 corridors), achieving CO$_2$ and PM$_{10}$ reductions of 19.58% and 20.63%, respectively. This enhanced post-peak performance is logical because the most significant traffic volumes were modelled during the A2-A2E peak, establishing a high baseline for comparison. Conversely, a disaggregated analysis by corridor revealed significant local variations in programme effectiveness, as detailed in Figure 12. Although the Woodhouse corridor consistently exhibited the highest baseline emission levels, A2E implementation yielded divergent results. Interventions in Chapel Allerton and Weetwood were successful. Chapel Allerton recorded a profound reduction in pollutant emission rates, ranging from 45% (CO$_2$) to 50% (PM$_{10}$ / PM$_{2.5}$) during the A2E scenario. The impact on Weetwood was more nominal, with reductions fluctuating between 0 (PM$_{10}$ / PM$_{2.5}$) and 5% (NO$_x$) relative to the base scenario. However, this stabilisation is significant when compared with the A2 scenario (pre-intervention peak), which saw emissions worsen by 9%–20% relative to the baseline, indicating that the intervention successfully mitigated a period of high pollution. This positive effect continued post-peak (A3E), where Weetwood's reductions improved to 23-26% and Chapel Allerton's to 28-33%. In other side, the Woodhouse and Armley corridors produced anomalous results, where the A2E intervention scenario led to a degradation of emission rates for certain pollutants. The A2E scenario yielded a smaller overall CO2 reduction (8%) than the non-intervention A2 peak (15%) in Woodhouse. Furthermore, while PM decreased by 4% compared with A2, this benefit was offset by increases in CO$_2$ (7%) and NO$_x$ (3%).The most harmful outcome was observed in Armley, where the A2E scenario increased all pollutant emission rates by 13%–18% relative to the baseline. This negative impact is directly attributed to the traffic diversion patterns identified in the SLA; traffic shifted to alternative routes (Sections 4B and 4D), which consequently experienced peak flow and congestion during the A2E scenario. Emission rates in Armley remained elevated (4-5% above baseline) even in the A3E scenario, only returning to a reductive state (9-11% reduction) once traffic normalised in scenario A3. These findings identify Armley and Woodhouse as critical anomalies, demonstrating that traffic diversion can negate or even reverse the environmental benefits of a School Streets programme.

5) Conclusion

This study explores the environmental and traffic implications of the School Streets programme in Leeds, UK, focusing on its effects on private vehicle route choice and air emissions. School Streets, which restrict motor vehicle access near primary schools during peak hours, aim to improve the safety and air quality of children [11, 18]. While prior research has highlighted safety benefits, this dissertation investigates the programme's broader environmental impact using traffic simulation and emission modelling. Four primary schools in Chapel Allerton, Woodhouse, Weetwood and Armley were selected based on their traffic relevance and participation in the School Streets initiative. Based on the analysis of the SATURN traffic model and DEFRA EFT for 5 morning time-segment scenarios [31], School Streets successfully eliminated traffic on penalised links, but diverted traffic increased congestion and travel costs. Travel indicators worsened across most corridors, with increases in travel time (up to 31.6%), cost (up to 49.9%), and average speed (up to 20.6%). This programme was also had potential cost-disbenefits of up to £558.7 at the end of the scenario. Route changes were significant in Chapel Allerton, Woodhouse, and Weetwood, whereas Armley showed minimal impact due to its peripheral traffic patterns. Emission analysis revealed that School Streets can reduce air pollution, although effectiveness varied by location. Chapel Allerton achieved the most substantial reductions, up to 50% across all pollutants, due to the sharp decline in traffic flow. Weetwood saw moderate reductions (15%–26%), while Woodhouse presented mixed results: PM emissions decreased, but CO$_2$ and NOx increased slightly. Armley was an anomaly, with emissions rising up to 18% due to traffic displacement onto alternative routes [20, 35]. Overall, scenarios A2E and A3E (representing School Streets during and after peak hours) consistently showed reductions in emissions compared to baseline (A1), with PM$_{2.5}$ showing the highest reduction (up to 20.3%).

The study concludes that School Streets can effectively reduce air emissions and improve traffic conditions near schools, but their success is highly context dependent. Limitations include the lack of micro-level road detail in SATURN m, which means thathe resulting traffic flow changes and air emission rates may not fully reflect real-world conditions. A primary weakness is the SATURN network's lack of detail at the neighbourhood level, where School Streets are typically implemented. This necessitated simulating closures on main arterial roads, which is not representative of the actual intervention and impacts the traffic assignment and emission calculations. Furthermore, the macro-level SATURN analysis lacks direct, on-site air quality monitoring to validate the results, and the calculations do not consider safe exposure limits for schoolchildren. Future research should ideally utilise more accurate on-site data, incorporate a more detailed road network, and employ on-site air quality monitoring devices, as seen in other studies [6, 20]

Despite these limitations, this study concludes that School Streets are effective in improving air quality near schools. This finding has direct policy implications for Leeds City Council, providing an initial overview of the programme's environmental impacts. The Council, whose focus has primarily been on student safety, can use this study as a basis to consider the environmental benefits of the programme initiated in 2020. Finally, future research should adopt more rational assumptions for road closures to better align simulation with real-world conditions. Further micro-level analysis is required to investigate the specific traffic impacts and the finding that air quality worsened in the Armley and Woodhouse corridors. Finally, a combined analysis could be conducted in the future, integrating the impacts of School Streets with other transport interventions such as 20 mph zones [36], park-and-stride schemes [37], or by re-simulating the interventions at different times of day [23].

6) Acknowledgement

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7) Funding Statement

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8) Data Availability

No new data were created or analysed in this study. Data sharing is not applicable to this study.

9) Conflict of Interest

The authors declar **no conflict of interest**.

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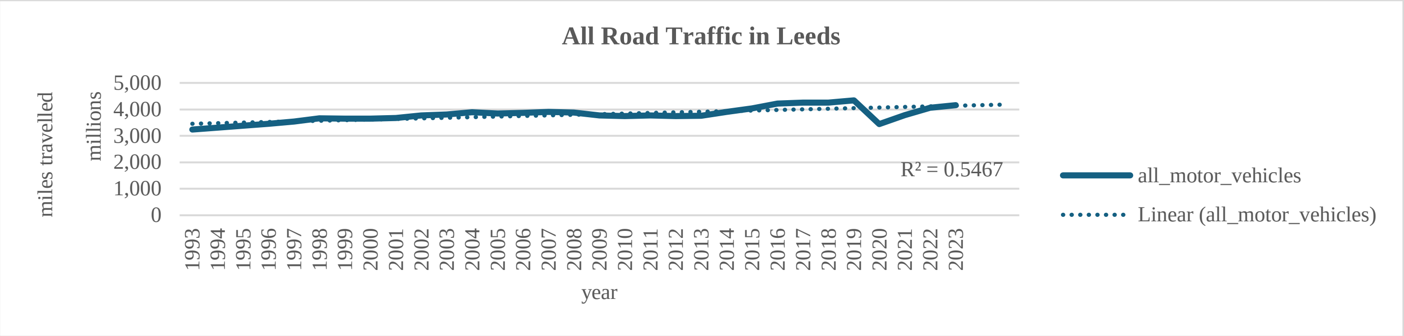
Appendices

Appendix 1 Banned streets applied in SATURN

Ward	School	Zone	Banned Streets		Street/Road Represented	Restriction Times		Banned Scenarios	
			Start Node	End Node		Start	End	A2	A3
Chapel Allerton	Chapel Allerton Primary	-	2161	2131	Harrogate Rd	08:30	09:15	Yes	Yes
Woodhouse	Bleinheim Primary School	317	6220	2066	Blackman Ln	08:15	09:00	Yes	No
			1974	2066	A58M West Little London & Woodhouse Exit*				
			2067	2066	A660				
			2066	1975	A660 Car Park - A64M*				
			2065	2066	Blackman Ln				
Weetwood	Ireland Wood Primary	725	2207	7689	Otley Old Rd	08:15	09:00**	Yes	Yes**
Armley	St. Bartholomews Church CE (VC) Primary	211	1477	5040	Tong Rd	08:15	09:00	Yes	No

Note: ** The node served as one-way traffic.*
*** Assumed to be extended to 09:15 am.*

Appendix 2 Traffic in Leeds from 1993 to 2023 by vehicle type in vehicle miles (millions), with predicted regression model for the next two years [40]



Year	Veh. Miles travelled
2017	4,255,000,000
2025	4,186,303,629
Growth	**0.984 times**

The total journey on the SATURN Leeds matrix is assumed to follow the total accumulated journey (in vehicle miles) on roads throughout Leeds sourced from the Department for Transport from 1993 to 2023 [40] and tabulated in a chart as shown in Appendix 1. If continued to the final condition, it will be known that the total travel in 2017 was 4.255 billion trips per year and the predicted travel in 2025 is approximately 4.186 billion trips, in line with equation (1) which indicates regression from 1993 to 2025. From a comparison of the total trips from 2017 and 2025, it will be found that,

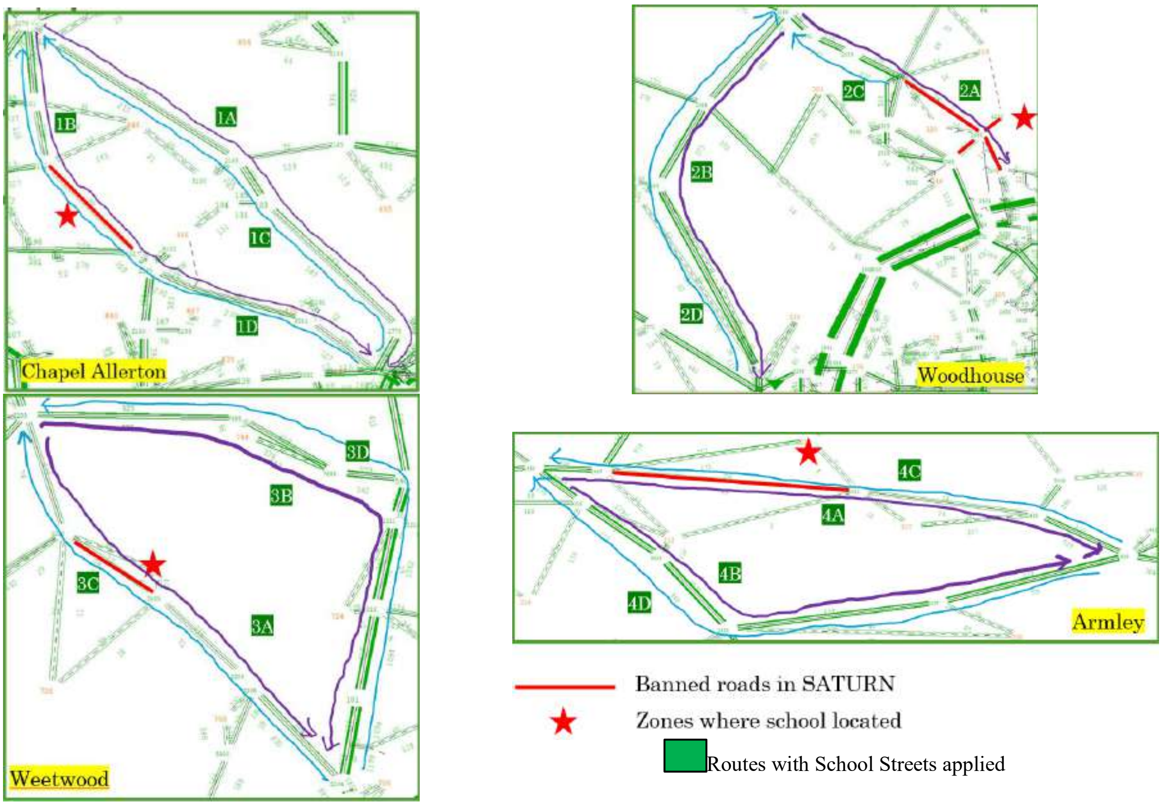
$$veh.travelled = -41{,}468{,}464{,}516.13 + 22{,}545{,}564.52 \times yea$$

$$T_{ij25} = f.T_{ij17}, \text{ with } f = \frac{total\ traffic\ in\ 2025}{total\ traffic\ in\ 2017}, \text{ then,}$$

$$f = \frac{4{,}186{,}303{,}629}{4{,}005{,}939{,}113}$$

$$f = 0.984$$

As a conclusion, total travel in 2025 would be 0.984 times compared to condition in 2017.
Appendix 3 Location of traffic flow test after School Streets implementation



Corridor	Grouped Nodes	
	A and C	**B and D**
Chapel Allerton	**2179**-126-2168-103-1778-**1770**	**2179**-5101-2161-2131-2130-9232-3081-**1770**
Little London & Woodhouse	**2068**-2061-2059-2067-*2066-1975-2066-**6220***	**2068**-2064-2063-2060-**2062**
Weetwood	**2208**-2207-7689-2206-2205-**2204**	**2208**-7685-7686-590-2211-2212-181-6246-**2204**
Armley	**1458**-1447-5040-1438-**1439**	**1458**-9306-5039-1435-5037-**1439**

Note:

- *For the reverse route, the starting point starts from the end note to the start of the route node*
- *Green shadings mean School Streets links included in the route*

Appendix 4 Summary of total possible routes and trip change for all UCs

Corridor	**O**	**D**	**Scenario**	**Possible routes**	**Route change**				
					UC1	**UC2**	**UC3**	**UC4**	**UC5**
Chapel Allerton	445	406	A2-A2E	2	Yes				
			A2E-A3E	2	No				
			A3E-A3	2	Back to original route				
Woodhouse	709	179	A2-A2E	2	Splitted	Yes			
			A2-A2E	2	Grouped into one route	Yes (new route)			
			A2E-A3E	2	No				
Weetwood	751	174	A3E-A3	7	Yes				
			A2-A2E	2	No				
			A2-A2E	1	Back to original route				
Armley	226	174	A2E-A3E	12	Splitted				
			A3E-A3	7	Grouped into one route				
			A2-A2E	3	No				

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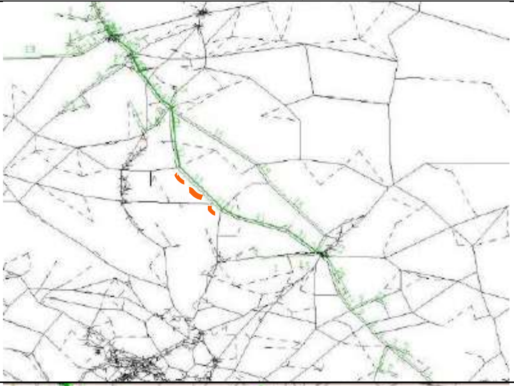
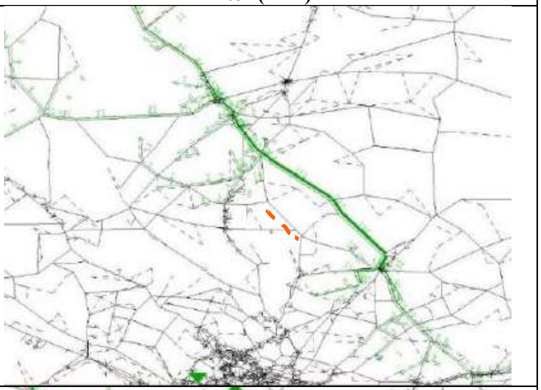
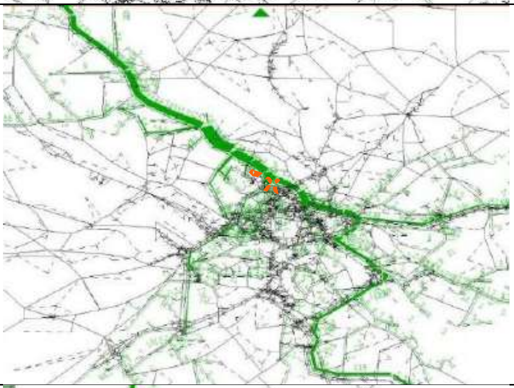
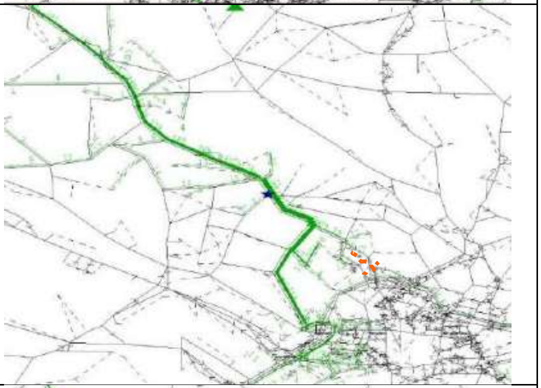
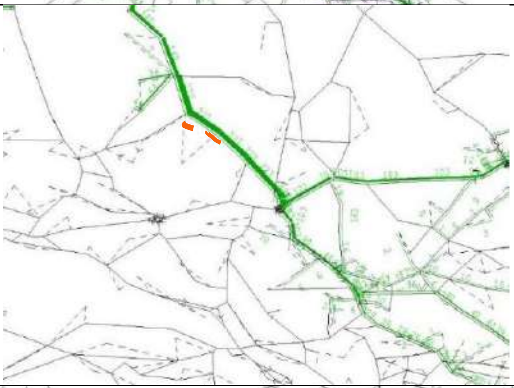
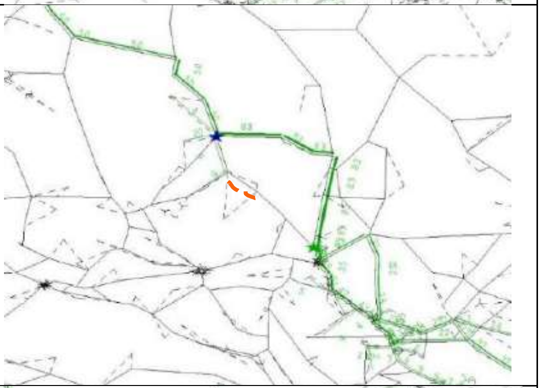
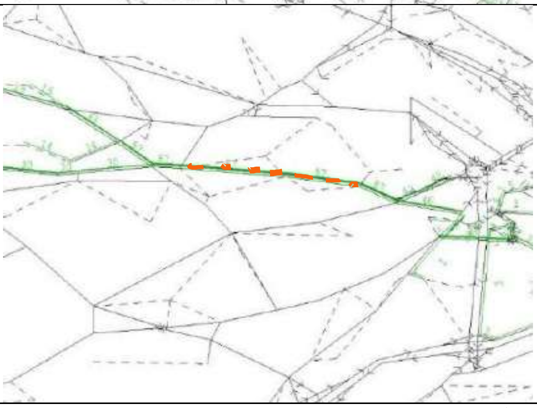
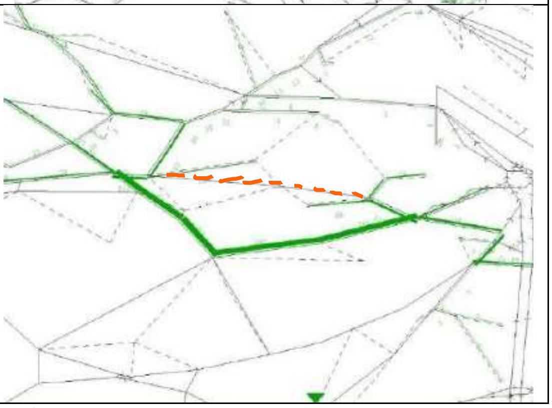
Appendix 5 Downstream (commute) traffic flow simulation result, before and after School Streets

	Before (A2)	**After (A2E)**
Chapel Allerton		
Woodhouse		
Weetwood		
Armley		

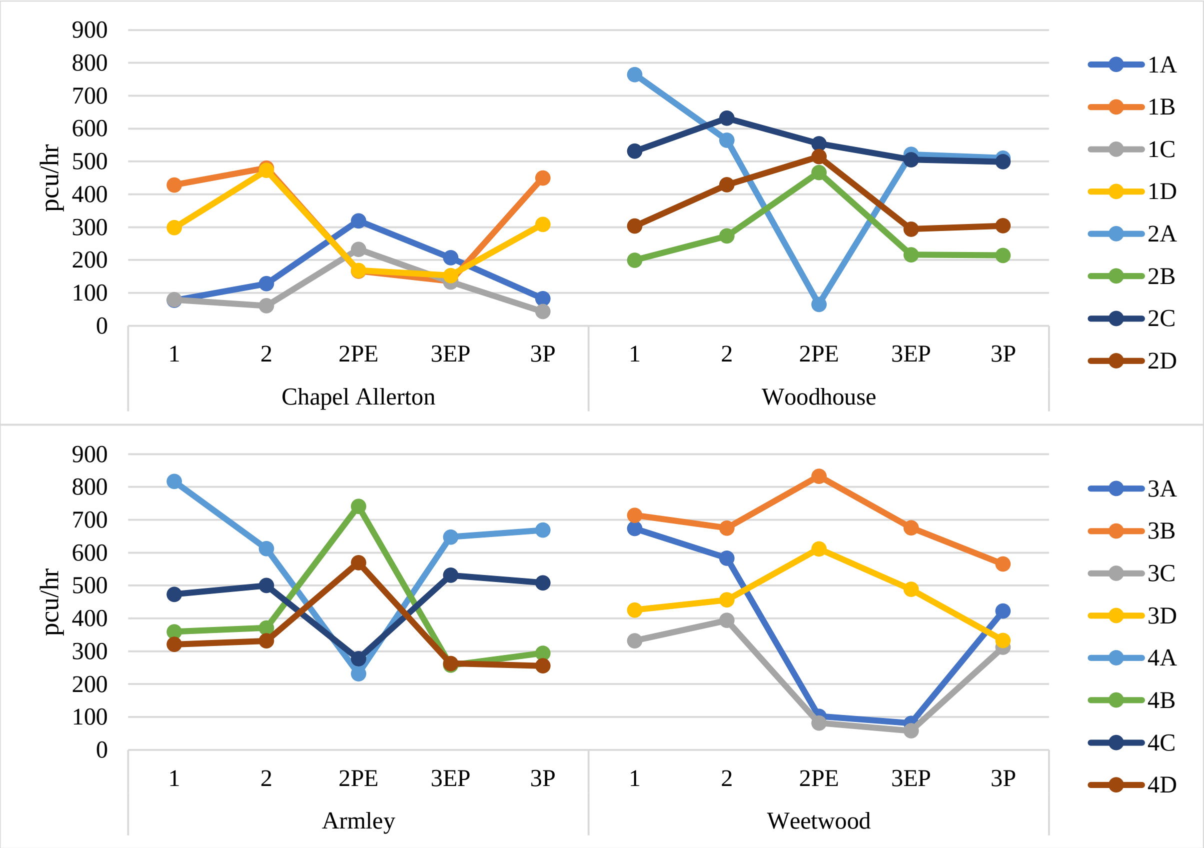
------------ banned roads

Appendix 6 **Traffic parameter results from UC1 simulation**

C	O	D	Traffic parameter	Scenarios					Deviation	
				A1	A2	A2E	A3E	A3	A2E-A2	A3E-A3
Chapel Allerton	**445**	**406**	Time (s)	666	676	813	780	673	20.27%	15.90%
			Delay (s)	41	53	65	42	54	22.64%	-22.22%
			Distance (m)	3901	3901	5134	5134	3901	31.61%	31.61%
			Speed (kph)	21.09	20.77	22.73	23.69	20.88	9.44%	13.46%
			Cost (p)	729.7	739.98	897.32	1103.94	736.55	21.26%	49.88%
Woodhouse	**709**	**179**	Time (s)	1183	981	1178	1015	991	20.08%	2.42%
			Delay (s)	313	100	163	89	64	63.00%	39.06%
			Distance (m)	6174	7071	8406	7325	7325	18.88%	0.00%
			Speed (kph)	18.79	25.94	25.68	25.97	26.6	-1.00%	-2.37%
			Cost (p)	1283.5	1096.9	1315.88	1135.18	1111.09	19.95%	2.17%
Weetwood	**751**	**174**	Time (s)	1461	1345	1771	1340	1181	31.67%	13.46%
			Delay (s)	319	217	504	88	52	132.26%	69.23%
			Distance (m)	9553	9472	10067	10066	9471	6.28%	6.28%
			Speed (kph)	23.54	25.36	20.46	27.05	28.87	-19.32%	-6.30%
			Cost (p)	1617.8	1499.5	1935.4	1504.6	1336.1	29.06%	12.61%
Armley	**226**	**174**	Time (s)	1024	1070	1347	871	744	25.89%	17.07%
			Delay (s)	281	368	621	173	76	68.75%	127.63%
			Distance (m)	5719	5738	5733	5782	5782	-0.09%	0.00%
			Speed (kph)	20.11	19.3	15.32	23.9	27.97	-20.62%	-14.55%
			Cost (p)	1117.8	1164.7	1437.4	966.01	838.75	23.41%	15.17%

Note: School Streets continued in Chapel Allerton and Weetwood

Appendix 7 Traffic flow change before and after School Streets



Notes:

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- A2: 8-8.30 am, peak morning without School Streets
- A2E: 8.30-9 am, peak morning with School Streets in 4 schools
- A3E: 9-9.30 am, afterpeak morning without School Streets
- A3:9.30-10 am, School Streets ended