School of Mathematics

Ysgol Mathemateg

TRAFFIC JUNCTION SIMULATION USING SIMUL8

Cardiff University

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Ethan Furminger - 2060124,

Jose Hernandez - 23084873,

Jonathan Mark Pearl - 23026127,

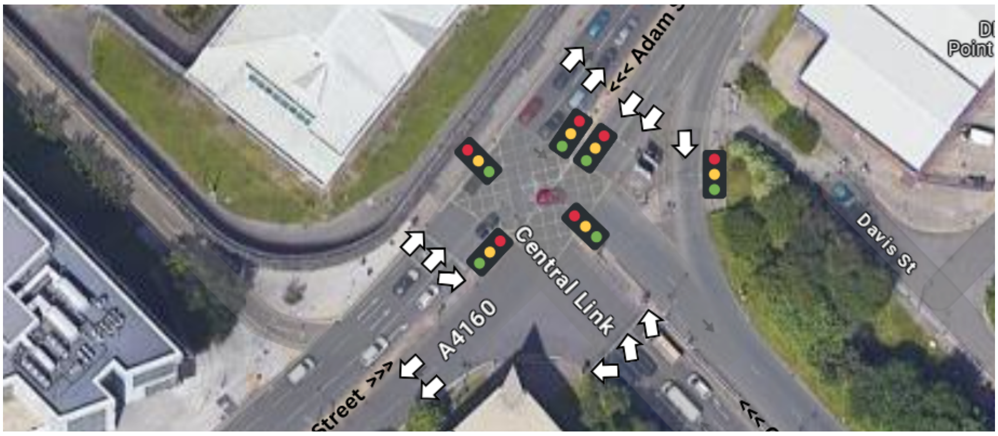
Siddhant Shanbhag - 22100145,

Gagan Chandra Kumar - 23085073.

INTRODUCTION

1.1 Background

Modern roadways are pivotal as the primary conduits for transporting goods and services, fostering trade, and supporting commerce. A critical factor influencing road transportation is the inevitable challenge posed by the sheer volume of vehicles on the road and efficient traffic flow management through mechanisms such as traffic lights. Junctions and intersections emerge as focal points where traffic congestion accumulates, leading to prolonged waiting times. This situation is undesirable as it results in delays, translating to both time and financial losses for businesses and individuals. According to The Department for Transport, "traffic within the UK increased by 8.8% between 2021 and 2022 and is expected to continue rising". Our group has chosen to target traffic congestion within Cardiff as our topic for simulation.



Satellite Image of where Central Link intersects with A4160(Adam St.)

1.2 Problem Statement & Objective

During our initial survey of junctions throughout Cardiff, we identified a junction showing signs of traffic flow issues and buildup. This junction is critical for linking city areas, particularly during peak hours. It is located south of Cardiff, where the Central Link Road intersects with the A4160(Adam St.). The road enables commuters from in and around Cardiff to have a quick and easy entrance to the city centre, and due to its location, most commuters travel through this junction. Critical changes could be made to this junction to help traffic flow smoother, restoring the effectiveness of this crucial intersection. Following the creation of our control simulation of the junction, we plan on running simulations of several changes to the control to allow us to measure their impact on traffic flow through the junction.

DATA PROCESSING

1.3 Data Collection

The traffic data for Cardiff was sourced from The Department of Road Transport, UK Government (Road et al., 2020). This source provided crucial information, such as the average daily vehicle flow on an annual basis, which played a pivotal role in setting realistic targets for our simulation. In addition, data from Tomtom (Cardiff et al.: Tomtom traffic index, 2023) used to understand the time taken to cover 10 kilometres of road in Cardiff at different times throughout the day. As we looked into the data further, particularly from the Tomtom dataset, we could see a distinct camel curve, indicating prolonged travel times during rush hours in Cardiff compared to cities of similar sizes. This observation sparked our interest in exploring the potential impact of signal timings on mitigating these challenges.

Shaded columns are the entry points into the junction

	7	A4160-E-A	A4160-W-A	A4160-N-N	A4160-S-N	A4234-N-A	A4234-S-A4160
		356	219		435	1888	
		413	357	1079	892	2163	1270
		435	630	1097	967	2688	1190
		340	399	886	1264		1066
				742	814	1962	946
						2540	1539
						2209	1425
						2299	1337
Mean		386	401.25	951	874.4	2249.857	1253.286
SD		45.2622	170.7871	168.924	298.9119	289.1317	204.903

8	A4160-E-A	A4160-W-A	A4160-N-N	A4160-S-N	A42
	789	393			
	652	669	1313	1215	
	521	846	1325	1362	
	412	626	1351	1570	
			1070	1177	
	593.5	633.5	1264.75	1331	31
	163.137	186.4698	130.7985	178.189	38

7	A4160-E-A	A4160-W-A	A4160-N-N	A4160-S-N	A4234-N-A	A4234-S-A4160
	0.098889	0.060833		0.120833	0.524444	
	0.114722	0.099167	0.299722	0.247778	0.600833	0.352778
	0.120833	0.175	0.304722	0.268611	0.746667	0.330556
	0.094444	0.110833	0.246111	0.351111		0.296111
			0.206111	0.226111	0.545	0.262778
					0.705556	0.4275

8	A4160-E-A	A4160-W-A	A4160-N-N	A4160-S-N	A42
	0.219167	0.109167			0.
	0.181111	0.185833	0.364722	0.3375	
	0.144722	0.235	0.368056	0.378333	0.8
	0.114444	0.173889	0.375278	0.436111	0.8
			0.297222	0.326944	1.
					0.

The traffic data obtained from the Department of Road Transport was filtered specifically for roads A4160 and A4234, considering traffic direction. Manual collection of signal timings for each signal at the Central link junction was conducted during peak traffic hours (1600-1900) and quieter hours, providing a nuanced understanding of potential discrepancies in signal timings at various times of the day. This comprehensive data collection and analysis approach formed the cornerstone of our study, and allowed us to form a set of averages for timings of the lights throughout different periods. It became apparent that the signal lights at this particular junction are not controlled independently throughout the day, and have a set timing regardless of traffic levels.

DATA PROCESSING

	A4160-E-W		A4160-E-S		A4160-W-E		A4160-W-S		A4234			
	Red	Green	Red	Green	Red	Green	Red	Green	Red	Green	Green Left	
	78	45	40	86	31	85	86	48	81	44	14	
	76	47	33	89	30	83	89	42	78	38	21	Rush Hour
	83	40	30	82	36	80	82	39	78	44	20	Normal Time
	77	41	36	82	39	90	82	40	78	45	25	Entire Column
	84	35	33	78	38	83	78	43	74	45	25	
	85	33	37	77	36	84	77	40	74	45	28	
	86	33	38	76	39	80	90	30	76	44	26	
	88	31	40	74	40	79	93	26	74	45	30	
	87	32	40	74	42	78	85	26	80	45	29	
	85	30	41	74	42	77	87	33	74	45	29	
	72	43	41	74	41	77	84	33	76	43	35	
	76	39	38	73	42	78	84	35	92	28		
	80	45	40	79	42	77	86	45	84	29	29	
	75	37	38	71					68	31		
	81	37	46	69					91	28	36	
	83	48	40	81					92	27		
	76	40	39	74					92	28		
	78	37	38	76					95	28		
	82	42	40	74					91	27		
	77	41	40	74					85	34	31	
									85	34	31	
									91	28		
Mean	82.9	36.7	36.8	79.2	41.14286	78	87	32.57143	76.63636	43.90909	25.63636	
Mean	78	40.9	40	74.5	35	84.16667	82.33333	42	87.81818	29.27273	31.75	
Mean	80.45	38.8	38.4	76.85	38.30769	80.84615	84.84615	36.92308	82.22727	36.59091	27.26667	
SD	4.332051	6.092801	3.735714	5.329165	1.214986	1.154701	3.366502	6.502747	2.54058	2.071451	5.696889	
SD	3.464102	3.695342	2.357023	3.503966	3.687818	3.311596	4.589844	3.286335	7.467505	2.572583	2.986079	
SD	4.570788	5.356747	3.454974	5.008151	4.069902	3.933746	4.506406	7.041088	7.89775	7.829487	5.737927	

To ensure the accuracy and reliability of our simulation, we physically obtained data on signal timings at the previously mentioned junction. This involved the use of stopwatches and timers for direct observation and included peak traffic hours (1600 - 1900) and quieter hours, allowing us to account for any discrepancies in signal timings at various times during the day. This meticulous data collection process was the foundation for constructing our simulation model. Analysis of the Tomtom data indicated that the time taken for vehicles to cover 10 kilometres during rush hours in Cardiff was notably high compared to cities of similar sizes. Despite Cardiff being a city known for its pedestrian-friendly environment and a well-established public transport system, we hypothesised that this time could be significantly reduced with effective signal timings.

1.4 Data Analysis

The initial stage of our data analysis involved a rigorous examination and cleansing process of the traffic data collected from The Department of Road Transport. Initially, both datasets used from the DoRT contained many unnecessary columns and rows that were not applicable to this model. Once those reductions were applied to the data, each junction road was then subdivided by direction of travel. Additionally, for the hourly rate dataset, all junction roads were subdivided by hour from 07:00-18:00. This was done in order to get the distribution by hour for each road. Outliers, signifying extreme traffic volumes or irregularities, were carefully reviewed to verify their validity within the data. Some values, especially in the hourly dataset, were taken out due to their extreme variance within the dataset.

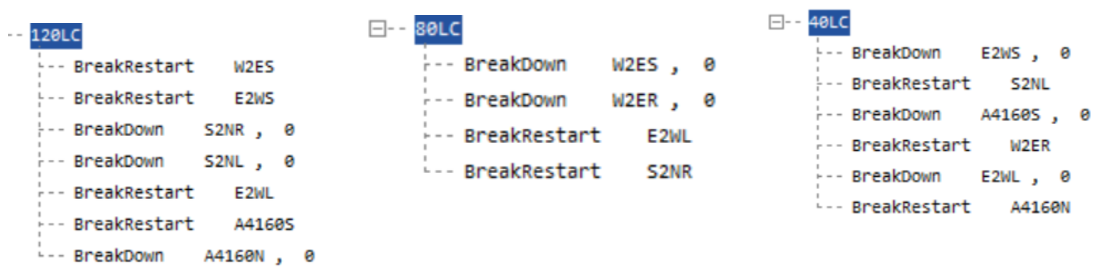
MODEL BUILDING & SIMULATION

1.5 Simulation Architecture

The A4160 (Adam St.), running from the southwest, comprises three lanes that diverge into two lanes heading northeast and one turning right onto the A4234 (Central Link). Conversely, the A4234 (Central Link) enters the intersection from the south with three lanes, two turning right onto the A4160 (Adam St.) and one turning right. Our simulation incorporated the foundational elements of this road intersection, including road signals, signal timings, road lanes, and the volume of vehicles.

Breaking down the model, we considered the direction of traffic, the types of lanes, and the traffic signal system. Queue systems were placed to simulate the road length from the preceding junction up to the point of lane decision for the vehicles using our junction. These queues had predefined capacities based on the physical dimensions of the road, considering factors such as length and width. Before each signal, vehicle count at the junction was monitored, and the queue capacities were calculated using the estimated space each vehicle would occupy (approximately 6 metres).

Notably, three queues were established for each road simulation: the initial queue represented the vehicles present at the road's starting point, the subsequent two queues reflected vehicles waiting at the junction for the signal to turn green, and a third queue at the road's exit simulated traffic build-up from adjacent junctions influencing the A4160 (Adam St.) - A4234 (Central Link) intersection.



Vehicles were given their intended direction before reaching the intersection. This was achieved through a labelling system assigned at the start point, guiding vehicles to move straight or make a turn based on their labels. Various Simul8 logic was employed, including the Breakdown and Break Restart functionality to simulate signals at the junction. Signal timings, uniformly averaged to 40, 80, and 120 sets, cycling every 120 seconds. User Scheduled Visual Logic was utilised to create intervals for these signal timings.

The model incorporated event scheduling using distributions and timed distributions for traffic inflow during different periods of the day. Average distribution was employed for quiet hours (0000 - 0600), while normal distribution was used for peak hours (0600 - 1800), reflecting data from the Department of Transport's Road Traffic Statistics. Exponential distribution was applied for the period when the number of vehicles reduced exponentially (1800 - 0000). Our model is designed for scalability, allowing it to be extended indefinitely to accommodate more extensive and more complex scenarios.

MODEL BUILDING & SIMULATION

1.6 Assumptions Made

To construct our foundational model, we employed a set of carefully calculated assumptions to streamline the simulation and maintain alignment with real-world scenarios. These assumptions enhance the model's efficiency and ensure a smoother simulation experience. The critical assumptions made are as follows:

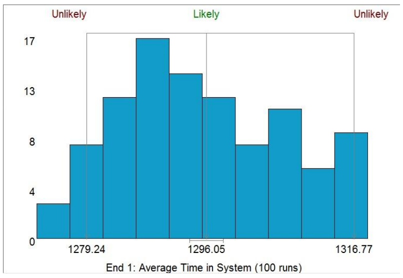
No Illegal Turns: The simulation assumes that no vehicles will make illegal turns. All traffic movements must strictly adhere to designated lanes and signal instructions.

Uniform Vehicle Type: All vehicles in the simulation are considered the same type, occupying a standard length of 6 metres, including the space between vehicles. This standardisation simplifies the simulation process by removing the need to account for diverse vehicle sizes.

Pedestrian Crossings Exclusion: The simulation does not factor in the impact of pedestrian crossings on signal timings. This assumption is made to isolate vehicular traffic dynamics and avoid introducing additional complexities associated with pedestrian movements.

These assumptions collectively contribute to the streamlined construction of our simulation model, providing a solid foundation for understanding and analysing traffic dynamics at the "A4160 (Adam St.) - A4234 (Central Link)" intersection. While these assumptions introduce a level of simplification, they allow us to focus on the core aspects of vehicular traffic flow and signal operations, facilitating a more effective and manageable simulation experience.

SIMULATION EXPERIMENTS & RESULTS



Control

Artificially Creating a Lane Blockage

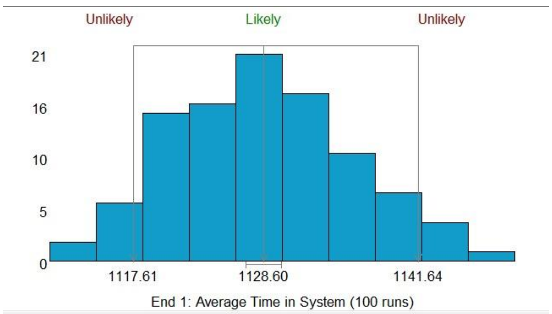
In our exploration of the simulation, we experimented by intentionally blocking a specific signal—W2ES—for an entire day. The observed outcomes revealed notable impacts on the overall functionality of the traffic junction. Specifically, the working percentage of the A4106N signal experienced a reduction of 12.96%. As a cascading effect, the number of vehicle movements from End1 also decreased to 680.

This decrease in working percentage and vehicle movements signifies operational inefficiencies within the traffic junction. The consequential result was increased congestion and the emergence of safety concerns. It becomes evident that the smooth functioning of individual signals is integral to the overall traffic flow at the junction.

To address these challenges, we suggest exploring dynamic traffic management systems. These systems can adapt to varying traffic conditions, enabling optimal lane utilisation. By dynamically adjusting signal timings and prioritising efficient traffic movement, such systems have the potential to mitigate operational inefficiencies, reduce congestion, and enhance overall safety at the junction.

This observation underscores the importance of proactive and adaptive traffic management strategies in ensuring complex traffic junctions' robust and efficient performance, ultimately contributing to improved traffic flow and safety.

	Average Time in System	Number Completed	"In System Less Than" time	% In System Less Than Time Limit	St Dev of	Maximum Time in System	Minimum Time in System
End 1	1124.607	3383	10	0.355	425.272	1442.891	6.488
End 2	64.988	9769	10	15.989	46.365	245.925	2.17
End 8	10.796	8036	10	74.676	12.074	46.136	1.629



SIMULATION EXPERIMENTS & RESULTS

Adjustment of Signal Timing

In this experiment, we manipulated the signal timings by reducing the time allocated to the W2ES signal. This was a result of multiple observed instances where W2ES would have greater backups than any other lane. The observed results demonstrated a consequential effect on the traffic dynamics at End1. Notably, the average time at End1 increased, accompanied by a negligible percentage increase in working time. As a result, the number of vehicles exiting from End1 also witnessed an increase, with minimal impact on the standard deviation.

This experiment leads us to the conclusion that a reduction in the red light duration of a traffic signal significantly influences the smooth movement of traffic. By increasing red light time for W2ES and the increased green light time at End1 allowed for a more efficient flow of vehicles through the junction, leading to a noticeable improvement in overall traffic dynamics.

To leverage these findings and enhance traffic management, we propose the implementation of adaptive traffic control systems. These systems can dynamically adjust signal timings based on real-time traffic patterns, optimising the allocation of green and red light durations. By exploring optimization strategies for signal timings, we can strike a balance between promoting continuous traffic flow and minimising waiting times.

The implications of this experiment highlight the potential for adaptive traffic control systems to improve the overall efficiency and responsiveness of traffic signals, contributing to a more fluid and streamlined traffic experience. Such advancements align with the broader goal of achieving optimal traffic management in urban environments.

	Minimum Queue Size	Average Queue Size	Maximum Queue Size	Minimum Queuing Time	Minimum (Non-zero) Queuing Time	Average Queuing Time	Average (Non-zero) Queuing Time	Maximum Queuing Time	Number of Non-zero Queuing Times	% Queued Less Than Time Limit	"Queued Less Than" Time	St Dev of Queuing Time	Current Contents	Items Entered
Queue for W2ES	0	10.396	20	0	0	432.309	484.569	720.412	1853	19.21	10	267.094	1	2078
Queue for E2WS	0	2.448	10	0	0.044	33.129	45.404	79.966	4637	39.559	10	28.249	0	6355
Queue for S2NL	0	0.101	13	0	0.003	4.669	27.123	40.193	335	85.612	10	11.551	0	1946
Queue for E2WL	0	0.573	5	0	0.002	6.303	20.252	40	2501	76.879	10	11.609	0	8036
Queue for W2ER	0	0.509	7	0	0	19.991	31.235	81.316	1408	58.409	10	26.467	0	2200
Queue for S2NR	0	15.366	30	0	0.019	681.841	732.64	1064.03	1812	8.988	10	373.598	0	1947
Queue for A4160S	0	0.957	33	0	0	10.337	13.224	110.417	6487	76.648	10	18.759	2	8301
Queue for A4160N	0	27.329	50	0	0.083	586.575	625.266	833.051	3775	8.499	10	300.639	0	4024
Queue for A4234	0	0.01	3	0	0	0.072	0.457	1.978	1614	100	10	0.223	0	10236
Queue for E2WGIL	0	0.006	2	0	0.001	0.045	0.539	5.181	1192	100	10	0.225	0	14392
Queue for W2EGIL	0	4.714	10	0	0.016	95.301	120.478	332.907	3384	32.492	10	79.078	0	4278
Queue for S2NGIL	0	4.913	10	0	0.794	109.293	139.136	355.014	3058	22.194	10	81.969	0	3893

SIMULATION EXPERIMENTS & RESULTS

Increasing Number of Lanes Available

In this scenario, we strategically incorporated an additional lane into our simulation, aligning with future urban planning considerations to address the escalating traffic demands at the targeted junction. The introduction of this extra lane yielded several positive outcomes:

Queue Reduction at W2ES: The presence of the extra lane resulted in a noticeable decrease in the number of vehicles queued at W2ES. This signifies improved traffic flow and reduced congestion, as vehicles could more efficiently navigate through the junction.

Enhanced Throughput at W2EGIL: The inflow of vehicles passing through the W2EGIL queue experienced an improvement. The efficient utilisation of the new lane contributed to increased throughput, enabling a smoother movement of vehicles through the junction.

Improved Operational Efficiency: The simulation outcomes, illustrated in the provided image, demonstrated a decrease in the maximum waiting time when compared to scenarios without the additional lane at W2ES. This reduction indicates enhanced operational efficiency, translating to faster progression through the intersection.

The simulation results collectively emphasise the positive impact of adding an extra lane on waiting times, traffic flow, and congestion levels. These findings underscore the significance of infrastructure enhancements, such as the introduction of additional lanes, in significantly contributing to the overall efficiency and safety of traffic junctions. The success of this simulation suggests that proactive urban planning, incorporating measures to accommodate growing traffic demands, can be instrumental in addressing congestion challenges and enhancing the overall functionality of critical intersections. This aligns with the broader goal of creating sustainable and efficient urban transportation systems.

	Minimum Queue Size	Average Queue Size	Maximum Queue Size	Minimum Queuing Time	Minimum (Non-zero) Queuing Time	Average Queuing Time	Average (Non-zero) Queuing Time	Maximum Queuing Time	Number of Non-zero Queuing Times	% Queued Less Than Time Limit	"Queued Less Than" Time	St Dev of Queuing Time	Current Contents	Items Entered
Queue for W2ES	0	0	1	0	8.219	4.045	20.226	32.234	2	90	10	0	0	10
Queue for E2WS	0	2.433	10	0	0.059	33.088	45.521	79.994	4599	39.497	10	28.23	1	6328
Queue for S2NL	0	0.114	10	0	0.007	3.002	25.372	40.265	399	90.896	10	9.531	0	3372
Queue for E2WL	0	0.575	5	0	0	6.333	20.163	40	2519	76.883	10	11.62	0	8020
Queue for W2ER	0	0	0	0	0	0	0	0	0	0	10	0	0	0
Queue for S2NR	0	14.985	30	0	0.724	384.158	403.061	575.436	3211	5.58	10	151.744	0	3369
Queue for A4160S	0	1.905	64	0	0	17.317	19.992	186.421	8401	54.913	10	23.659	0	9699
Queue for A4160N	0	25.296	50	0	0.11	646.778	701.611	834.172	3114	9.917	10	247.795	1	3379
Queue for A4234	0	0.009	3	0	0	0.087	0.482	3.195	1447	100	10	0.257	0	8020
Queue for E2WGIL	0	0.006	3	0	0	0.044	0.537	5.116	1178	100	10	0.226	0	14348
Queue for W2EGIL	0	9.707	10	0	1.101	0.417	1.75	2.369	5	100	10	0.791	10	31
Queue for S2NGIL	0	4.713	10	0	0.027	60.56	69.534	207.521	5871	14.345	10	45.286	0	6741
Queue for W2ES 2	0	9.857	10	0	0	0	0	0	0	0	10	0	10	10
Queue for A4160N 2	0	0	0	0	0	0	0	0	0	0	10	0	0	0

SIMULATION EXPERIMENTS & RESULTS

CONCLUSION

Among the three scenarios discussed, adjusting signal timings appears to be a realistic intervention to implement on an actual road network. Here are the justifications for this choice:

Adaptability to Real-Time Conditions: Dynamic signal timing adjustments allow for responsiveness to real-time traffic conditions. This adaptability is crucial in managing variable traffic patterns, unexpected events, and fluctuations in demand, making it a practical choice for implementation.

Mitigation of Congestion: The simulation results show that changes in signal timings have a direct impact on traffic flow and waiting times. Optimising signal timings can mitigate congestion, reduce delays, and improve the overall efficiency of traffic movement through the junction, addressing common challenges in urban traffic management.

Flexibility for Experimentation: Signal timing changes provide a flexible and scalable solution. Unlike physical infrastructure modifications, altering signal timings allows for experimentation and fine-tuning without the need for extensive construction or road layout changes. This adaptability is advantageous in addressing evolving traffic conditions.

Cost-Effectiveness: Adjusting signal timings is often a more cost-effective solution compared to extensive infrastructural changes. Implementing dynamic signal control systems can leverage existing infrastructure, making it a practical and resource-efficient approach for municipalities and transportation authorities.

Balancing Efficiency and Waiting Times: The simulation results demonstrate that changes in signal timings strike a balance between traffic flow and waiting times. This optimization is crucial for ensuring smooth traffic progression while minimising delays, making it a realistic and beneficial intervention for real-world scenarios.

While adding an extra lane is a traditional and effective strategy, signal timing adjustments offer a dynamic and adaptable solution that aligns with modern approaches to urban traffic management. The choice between these interventions depends on factors such as local traffic patterns, available resources, and the specific challenges of the road network in question.

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