Fermanagh Community Transport Project: Self-assessment checklist

Please use the following form to explain where you have addressed each of the requirements for the assignment that are listed in the assessment rubric on CANVAS.

	Prompt	Description
Problem	Describe the problem you have tackled in your report and where the problem that you have studied in your report is introduced.	The problem I chose to tackle congestion on the Enniskillen to Belfast route, and the impact of staggering institutional start times (schools and workplaces). The problem is introduced in page 1, paragraph 1.
	Explain where you discuss your motivation for studying this problem	My motivation is explained on page 2, paragraph 2. I aim to reduce peak traffic delays and improve travel times.
	Explain why you describe the context and the relationship between this problem and the work of the community partner.	The relationship between this problem and the work of the community partner is explained on page 1, paragraph 1.
Modelling	Describe where I can find the explanation for the rationale for the modelling you have used in your report.	The rationale of the modelling I have used is first discussed in page 2, paragraph 6 (final paragraph). Further I explain the model's rationale of the model in the Model section – page 5, paragraph 1. I use a time dependent Poisson queue to model the changing peak traffic rates.
	Describe places in the report where the model's assumptions and limitations are discussed.	The assumptions and limitations are discussed in the Assumptions and Limitations subsection in the Model section, found on (page 5).
Interpretation	How many figures have you included in your report? How many of these figures have captions and how many references to each of the figures are there in the main text?	I have included 5 figures in my report. 5/5 figures have captions. 5/5 have references within the main text to explain them.
	Discuss where I can find the reason for constructing each of the figures in your report? In other words,	Reasoning for the respective figures can be found in; Figure 1: page 2, paragraph 3-5. Figure 2: page 3, paragraph 1

	write a sentence something like: "The reason figure 1 is shown is discussed in the third paragraph of page 2" for each of the figures in your report.	Figure 3: page 3, paragraph 1 Figure 4: page 6, paragraph 1, and table 1 Figure 5: page 6, paragraph 1, and table 1
	Provide evidence that you have discussed how the figures support the answer to your research that you have arrived at in your report by referencing your report.	Figure 1 shows that travel time taken to get from Enniskillen to Belfast fluctuates throughout the day, and is dependent on time, specifically peak commute hours of 8am and 3pm. Figures 2 and 3 show that weekdays and weekends have distinct travel-time patterns, but still follow a temporal trend. Travel-time still follows a trend. Figures 4 and 5 show how a queue model explains these patterns and how staggering start times reduces congestion.
Partner	Provide evidence that you have explained why the problem you have studied matters to the community partner.	I have briefly described this as reducing travel times in paragraph 1 page 1 being in the best interest of the FCT, and this is a logical assumption as they care about getting from place A -> B as quickly as possible.
	Provide evidence that you have made meaningful recommendations to the community partner based on the results from your study.	A recommendation has been made in page 6, table 1 and again in the conclusion. The FCT may lobby for societal changes within the region to ease traffic congestion. Or they could fund further research to achieve backing of the scientific community to increase likelihood of implementation of such policy changes.

Simulating and Optimising Traffic Congestion Using M(t)/D/1/K Queuing Model

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Abstract

This study proposes a generalized macroscopic traffic simulation using a $M_t/D/1/K$ queue to model congestion along the Fermanagh–Belfast route. Empirical traffic data from Google's Directions API is used to calibrate the model, thus explaining peak commute times which we model using queue length. Simulations of staggered institutional start times showed potential reductions in queue lengths, suggesting time-based interventions to improve rural-to-urban traffic flow.

1 Introduction

Road commuters often face congestion during peak periods, particularly around institutional start times such as schools and workplaces. This is especially true for regional routes like Enniskillen to Belfast, which pass multiple workplaces and urban areas, causing significant travel time delays. Understanding travel patterns and creating models to address this is a form of traffic management to reduce road congestion, aligning with the interests of Fermanagh Community Transport. This project proposes a macroscopic traffic management simulation to model a queue along the Enniskillen-Belfast route, with the aim of explaining traffic congestion, suggesting simulated policies, and outlines future research directions.

Real-time traffic data from Google's Directions API was collected over 30 days at 10-minute intervals to support the assumption that school and institutional start times are primary causes of congestion. This data allows for the construction of a Typical Day Model (TDM[1]), which explains the dynamics of daily travel times, including the peaks in the morning, midday and afternoon. Using the TDM, I assumed travel time is related to congestion which can be modelled by a queue, thus developing a non-stationary ($M_t/D/1/K$) queuing model where the arrival rate ($\lambda(t)$) is modelled as a non-homogeneous Poisson process.

[1]The "Typical Day Model" is hereafter abbreviated as TDM.

The benefit of using these adjustable arrival rates is that the model can be tuned to specific traffic fluctuations, such as morning and evening peaks. The model represents macro-traffic conditions, which evaluates overall system capacity rather than individual vehicle behaviour which is ideal for proposing large-scale traffic interventions. Then adjusting the model to simulate interventions like staggered institutional start times, I observed impacts on queue length and the consequent reduction of congestion and travel time.

The findings give insight into improving traffic flow and reducing congestion using the Enniskillen-Belfast route as a case study, but could be extended to any urban setting. This study contributes to regional transportation planning by demonstrating the applicability of non-stationary queuing models in rural-to-urban contexts and shows the potential benefits of time-based traffic interventions targeting the heart of the problem, which is too many vehicles on the road.

2 Data Collection and Processing

To accurately model traffic congestion on the Enniskillen to Belfast route, I collected empirical travel time data using Google's Directions API [1] between the nodes, Enniskillen and Belfast. The data collection spanned a 30-day period from 25th October to 25th November, during which travel times were recorded at 10-minute intervals over a 24-hour cycle. This discrete sampling gave a view of the variations in traffic patterns across a day, averaged over the span of a month, allowing us to spot differences between weekdays and weekends.

2.1 Typical Day Model

I processed the raw travel time data to develop the Typical Day Model (TDM). For each 10-minute interval, I calculated the mean travel time $\bar{x}$ over the 30-day sample. To assess variability and ensure statistical confidence, I computed the 95% confidence interval for the mean at each interval.

Treating each daily time segment as an individual sample helps account for variability in travel times per day and allows me to create the TDM. I use the TDM as a foundational reference for identifying peak congestion periods, which are essential to create the queueing model.

The TDM in Figure 1 shows a baseline travel time regardless of time of day, with the journey taking 86 minutes even at 4am. Peaks are observed at 7–8AM and 15–16PM, strongly supporting the hypothesis that institutional work start times significantly impact travel time.

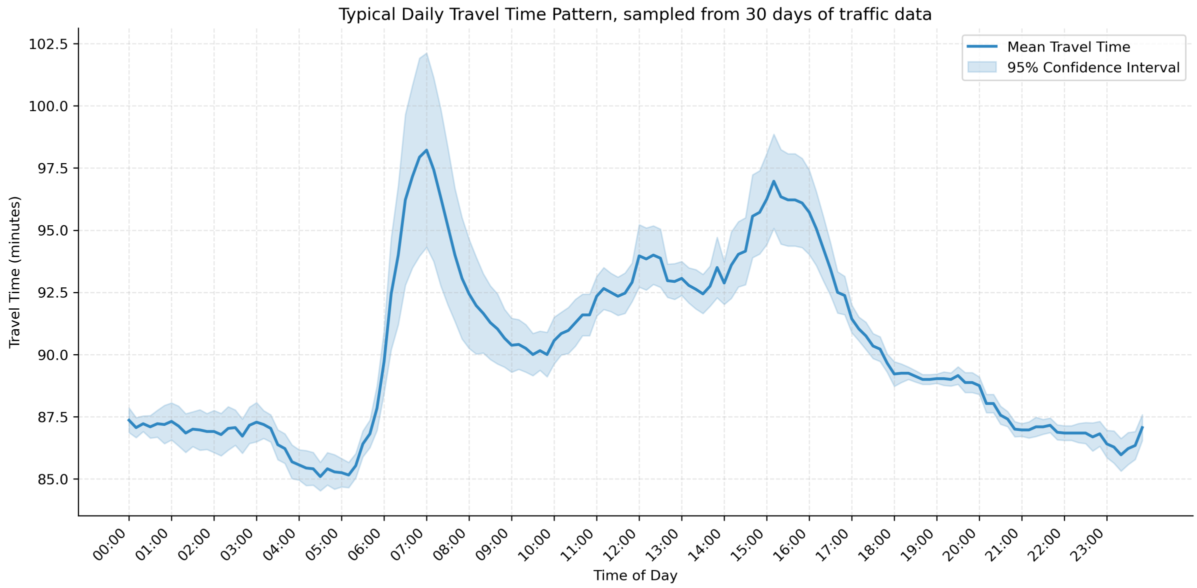

Figure 1: Typical daily travel time pattern with 95% confidence intervals, based on 30 days of traffic data for the Enniskillen to Belfast route.

2.2 Insights from Data

A closer analysis of the travel time data revealed clear differences between weekday and weekend patterns. To illustrate these differences, I categorised the travel times into three states using the 60th and 90th percentiles, denoted as $Q_{0.6}$ and $Q_{0.9}$, as threshold values. Specifically, I defined:

- *Low travel times (green)*: $t < Q_{0.6}$
- *Medium travel times (orange)*: $Q_{0.6} \leq t \leq Q_{0.9}$
- *High travel times (red)*: $t > Q_{0.9}$

I observed the following:

- **Weekday Patterns**: Figure 2 shows clear peaks in travel times during typical commuting hours (07:00–09:00 and 14:00–18:00), indicating higher traffic from school and work schedules.
- **Weekend Patterns**: Figure 3 shows lower peaks (108 minutes on weekdays vs. 92 minutes on weekends) with reduced variability and no sharp spikes, indicating less commuting. The main commuting period shifts to midday (11:00–16:00).

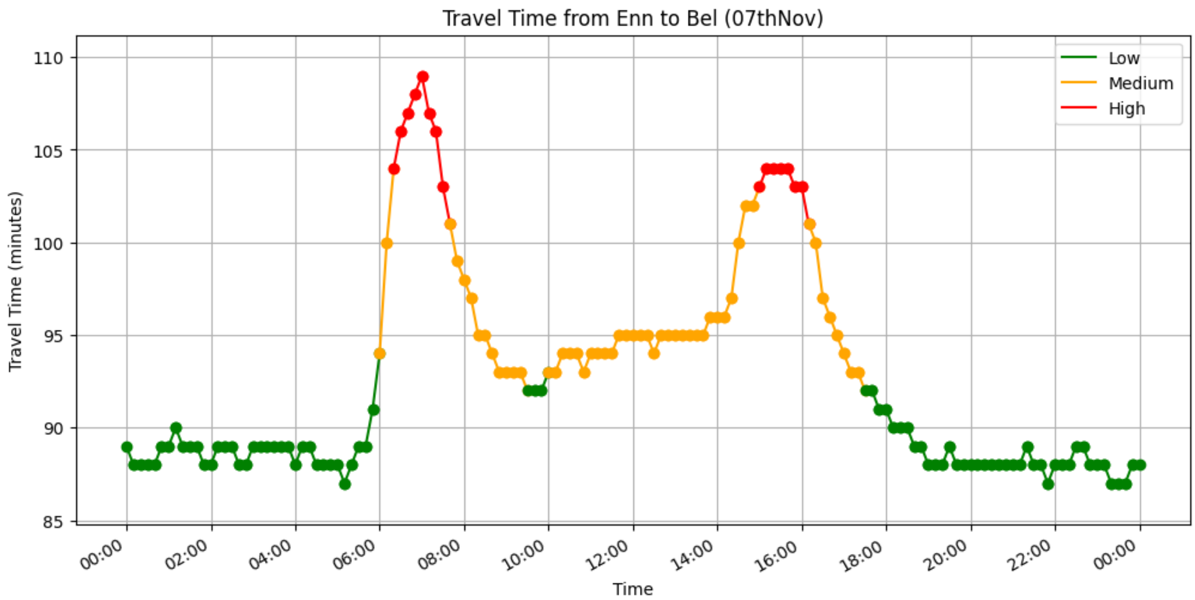

Figure 2: Travel time pattern for Thursday, 7 November 2024, on the Enniskillen to Belfast route, highlighting peak congestion periods during commuting hours.

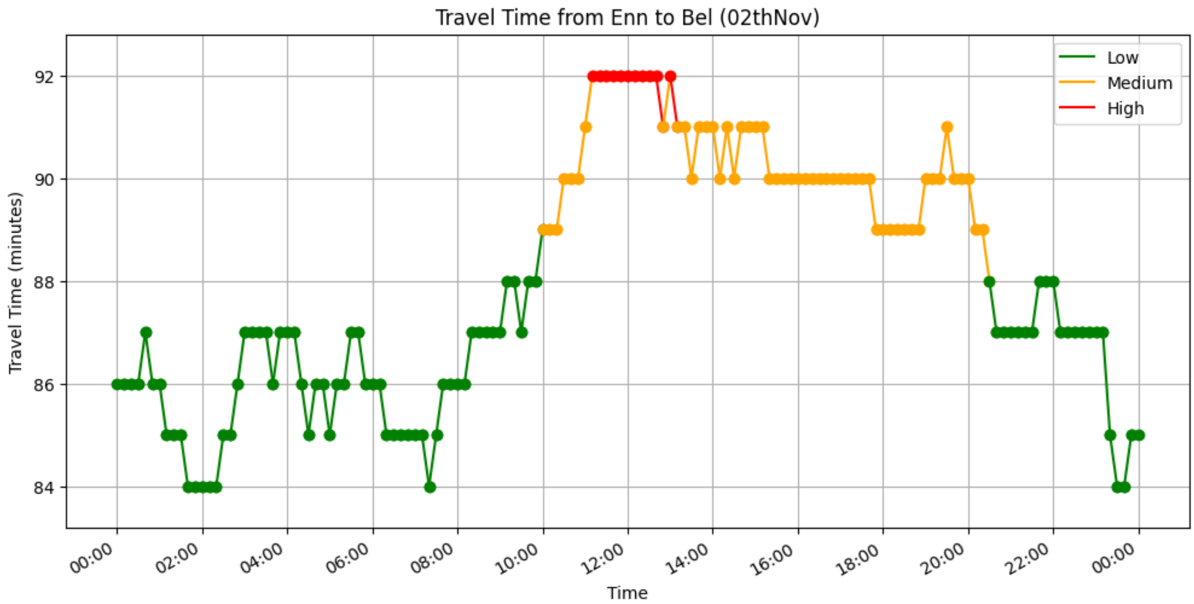

Figure 3: Travel time pattern for Saturday, 9 November 2024, on the Enniskillen to Belfast route, showing reduced maximum congestion and variability compared to weekdays.

Weekday peaks reach 108 minutes when schools and workplaces are in session, compared to weekend peaks of 92 minutes. Additionally, weekend traffic patterns are more flattened with no explicit peaks, unlike the pronounced peaks observed on weekdays. These figures show distinct traffic flow patterns when institutions are in session, supporting my hypothesis they impact travel times.

3 Model

The model I chose to simulate a queue is a $M_t/D/1/K$ model, which uses time-dependent Poisson arrivals (M_t), a constant service rate (D), a single server (1), and finite capacity (K) to simulate traffic congestion on the Enniskillen–Belfast route. The time-varying arrival rate $\lambda(t)$ models peak traffic times. We treat the road as if it can hold a maximum of K vehicles at once; once K vehicles are on the route, new arrivals are turned away. The model assumes 120,000 vehicles travel the route daily, ensuring the simulation reflects traffic distribution changes rather than volume changes.

3.1 Assumptions and Limitations

The rationale and key assumptions that guide my model include:

1. **Time-Varying Poisson Arrivals:** Vehicle arrivals follow a non-homogeneous Poisson process with a time-dependent rate $\lambda(t)$. I model $\lambda(t)$ as a Gaussian Mixture:

$$\lambda(t) = \lambda_0 + \sum_{i=1}^{N} A_i \exp\left(-\frac{(t-t_i)^2}{2\sigma_i^2}\right),$$

   where:

   - λ_0 is the base arrival rate.
   - A_i is the amplitude of the i-th peak.
   - t_i is the time of the i-th peak.
   - σ_i is the duration (width) of the i-th peak.

   This approach enables calibrating $\lambda(t)$ to the daily traffic variations observed in the TDM, and simulating policy changes like staggered start times.

2. **Single and Finite Route Queue:** I treat the entire route as one queue, ignoring traffic lights and junctions. This is a macroscopic focus on overall congestion rather than local details. If the system already has K vehicles, arrivals are turned away until space becomes available.

3. **Congestion-Dependent Waiting Times:** Waiting time depends only on how many vehicles are already using the route. Factors like driver behaviour, weather, or accidents are not included.

4. **Deterministic Service (D):** Each vehicle is assumed to travel for exactly 90.1 minutes (obtained from the TDM) over the 82.4-mile route, corresponding to an average speed of about 55 mph. In reality, vehicles do not move at a perfectly constant speed, but this approach allows us to simplify modelling while preserving realism.

4 Simulation

Simulating this model, and tuning the peaks in $\lambda(t)$ based on empirical data from the TDM means we can make my model correspond to school and work commute times. In the baseline scenario, $\lambda(t)$ reflected existing traffic peaks between 07:00–09:00 and 14:00–18:00. Under the proposed staggered policy, arrival rates were adjusted to create staggered peaks, aiming to distribute traffic more evenly and reduce congestion during traditional peak hours.

Table 1: Traffic Peaks for Typical Day and Staggered Policy Models

Model	**Peak**	**Description**	**Time (HH:MM)**	**Width (minutes)**
Typical Day	1	Morning Peak	07:00	90
	2	Mid-morning Peak	11:00	120
	3	Afternoon Peak	15:00	120
Staggered Start Times Policy	1	Morning Peak 1	05:00	90
	2	Morning Peak 2	08:00	90
	3	Mid-morning Peak	11:00	120
	4	Afternoon Peak 1	13:00	120
	5	Afternoon Peak 2	16:00	120

Table 1 summarises the parameters for peak traffic for typical day and staggered policy models, with peaks defined by their time of the day and duration they last for. The simulation results are shown in Figures 4 and 5, which illustrate the queue lengths over time for both the current traffic pattern and the proposed staggered policy.

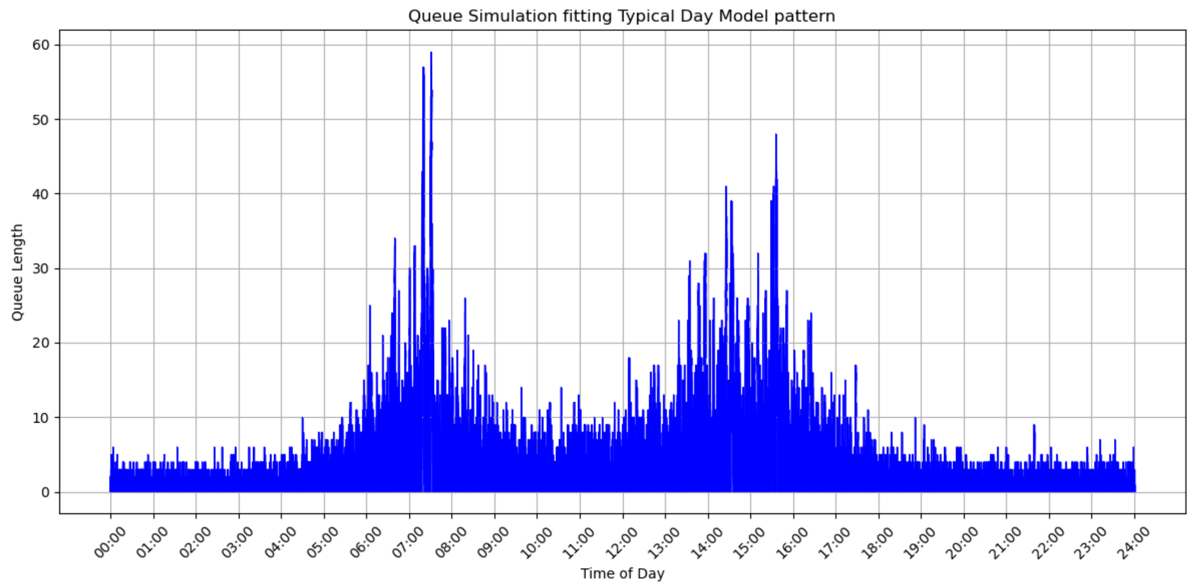

Figure 4: Simulated queue length over time under current traffic patterns, showing pronounced peaks during traditional commuting hours.

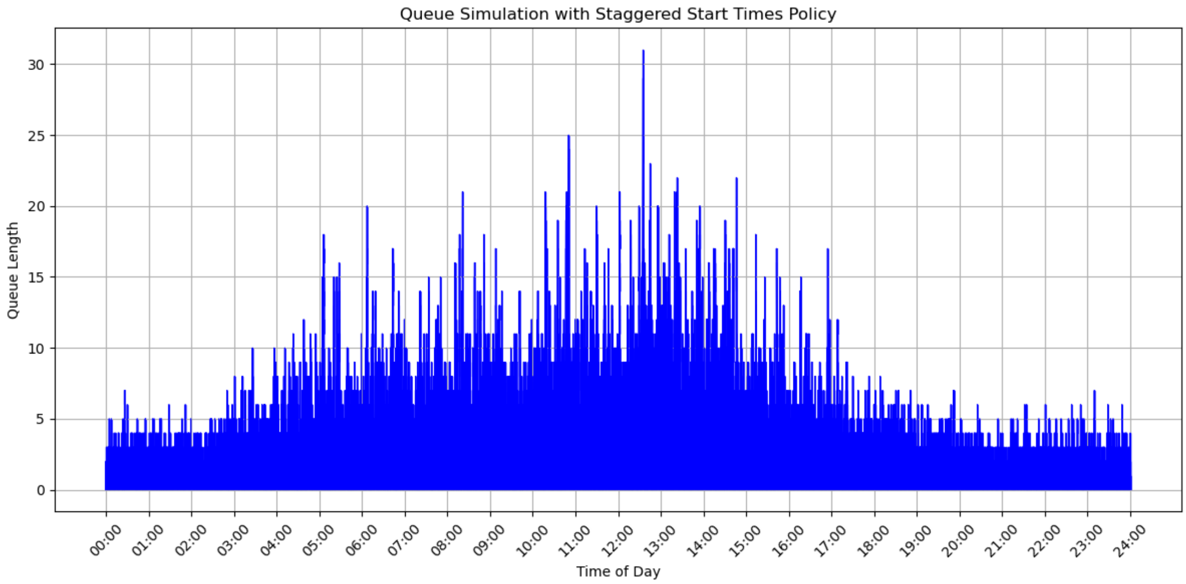

Figure 5: Simulated queue length over time under the proposed staggered policy, illustrating reduced peak congestion and more evenly distributed traffic flow.

Figure 4 shows sharp increases in queue length during morning (07:00–09:00) and afternoon (14:00–18:00). The maximum queue length is 59 vehicles during these periods, and average queue length is 3.99.

Figure 5 shows that staggering morning departures (half of society leaving an hour earlier, and half departing an hour later) flattens the traffic peak and lowers average queue length to 2.44 vehicles. The peak queue length is now 31 vehicles. Thus both average wait times and queue lengths are reduced compared to the TDM scenario.

5 Conclusion

The simulation suggests that staggering institutional start times can reduce congestion by broadening arrival peaks. Fewer vehicles pile onto the route simultaneously, reducing average queue lengths and travel times down. While the model ignores many road complexities into a simplified approach assuming just one queue, our results align with practical intuition that staggering departure times lowers peak stress on the system, improving commuting for the majority of road users.

A logical next step is building a queue microscopic model to account for multiple bottlenecks (roundabouts, lights) and verifying the same patterns are held. One could also compare alternative distributions for $\lambda(t)$ to find the most optimal institutional start-times. Nonetheless, my present results support staggered scheduling as a straightforward congestion reducing method to improve road usage for most commuters.

References

[1] Google Maps Platform Documentation: Directions API, https://developers.google.com/maps/documentation/directions/overview, accessed 10th November 2024.