Evaluating the Efficacy of Educational Software in Communicating Induced Traffic Demand Concepts.

Assessing the effectiveness of interactive software in increasing public awareness and understanding of induced traffic demand.

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1. Introduction

This study aims to determine the effectiveness of interactive software in conveying underlying factors instigating traffic congestion to members of the public. Alongside a comparison of the success of this interactive approach with non-interactive methods, such as reading and static diagrams, this involves communicating and bolstering knowledge surrounding traffic systems, focusing on the Induced Traffic Demand (ITD) phenomenon as it plays a significant role in the generation of vehicular traffic congestion. Congestion is a concern for every commuter, yet ITD, a common congestion instigator, is unfamiliar. More awareness of this and similar traffic-related phenomena can bolster public investment in combating traffic congestion, encouraging projects that deliver an upheld effect by mitigating this logistical challenge.

Research entailed developing interactive software to visualise congestion phenomena within a traffic simulation. The software allows users to alter road layouts and observe the impact these alterations have on congestion, rather than learning via conventional teaching methods. The resulting learning exercise employing a prototype of this software demonstrated the value in using interactive mechanisms within a software solution to communicate ITD to participants, exhibiting that interactivity is a suitable avenue towards better conveying urban planning importance through imparting underlying logistical concepts in a simulated environment.

2. Literature Review

2.1 | Overview

Traffic congestion is an infamous time-waster. Commuters spend considerable amounts of their lifetime slowed by traffic. Notwithstanding the ever-presence of congestion, commuters interacting with congestion are often unaware of how it is generated, despite a collective desire for traffic congestion to be reduced or “solved” (Department of Transport, 2018). This results in contention when congestion mitigation projects are misunderstood as ineffective or counterproductive; leading to these proposed projects and policy changes being contested, facilitating their cancellation (Herriges, 2022). This concerns planning administrators, as public influence over decisions traditionally made by experienced specialists comes with the risk of decisions being made that neglect efficiency or feasibility. Thus, this risk becomes exacerbated when significant portions of the public demonstrate a notable lack of knowledge and understanding regarding why proposed projects will reduce congestion, resulting in attempts to enlighten the public on the rationale behind these projects becoming less effective over time unless this knowledge is common (Quick, 2014).

Unfortunately, attempts at communication surrounding newly implemented transportation infrastructure, such as online information campaigns, facing difficulties in effectively educating the public on said infrastructure. In 2017, Sun Yat-Sen and Sheffield University conducted a survey on London’s smart parking system, finding that 74% of citizens were unaware of—and did not engage with—the system (Peng et al., 2016). This also applies to the car-reducing practice of car sharing, where awareness has been demonstrably low among consumers, business and public bodies alike. With most attitudes towards the topic trending towards indifference (Rodrigues et al., 2016). From this we can argue that, because of these shortcomings in cultivating understanding and awareness, anti-congestion developments become unused or misunderstood; to some citizens, the interests of these schemes appear misaligned with their own (Noonan et al., 2017). Engaging, interactive approaches towards communicating congestion may prove useful in clarifying the rationale of these projects to resolve this misalignment, through improving knowledge retention and understanding the transportation topics underpinning this rationale.

2.2 | Selection Criteria

This analysis reviews works related to public perceptions of traffic congestion, particularly around induced traffic demand in city environments. Despite this review focusing on the flow of people and vehicles, other researched aspects of urban planning and infrastructure are covered, if only in passing. All works have been selected using desk research methodology for a scoping literature review, identifying why public misalignment may occur and what unexplored solutions could be employed. Referenced works contain a relevant analysis of induced demand or related phenomena influencing commuter traffic or examine the influence of interactivity on student knowledge retention and understanding of taught information. The latter may discuss interactive mechanisms implemented outside of computer software, despite being more common within.

2.3 | Induced Traffic Demand and Public Attitudes Towards Congestion

Traffic congestion can be instigated through a phenomenon known as "Induced Traffic (or Travel) Demand" (ITD). Often brought into effect by road widening projects in attempts to mitigate congestion, ITD is a principle wherein increases in road capacity situated where travel demand is high inevitably result in more road vehicles travelling on the widened road. Subsequently, the desired reduction in congestion occurs only briefly before the new capacity is invalidated by changes in commuter behaviour (Hymel, 2019; Nugmanova et al., 2019; Krol, 2019). This behaviour denotes that adding lanes to congested highways increases traffic speeds, lowering the commuter's cost of driving; this decreased time and lower fuel costs enable commuters to take longer and more frequent trips (Krol, 2019; Department of Transport, 2018), increasing overall Vehicle Miles Travelled (Volker et al., 2020). This phenomenon is pervasive, continuing to influence congestion-mitigation projects after they have been constructed. Nonetheless, these projects remain vital to the problem-solving ecosystem of highway infrastructure. Upon examination, it's clear that road widening solves logistical issues (Hymel, 2019); and is merely unsuited for solving congestion.

When road widening is required, the bare minimum required lanes are constructed (Said et al., 2019). This follows the majority of responses to the *Public Opinion Survey on Traffic and Road Use* (Department of Transport, 2020). However, the report highlights that road space reallocation favouring cyclists is more strongly opposed, despite the benefits. Thus, better communication of how alternative transport modes influence ITD would enable planners to push forward congestion mitigation measures with public approval, not opposition. Potentially, visually demonstrating how capacity and alternative travel modes impact congestion can inform public perceptions towards congestion, prompting publicly-interested policy change through an informed visualisation of potential transportation solutions that combat congestion (Klein et al., 2021).

Congestion mitigation varies widely in implementation and reception; yet, effective solutions cannot be constructed when widely opposed, such as by interest groups (Tobler, 2017), especially when opposition is misinformed due to an incomplete understanding surrounding the wider picture the solution is part of.

For example, Congestion Pricing via toll gates (Krol, 2019). Comparable to how aeroplane ticket prices increase during peak holiday times, tolls allow congested routes to be ascertained so higher toll fees can be applied, reducing congestion. As an unsatisfying commuter experience, public disapproval alone makes implementing this system difficult. Commuters may believe that planners are unconcerned about commuter interests and are attempting to generate profit instead.

Alternatively, The University of Cantabria (Nogués et al., 2020) proposes Autonomous Vehicle (AV) usage to remove human inefficiencies and smooth traffic flow. However, flow smoothing equates to capacity expansion, instigating ITD (Almatrudi et al., 2022). Thus, while explaining AVs is straightforward, they're less viable as a congestion solution to serve as an example in ITD education. This highlights another challenge in public education: not every project is wholly suited for education. While education may increase the likelihood of the proposed project being supported, it may not foster a public understanding of the topic, having a limited impact on assisting the reception of future similar projects.

Lastly, an often-overlooked approach involves manipulating ITD to reduce congestion. Whilst lanes additions induce congestion, lane removals can dissuade congestion; for instance, by adjusting multiple routes to be similarly viable in fuel and time commitments, reducing congestion risk. Generally, "traffic will be bad where there are a lot of drivers, they have to travel long distances to meet their basic needs, and they are funnelled onto a small number of routes to do so" (Herriges, 2020); therefore, a larger number of routes not only mitigates congestion, but also the impact of road accidents that congest traffic on a single route. Because of this, communicating "road thinning" in addition to road widening is necessary in fully demonstrating ITD in the context of road capacity. This bilateral nature of ITD makes road widening and "road thinning" more suitable examples in envisioning ITD than Congestion Pricing and Automated Vehicles.

This is where common education solutions or "public engagement tools" (PETs), and awareness solutions or "public awareness tools" (PATs), come into play; informing the public on the background context that forms the rational justifying infrastructure projects.

Engagement tools "build the citizens' capacity to become further involved" in public engagement events discussing planning decisions, whereas awareness tools "not only state the 'when', 'where', and 'what' of the event, but also stimulate interest" (Miskowiak, 2003). Together, these are two key components of public engagement and notification, prompting the public to later weigh-in with their own informed opinions on proposals that have an impact on the public, such as urban planning projects.

A disruptive barrier to many implementations is negative public prejudices towards them. Using the example of toll gates, despite Krol's argument that these gates could be incentivized with the replacement of fuel taxes, the implementation would require systemic change regarding taxation and thus becomes immediately controversial due to the far-reaching nature of the proposition. The potential for the average citizen's preconceptions to be influenced by facts acquired out-of-context such as these can limit future receptiveness in further learning about these suggestions. The absence of knowledge surrounding the benefits citizens receive from proposals furthers these preconceptions, complicating the challenges planners face in arguing for proposals.

Current engagement tools, such as newsletters, are prone to falling short when fostering knowledge, requiring members to maintain engagement with them to ensure they remain fully informed. This extends to "open house settings" (OHSs), where experts use infographics to inform members of the public, who can then give their input and ask questions (Miskowiak, 2003). These settings possess more complications than newsletters; while allowing for direct interaction with members of the public, they require members to be physically present within their own time, which many citizens are reluctant or unable to do (Marcel et al., 2017). Furthermore, these two engagement tools are more suitable for local projects and struggle to be applicable on a national or county-wide level.

Similarly, awareness tools, such as electronic and physical mail, may be bothersome for recipients, prompting those who initially engage with the proposition to consider disengaging if they become more moderate or indifferent to the proposal. However, these shortcomings in fostering wide-scale awareness are better addressed by another awareness tool: mass media, comprising radio, television, and social media; the latter option potentially being the most effective (Lee & Kwak, 2012). Given enough coverage, these methods can keep planning proposals within the public consciousness but cannot communicate the relevant background information that justifies planning alone. The attention they attract is temporary (advertisements, announcements, etc.) and, while enough to maintain awareness, cannot effectively communicate lengthy information. Thus, PETs are arguably more significant, as they are the education methods, and current methods have limitations, requiring a new form that is both engaging and can benefit from wide-reaching PATs such as mass media.

2.4 | Effective Engagement and Communication of Planning Considerations

Effective infrastructure directly influences the wellbeing of local residents: pedestrianisation projects targeting commonly accessed public areas, revolve planning objectives around human needs to resolve wellbeing concerns, and improve the performance of retail and restaurants by encouraging development in economically productive areas (Nogués et al., 2020). Making members of the public aware of beneficial, human-centric proposals, and how ITD can facilitate them, is a sound approach for reinforcing engagement and support towards congestion mitigation initiatives. For example, explaining how through improving liveability standards, cities can become more attractive places to live. Through this elucidation, there will be known incentives for supporting the proposals of this nature; congestion initiatives fall into the category of regularly due to their impact on a significant number of citizens. Conversely, without public engagement, wellbeing-oriented proposals that could be implemented with public support, yet lack said support, may risk rejection by the public due to a lack of awareness and understanding, despite the proposal in question pushing for developments that have the public's best interest in mind. Unaware citizens may presume that the proposal is purely economic, becoming indifferent to proposals that do consider humanitarian needs; one of many public attitudes towards proposals potentially hindering their implementation (Huber et al., 2020).

A lack of transport modes can also isolate people socially and limit access to local facilities. 66% of over-65s within the UK are unable to access hospitals within 30 minutes via public transport and many young women feel unsafe when engaging in shared automobile travel – hampering carpooling as a transportation practice (Lucas, 2019). As public engagement can reinforce support from citizens via explaining the proposed benefits to their wellbeing, so can engagement can make citizens aware of solutions to issues they are currently facing, or have previously faced. Communicating the latter issue of vehicle sharing lacking security could also prompt support for alternative transport modes that provide better security; the same transport modes that can also be communicated more effectively via increased engagement with the public.

Another vital consideration in urban city planning is disease, as demonstrated by the COVID-19 global pandemic that began in late 2019. Due to the practise of social distancing, the usage of cars dropped drastically in urban environments; prompting "the reimaging of urban public spaces away from the dominance of cars" (Martínez & Short, 2021). Additionally, multiple "third spaces" – spaces that neither qualify as work nor home suffered widespread closures during coronavirus outbreak. These spaces include hairdressers, gyms and hospitality businesses – significant to the backbone of a city goer's daily life. Due to the significant social impact that both these closures and the travel restrictions had on the populace, society has now had a glimpse into the possibilities of alternative transport modes and non-motorised commutes. Barbarossa (2020) argues that the COVID-19 pandemic has highlighted the connections between mobility, urban spaces and health; therefore, cities should not fully return to post-pandemic practises but build a better, more resilient society instead.

To reinforce these assertions, public engagement is once again an effective method, as it can utilise the eye-opening experiences that members of the public have had during lockdown to better convey and promote the proposal; through their pandemic experiences, citizens can relate to pandemic-related wellbeing proposals on a personal level, and understand the goals of said proposals through that relation. Such proposals do entail ITD and congestion, as car-related dominance has become more widely recognised due to the steep decline in road traffic during the pandemic (Martínez & Short, 2021), creating a notable contrast in city life before, during, and after the COVID-19 pandemic. The key discernment from this however, is that a global pandemic was the trigger for this public realisation, not any prior education or public health announcements, campaigns or education policies. Furthermore, this realisation will not remain for long after society fully returns to its pre-pandemic state, demonstrating the tendency of the public to return to their preconceived notions when accustoming to traverse current transportation systems and layouts. An element of incorporating broad pedestrianisation is breaking the public's dependency on cars to travel; not only a necessity in achieving climate goals, but also improving city walkability and enabling pedestrianisation.

However, the impact of the pandemic indicates that public transit cannot run at full capacity (Barbarossa, 2020) and requires complementary logistical solutions to allow transport systems to persevere in times of unexpected stress. Such a solution would require implementing multiple alternative transport modes in equal measure together, naturally entailing reduced capacity for transportation modes that currently operate in excess. This undertaking would require informing the public of why drastic changes are occurring and why they should adjust their transportation preferences appropriately to benefit from these changes. Due the physical nature of transportation systems, "two-dimensional media such as book and blackboards" are less effective in communicating difficult to visualise material (Guzman et al., 2010); for example, how a lack of transport variety hampers transport systems. Thus, visual demonstrations of how transport modes influence transportation systems become a natural solution to demonstrate intricate aspects of said systems. However, these visualisations cannot simply continue to impart information that may not successfully be retained. To remedy this, interactivity can be incorporated; user interaction has been shown to improve understanding of dynamic processes, such as induced demand, and the relationship dynamics between the involved objects (Guzman et al., 2010) – in this case, road capacity and capacity distribution between transport modes. Interactivity has also proven effective as a mechanism for positively developing learners' inner imagery of a topic through an engaging, and motivating learning experience (Rodrı´guez-Ardura & Meseguer-Artola, 2016) – sometimes referred to as the "Interactivity Effect" (Evans & Gibbons, 2007).

To facilitate the requirement of interactivity in this new educational media, this solution is best produced in the form of computer software with a design surrounding ease-of-use and clarity. Software allowing users to interact with the learning process would allow interactivity to be used in the learning process, increasing the knowledge retention (Putz et al., 2020) of explored topics, such as ITD, as well as addressing the shortcomings in effective communication present in previous non-interactive attempts; attempts which struggle in communicating the benefits of proposed infrastructure changes that aren't immediately cogitable. However, to achieve this increased benefit via the use of software, the specific content and objectives of the software needs to be determined in order to effectively demonstrate the phenomena it is attempting to elucidate.

2.5 | Software Goals to Educate Perspectives

Software interventions created specifically for situations surrounding ITD do exist; Volker, Lee and Handy (2020) proposed and developed an online tool for calculating "induced vehicle travel" (i.e., ITD) impacts of roadway expansion. While this solution is designed for use by those who wish to plan road expansion, the context in which this tool is used isn't suitable for public educational purposes, this does support the notion that interactive mechanisms (e.g., user-made interactions) can assist humans in better understanding ITD. However, for interactive software to be beneficial and effective for educational purposes as a PET, there are key goals such software needs to achieve. These goals, or aims, relate to the education and visualisation of ITD and congestion, as well as using interactive mechanisms to effectively communicate these ideas with clarity. These aims will determine the covered content, how it is presented and the specific interactive methods used to effectively communicate this content.

To further inform these interactive educational software goals, the strengths of current solutions must be identified. Aforementioned solutions such as open house settings entail the use of visualisations to better communicate concepts with higher clarity. Visualisation is a common feature in multiple proposed software solutions relating to urban planning, echoing this sentiment. For instance, proposed public engagement software from The University of Tokyo's "My City Forecast" (2019) demonstrates the importance of content clarity, utilising user-oriented interactive maps displays and statistics to inform users on upcoming urban management projects within their area; improving the public's attitude towards urban planning proposals and increasing the probability that they will pass. For solutions whose purpose drifts towards education in preference to user input and response, clarity in the user's understanding as communicated via education mechanisms is a primary goal; a lack of clarity not only cripples a user's understanding, but has a high likely of damaging their understanding with incomplete or incorrect knowledge. Interactive engagement software with these goals may provide more effective results through visualisation and interactivity-oriented approaches; the usage of visualisation can build models to be incorporated into relevant aspects of learning (Hamilton et al., 2001), and facilitating interactivity into these models can increase clarity through incorporation of "Discovery learning" (Weber, 2005).

Discovery learning, as the name implies, is a form of exploratory self-guided learning through experimentation and subsequent observation—users can interact with a model in their own manner, coming to conclusion and answers in their own time and pace. As Weber asserts, this level of interactivity prompts deep thinking from the user; resulting in a stronger understanding that is supported by a memorable, tangible encounter with the learning experience that can function as a mental reference—also referred to as "personal constructs" (Hamilton et al., 2001). Approaches that encourage discovery learning assert that the information users are accessing must be enhanced, such that the comprehension of this information is clear through the use of visual models and tools; mechanisms "that enable citizens to formulate their own ideas, knowledge and meanings" (Christmann et al., 2020). This focus on user-friendliness and understanding is supported by Daher and her colleagues, who argue this comprehension should be achieved through the relevant information being presented in a "way that in understandable for non-experts" (Daher et al., 2022). Thus, a necessary requirement of interactive education software, both within and outside of the urban planning field, is "subject intelligibility"; this, as demonstrated, can be achieved via the effective usage of scrutable visualisations by modelling the concept being conveyed.

However, a balance between clarity and other key solution objectives needs to be established to ensure the education process remains effective. Wilson and his colleagues argue that technological applications designed for public engagement "must walk a fine line between being fluid and engaging, fitting within decision-making mechanisms that are often more static" (Wilson et al., 2017). Educational tools that foster limited motivated-engagement endangers the education process; yet, excessive gamification for engagement could also dilute this process. Regardless, utilising gamified learning for engagement can have a positive impact on a learner's knowledge retention, attitude, engagement and performance via good design (Subhash & Cudney, 2018). Thus, design decisions surrounding the balance and quality of these two goals—engagement and flow—will determine the effectiveness of an ITD-oriented PET; additionally, effective software needs to correctly incorporate these design goals. This is where a software solution's potential for interactivity triumphs over conventional, reading-oriented solutions: excessive reading is tiresome for most people. As previously discussed, the inclusion of interactive mechanisms can add clarity to the learning process. Likewise, interactivity can facilitate user engagement, which "loosens up the learning process" via support-oriented interactive mechanisms (Weber, 2005). Through implementation of appropriate interactive mechanisms that improve clarity and user engagement, the two elements to break away from the limits they impose upon each other to some extent.

A major consideration when considering the prevalence of interactivity so far, is what can be considered "good interactivity". More specifically, what are the vectors that differentiate poor from effective implementations of interactive mechanisms for education. Due to the numerous differing situations interactivity is implemented within pre-existing PETs, interactivity too is often envisioned as consisting of multiple different "levels", or existing on a spectrum from 'active' to 'expositive' (Weber, 2005). Within the spectrum interpretation, the term 'active' entails action from the user that is productive to the learning process, prompting deeper understanding of the subject matter as previously mentioned. The term 'expositive' refers to pre-existing solutions with minimal interactivity, with interactive mechanisms serving a quality-of-life role in the procedure. Yet, for determining suitability, this model is vague and impractical. Weber acknowledges this unclear, binary nature of this construal, and instead proposes the multi-level interpretation—consisting of level ranging from observing content and its various representations, to modifying and, potentially, the creation of the content itself to deepen understanding.

This content creation as an education method, especially in the context of ITD, brings forth a perception that "more interactivity" isn't necessarily "better interactivity"; applications of the incorrect or irrelevant level(s) of interactivity can result in more confusion due to guidance structures regressing into flexibility systems. Furthermore, levels of interactivity that are too high for the given situation are possibly more detrimental than those that are too low; while the latter becomes inconsequential, the former muddies the solution with unneeded and confusing mechanics that harm the aforementioned clarity and engagement of the solution. From this interpretation, effective interactive mechanisms are purposeful, not numerous, and "good" implementation entails moulding it to the needs of the project while maintaining the intended purpose. Additionally, while interactivity can unchain the aims of clarity and user engagement from restraining each other, when poorly implemented, interactivity undermines its own purpose of supporting the aims of the desired public education software: supporting urban planning proposals through clear and beneficial, reciprocal teaching.

2.6 | Conclusions

Within this review, limitations in public understanding of ITD have been exposed, as well as how current tools fall short in rectifying these limitations. Furthermore, through the use of software solutions to account for and resolve these shortcomings—via the use of interactive mechanisms, visualisation, and applied gamification—planners can increase knowledge retention, clarity, and user engagement with more effective public engagement (and education) tools. Such tools are vital in building support and quelling discontent through transparent planning proposals, granting citizens the knowledge to inform their assertions.

Thus, developing a public engagement tool incorporating interactive mechanisms becomes a legitimate avenue for addressing flaws in current tools and the approach this project will take moving forward. Pre-existing solutions—some proposed by previously mentioned authors—direct this project's approach heavily towards computer software as the medium for interactive mechanisms. The key difference between this approach and current methods However, before these mechanisms can be designed, potential approaches and methodologies must be explored to select the most appropriate approach for this project's scope, requirements, and purposes.

3. Potential Approaches

3.1 | Overview

While there are multiple approaches to organising the design, development and testing stages of this project, a commonality they share is the translation of software aims into software "technological requirements" (Wilson et al., 2017). In 1998, Smith et al. designed a piece of software to model tangible cities for educating and facilitating communication with the public, demonstrating the importance of identifying key software requirements and their successive implementation as software features. Culminating towards the organisation of these aims into specific interactive mechanisms that users can engage with. To arrive at these requirements, the means and environment in which they will be achieved must first be determined; encompassing both design and technical elements of the software to formulate an approach towards this project's goals.

3.2 | The Influence of Solution Aims on Approaches

When designing an education tool to benefit from interactivity, solutions presenting ITD must successfully communicate how it functions, where it originates from, and how it generates congestion. The influence of road capacity on congestion must be demonstrated, and when doing so with interactive elements, must be utilised to increase comprehension of the topic. This could be achieved through interactive visualisations of traffic gradually becoming congested from excessive road capacity, as well as visualising the opposite: mitigating congestion by dividing capacity among smaller routes, as discussed in *section 2.2*. This proposition entails the visualisation being perception-oriented, as congestion relates heavily to physical travel space. Thus, interactive visualisations of physical spaces encourage approaches enabling users to "modify the communication environment", a core dimension of interactivity referred to as "Perceived Control" by Rodrı´guez-Ardura and Meseguer-Artola (2016).

These design goals make path-searching algorithms a beneficial approach for development. Through these algorithms, achievable paths between a given origin and destination could be generated; creating routes for simulated vehicle to travel and become congested within. These search algorithms do not need to be intricate, only emulating traffic flow and behaviour, as visualising ITD is the objective, not full simulation. Similarly beneficial, and likely necessary, are algorithms that emulate decision-making behaviour in commuters; ITD originates from human decisions made with travel-cost considerations, the PET's design needs to reflect this property through its visualisation of ITD. Other potential algorithms could serve roles in decision-making. For example, opting between multiple lanes when entering a road, or whether the commuter should reconsider their vehicle choice based on the information they have at hand—such as average commute times or total lane occupancy.

3.3 | Development Environment, Language and Target Platform(s)

When considering target platforms, there are few suitable platforms outside of mobile devices and computers, which most people already own. While recent videogames consoles can browse the internet, these consoles are broadly used for relaxation, using games controllers as their form of input. A formal, educational piece of software designed for touch and/or mouse input would need to be adapted to not only recognise and interface with the connection of a controller, but also support the controller's unique form of input—this is substantial effort put towards a platform less worthwhile. Thus, due to the prevalence of personal computers and mobile devices, as well as their suitability for this software, they are suitable target platforms.

To increase user accessibility, hosting the solution as a browser-based web application is a straightforward way to broaden the range of devices from which the software can be accessed, such as mobile devices. Such approaches often entail utilising interpreted scripting languages, such as JavaScript, that are suited for web development. These languages facilitate agile software development, with changes being performed quicker due to scripting languages compiling at runtime, allowing code to be tested without lengthy compilation. However, due to this project's scope, the integration of the software as a web application and ensuring mobile device compatibility aren't required for this project to achieve valuable data. Additionally, in comparison with JavaScript, the C family of languages boasts superior threading capabilities, allowing for uncomplicated optimisation. Smoothly processing many objects is important when simulating significant numbers of vehicles, as vast quantities of vehicle objects are required to enable congestion to form within the interactive model. Therefore, the chosen language for this project will be C++ with a focus on development for Windows computers, as Windows continues to be the operating system the majority of the public uses.

The chosen API software will be DirectX11, developed using Microsoft Visual Studio 2020, as opposed to more component-rich environments such as the Unreal or Unity engines. This stems from the proposed solution possessing low technical complexity; sophisticated features such as particle systems are inessential. Furthermore, the solution isn't video game software but educational. While Unity and Unreal are valid development environments for similar projects, proprietary game engines limit flexibility. The rationale behind using DirectX as the chosen graphics API for Visual Studio—as opposed to alternatives such as OpenGL—is that DirectX is more specialised for Windows while being simultaneously incompatible with non-Windows systems. However, as Windows users are in the majority, choosing this API becomes reasonable for this project's scope. Due to the proposed solution being object-focused, programming practices such as inheritance and object-oriented programming are suitable for modelling vehicles as tangible objects in a simulated environment.

3.4 | Methodologies

This project's development will largely operate under an agile approach; specifically, an approach similar to an Extreme Programming Methodology (EPM). In this project's context, this methodology focuses on achieving goals using simpler designs or designs lacking the depth that longer-term artefact solutions possess. This suits this project's goals: to determine the effectiveness of interactive software; not producing objectively successful software for public-use. This methodology is also suitable for the potential alterations or additions in software requirements as development progresses, as planning and design are iterated upon within EPM. Unlike traditional development methodologies such as Waterfall methodologies, software requirements aren't set-in-stone prior to development and are revised and improved upon during development.

4. Design

4.1 | Artefact Requirements

This chapter contains a list of requirements and in-depth descriptions surrounding the design rationale of key software features. These requirements maintain the project's focus and are therefore derived from the literature review, particularly the shortcomings of non-interactive methods in ensuring information remains retained in the long term.

4.1.1 | Purposeful Interactivity

As discussed in *section 2.4*, educational software making use of interactive mechanisms must utilise these mechanisms with purpose to teach effectively. Therefore, any application of interactivity should have the purpose of increasing clarity, understanding, or engagement surrounding the presented content. To achieve this, employing interactivity to enhance visualisations of complex aspects of ITD seems appropriate, as visualisations communicate concepts involving interactions between real-world objects effectively. This is appropriate for complex processes, as interactive mechanisms have been shown to be proficient at demonstrating processes with intricate "mechanical details" that hinder user understanding (Guzman et al., 2010). Therefore, an interactivity level leaning towards an active implementation over an expositive one is fitting, as the manipulation or creation of a learning environment can be implemented as adjustable simulation parameters. Furthermore, providing user interactivity with a vehicle simulation allows these concepts to be more digestible and more easily learned.

4.1.2 | Facilitating Discovery Learning

Interactive mechanisms integrate capably with discovery learning, due to interactive mechanisms facilitating learning environments for users to discover and process concepts at their own pace. Discovery learning isn't limited to purely educational contexts; video games often refer to a similar phenomenon as "emergent gameplay," where gameplay elements are discovered by the player through experimentation. This approach wouldn't be too dissimilar in public education software and is also necessary to harness the full potential of interactive mechanisms when cultivating long-term knowledge within users. Due to this relationship with interactivity, discovery learning and its benefits are key to enforcing the software's purposeful interactivity.

4.1.3 | Clarity of Information

Information instilled by successful educational software must do so with clarity. Although material may be factual and accessible, information presented to users in an unclear manner threatens understanding of the material via gaps in knowledge or utter misunderstandings. The latter is what this software is attempting to resolve, with increased awareness of ITD and its association with congestion. Therefore, the presentation of ITD learning material using interactive mechanisms must not become overcomplicated due to these same mechanisms; unnecessary interactive features of the software should be avoided.

4.1.4 | Table of Specifications

Requirement Category	*Software Requirement*	*Elaboration on the Requirement's Purpose*	*Level of Complexity*
Functional	Emulates ITD and Traffic Congestion.	The software emulates Induced Traffic Demand and Traffic Congestion via a simulation of traffic behaviour.	High
Functional	Emulates Human Traffic Behaviour	The software emulates human traffic behaviour by emulating human decision-making processes.	High
Interface	Possesses an Ergonomic User Interface.	The software's user interface is straightforward for users to understand and comfortable to use.	Medium
Interface	Facilitates discovery learning.	The software facilitates a learning environment for users to learn about content via discovery learning.	Low
Quality	Exhibits Clarity in the Presentation of Information.	The software communicates knowledge on Induced Traffic Demand and Traffic Congestion with clarity in order to make these concepts easier to fully understand by users.	Low
Performance	Accessible to Lower-end Systems.	The software experiences no slowdown or performance issues on lower-end hardware, increasing the accessibility.	Low

Fig. 1 A table of the software's specifications based on the aforementioned requirements.

This table, *Fig. 1*, displays software requirements that are categorised in a similar fashion to the SRS (Software Requirements Specifications) format. It lists the level of complexity of each requirement in comparison to all others, conveying project priorities as well as the development time expected for the requirement's fulfilment. As a whole, Fig. 1 does not aim to present information in detail comparable to in-depth SRS documents, instead breaking down software requirements to present readily digestible chunks of information.

4.2 | Top-down Decomposition of the Software

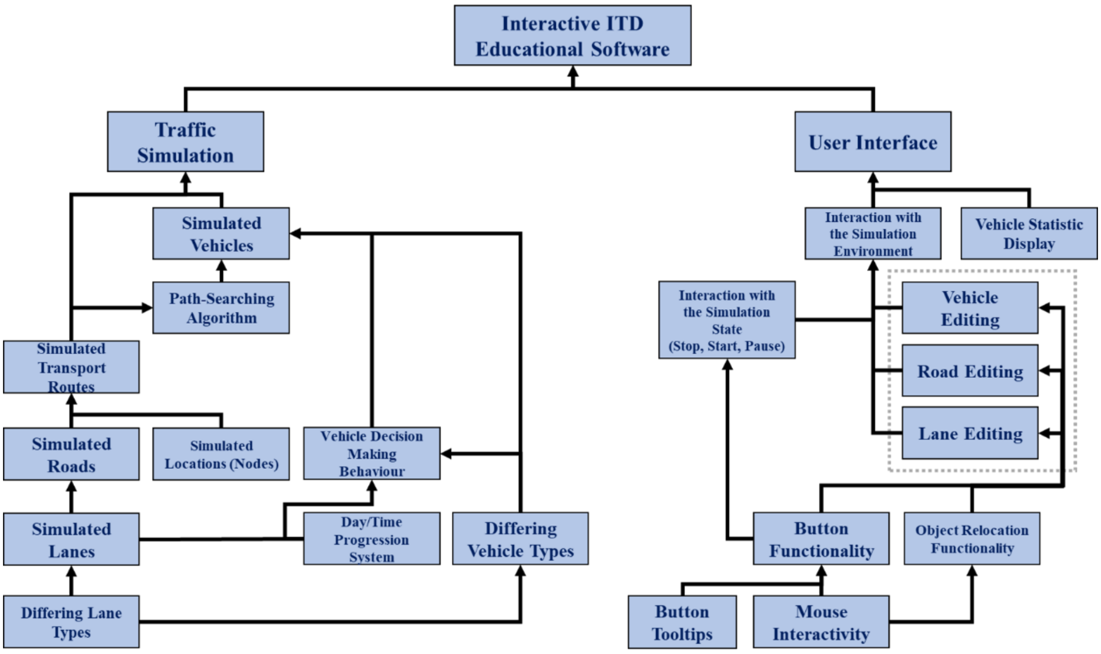


Fig. 2 A top-down decomposition illustration detailing the components of the software, exhibiting the software's general function(s).

These requirements translated into *Fig. 2*, where the majority of software components are split between two branches: simulation functionality and user interaction. The priorities of the former coincide with functional requirements laid out within *Fig. 1*, whereas the latter overlaps with the quality and interface categories. Within this illustration, multiple components are interlaced with one another; thus, many phases of this project's development will likely be dependent on another task's completion. However, this is expected, and by design, many components are co-dependent due to sharing design goals, as seen within both simulation and interface branches. The user interface system necessitates button functionality for most of its components. Therefore, multiple components are expected to become further interlaced as the project progresses.

4.3 | Feature: Interactable Road Traffic Simulation

To visually demonstrate ITD while using interactivity to enhance the learning process, real-time modelling of traffic behaviour is fitting and feasible for a software approach to tackling congestion misconceptions. As previously mentioned, simulation parameters can be changed to influence the events within; thus, users interacting with simulations may alter parameters—for instance, the number of lanes within a road—to influence them. However, as the software is for educational public use, not practical industry use, this simulation leans towards emulating reality rather than an infallible, precise, realistic model. This is due to numerous factors influencing ITD, many of which add complexity that could hinder user understanding through "un-purposeful" interactivity. Regardless of the intricacy, there are necessary capabilities that this simulated environment must possess to model ITD for users, such as simulated vehicles, roads, and lanes within said roads. These are the elements that make up the environment through their interconnected relationships and interactions. To make these relationships represent reality, roads in this simulated context should functionally be containers for a given number of lanes, as lanes are characteristics of roads and supply road capacity. Vehicles will travel these roads, represented as lines, choosing a lane within to occupy as they do so, emulating reality. The user can interact with these elements, and through the addition, relocation, or removal of these elements, the user can observe how the quantity of road lanes influences commuting vehicles.

This is expanded upon with different lane types, such bus-only lanes. These designate the vehicle types that can travel within them, as specialised lanes do in reality. While pedestrians and cycles do not travel via roads but rather paths, these infrastructure elements should also be accounted for. Differing lane types also influences road capacity through the allotment of a road's total capacity, in lieu of altering the road's total capacity directly. Car travel capacity could be reduced by converting regular road lanes to bus-only lanes for bus-only travel. This is the purpose of reality's bus lanes: quickening public transport by avoiding car-centric traffic congestion (Alam et al., 2014), supporting these systems inside high-traffic environments.

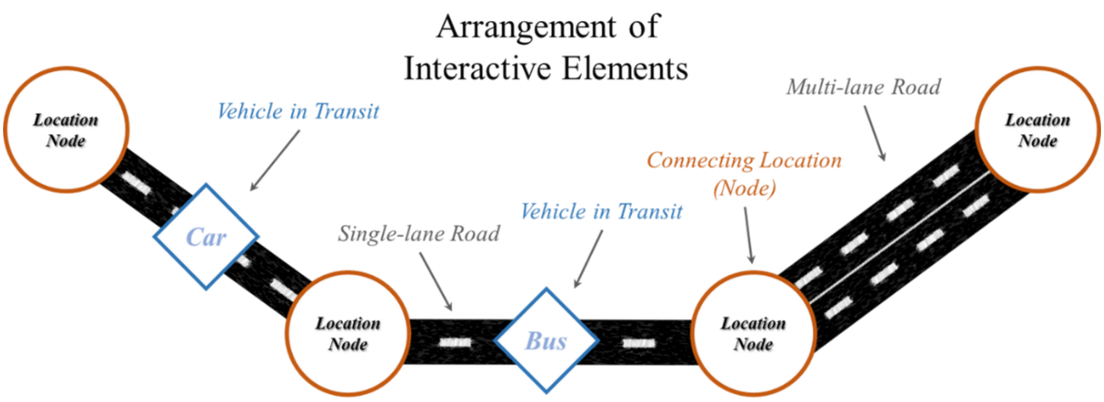


Fig. 3 A diagram displaying the proposed layout of simulation elements to form a functional road system.

Traffic emulation using these elements will be executed using a node-based system, as shown in *Fig. 3.* To reiterate, lines signify roads along with the lanes within them. Linking these roads together are circular nodes, functioning as points of interest for vehicles. These nodes emulate cities, villages, and towns, also serving as vehicle origins, destinations, or locations travelling vehicles pass through. This approach facilitates the use of path-finding algorithms in constructing a path from one node to another, enabling simulated vehicles to travel. While travelling, simulated vehicles will choose lanes that have low congestion, space for the vehicle, and a lane type supporting the vehicle—for example, a car cannot enter a bus-only lane. If these conditions aren't met, the vehicle decelerates, stopping until a valid lane becomes available; the stopped vehicle then becomes a potential obstacle for others, consequently creating congestion with queues of idle vehicles along the route.

4.4 | Feature: Vehicle Decision-Making Algorithm(s)

Modelling ITD, a human-driven phenomenon, requires some simulated equivalent of decision-making, aiming to achieve human-like behaviour. While human decisions aren't consistently logic-driven and their outcomes are different among individuals, commuters travelling by road will tend to exhibit similar choices, likely resulting from shared time and fuel considerations. Therefore, this behaviour will be emulated via an algorithm considering commute times when determining a vehicle's travel mode. When commute times for buses are faster than the car's, commuters will consider travelling via the bus, accepting the associated advantages and disadvantages, as simulated buses will transport multiple commuters but will stop to collect more passengers. Thus, buses experience less congestion than cars despite exhibiting identical speeds, leading to shorter bus commutes than car commutes, provided the latter is experiencing notable congestion. In conjunction with the option of bus-only lanes, users are presented with an active scenario in which road design impacts the effectiveness of multiple transport modes, leading to all simulated vehicles reassessing their chosen transportation mode and adapting to their shifting commute environment, taking advantage of available road capacity where possible.

However, it remains that humans do not act logically as an automated process does, and varying behaviours among humans do occur. Thus, to add some variation between individual vehicles and prevent all vehicles from behaving in the same manner, a variable named *comfort* will be implemented. A floating-point number between zero and one, *comfort* represents the importance an individual vehicle places on the luxuries of car travel over the convenience and commute times of bus travel. Higher values result in commuters favouring car travel more, bringing about situations where bus commutes are marginally shorter, yet the commuter begins to use or maintain car travel. This opportunity for simulated commuters to "ignore" better options allows vehicles to take unoptimized routes, aligning with humans, who may potentially pick slower travel modes for comfort if comparable modes have similar durations. Vehicle comfort influences human travel decisions heavily; a commuter's own private vehicle guarantees comfort, whereas public buses may not provide guaranteed comfort or service quality (Urbanek, 2021). The implementation of a variable differing between individual vehicles is key, as congestion generated by ITD isn't immediate but gradual from when the instigating capacity change began. Without this, simulated vehicles would behave identically, changing routes and transport modes at the same opportunity. This is unrealistic, resulting in visualisations that display ITD ineffectively to users.

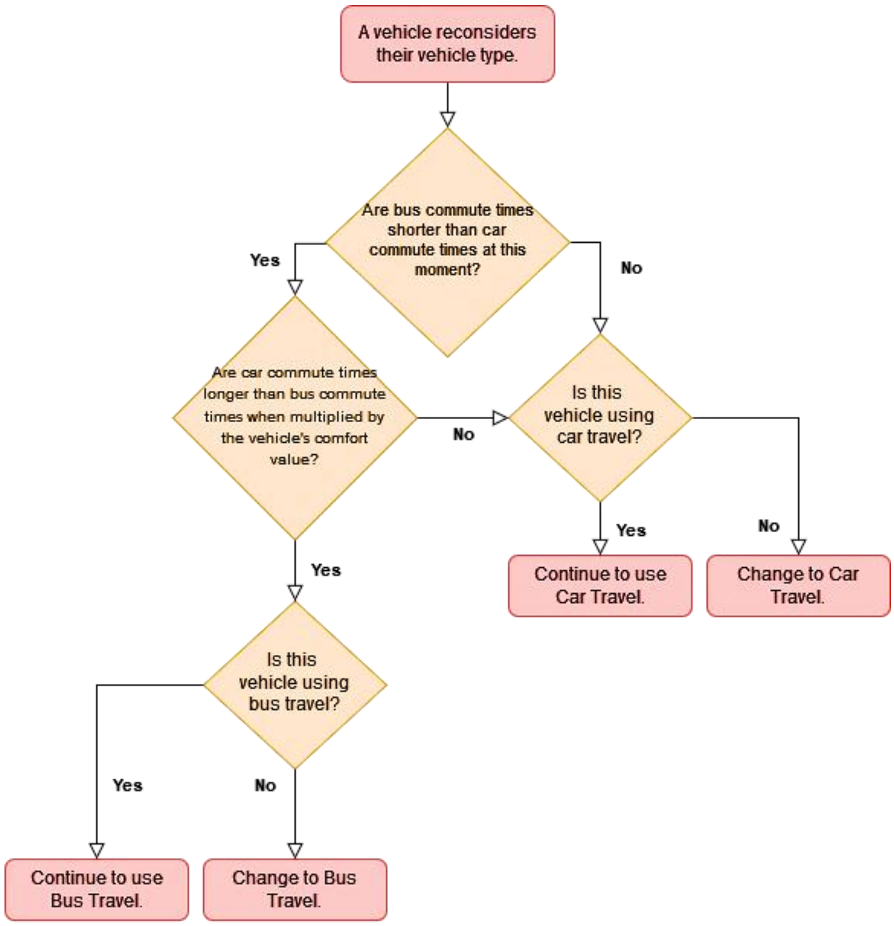


Fig. 4 The resulting flow diagram illustrating the decision-making process of simulated vehicles.

As shown in *Fig. 4* and pseudocode (*see Appendix A*), when vehicles reconsider their transport mode, they compare the commute times of different modes, influenced by their comfort variable. If bus times are shorter, then bus travel is determined to be superior; otherwise, car travel is preferred. These vehicles are the main medium for demonstrating ITD, as bicycles are often disregarded when choosing travel modes. Furthermore, congested bicycles and pedestrians are uncommon, either because they're less used or of smaller size than road vehicles. Therefore, they aren't primary mediums for demonstrating ITD within the software.

Nonetheless, there remains potential for users to observe the impact of these modes on road transport modes, as commuters utilising road-less transport aren't contributors to road-based congestion. Additionally, commuters converting from road-based to road-less transport no longer contribute to motor vehicle congestion. Thus, the software maintains functionality for simulated bicycles, pedestrians, and their exclusive lane types: cycle paths and footpaths. This enables discovery learning by enabling users to observe lanes influencing congestion. Users, through curiosity, may add these road-less lanes to observe their impact on congestion or attempt to create an alternative travel system using these lanes. This allows for an alternative simulation environment that users can compare with a road-based environment, facilitating further understanding of the relationship between transport modes and how they accommodate each other.

4.5 | Feature: Ergonomic User Interface and ITD Demonstration

The user interface is the user's means of interaction and thus must make this interaction possible while preserving clarity; interface elements must clarify their purpose prior to interaction. Therefore, clickable interface buttons will display tooltips when the user's mouse is on them, displaying text describing the button's function. This is common in software, serving to clarify the functionality of UI elements.

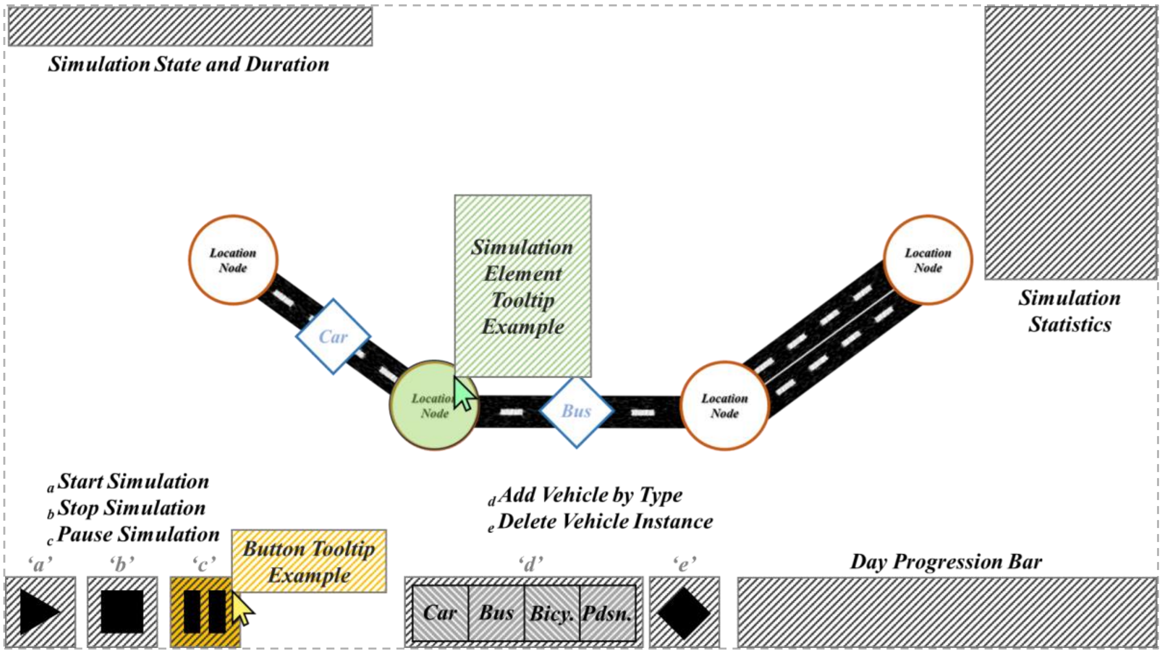


Fig. 5 A mock-up of the user interface layout, including interactive buttons and tooltips..

Through this interface, the user can commence the simulation loop. Accomplished via a cycle-based system, this loop consists of cycles (or "days"), with simulated vehicles travelling across the road network each day. Demonstrating commuters travelling between their home and place of work, vehicles are given a reconsideration period when the day begins, performing the algorithm discussed in section 4.4 and potentially changing travel modes. To make users aware of this cycle, the interface features a progression meter indicating the progress of the current day, filling up before resetting when a day has passed. Providing the user with a visual representation of information to increase clarity and comprehension with shapes instead of text.

5. Development

5.1 | Initial Development Schedule

When development began, task dependencies, priority tasks, and key features were designated, including more complex features such as user interactivity with lanes and vehicles. First came the object rendering system, state machine and base entity class, the latter being the parent entity for all entity objects. This arrangement allows entity classes with different properties to be treated similarly; as all entities under this system can, via type-casting, coexist within the same data structure. Inheritance of this parent featured heavily in development, with this base "generic" entity providing functions allowing transformations of all entities.

Task dependency in presented within *Appendix B*, showing vital simulation elements displayed in *Fig. 3* entailing multiple prerequisite features.

5.2 | Milestone 1: Implementation of Simulation Elements

The simulated environment must come before the simulated vehicles. Therefore, a child of the generic entity named *Entity_RoadSegment* was created, alongside new classes: *RoadConnector* and *Lane*. These facilitate the emulation of travel locations, roads, and lanes, respectively, utilising pointers to instances of each other, as shown in *Fig. 6*.

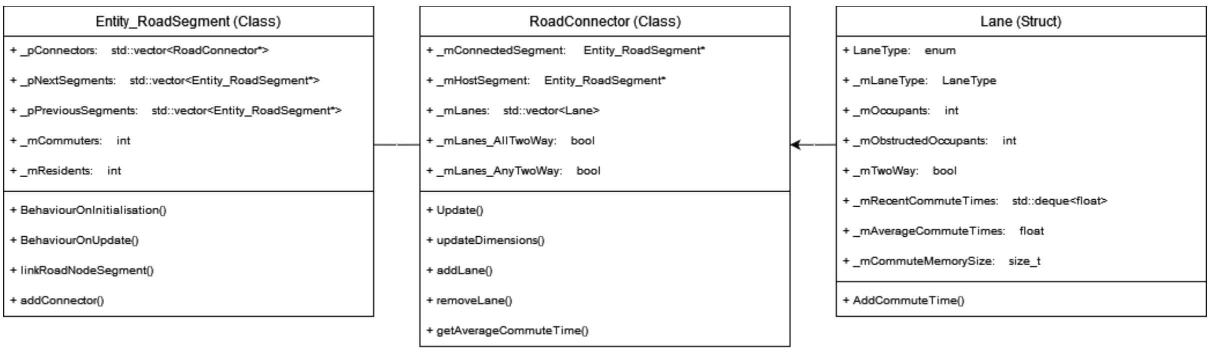


Fig. 6 Class Diagrams picturing the aforementioned classes.

A *Road Manager* class was implemented to manage these environment classes while enabling vehicles to access the information of these classes via pointers to this manager. When required, other classes also access different manager classes with pointers. Unlike entities, these manager classes do not make use of inheritance as each manager is specialised. The road manager contains functions for connecting or disconnecting road segments and connectors, with the user performing these actions with the mouse. When the user holds down the right mouse button over a node and moves the mouse, a line stretching from the node towards the mouse cursor appears. Releasing the button with the cursor above another node creates a road connector linking the two, whereas releasing the button over an empty space where no node is present creates a new node to link the former to. This behaviour is handled within two functions, *LinkWithExistingRoadNode* and *LinkWithNewRoadNode*, the latter calling another named *CreateNewUnlinkedNode* to instantiate a new node. This creation system allows users to drag their mouse to "draw" a road in a fluid manner without requiring large mouse movements. Created connections are one-way, permitting vehicle travel in one direction. However, as most roads are two-way, the user can perform the connection process in the opposite direction to make the connection bidirectional.

Unfortunately, while this ability facilitates discovery learning and allows users to interact with the simulation environment, it was disabled in the final build, serving as the most significant design change during development. This feature threatened clear communication in ITD, as the freedom provided left users prone to unpredictable results in the software's teaching walkthrough, even though road creation and removal can influence congestion. Lane addition and removal became the main interactive mechanism for demonstrating ITD, serving as a more digestible exploration while continuing to enable ITD-generated vehicle behaviour.

After the road environment, vehicles followed. All vehicle entities inherit functionality from parent *Entity_Vehicle*, and are stored within a class named *Manager_Vehicles*. Differences between vehicle types, such as speed and lane access, lie within *Entity_Vehicle*'s children: *Entity_Car*, *Entity_Bicycle* and *Entity_Pedestrian*. *Entity_Bus*' creation occurred later due to possessing unique properties. All simulated vehicles contain functions such as *TravelToPoint* and *TravelToPointOnRoad* which together move the vehicle towards a given location on a road at their assigned vehicle speed, displaying vehicle travel to the user. To emulate congestion, *IsVehicleObstructed* was created to determine when vehicles are obstructed by others ahead. This function ensures induced travel impacts commute times, returning true when distances between queued vehicles subceed a set length, said length being based upon the real-life separation distances. When true, vehicles decelerate to a stop behind others to maintain this distance, inducing queues of vehicles seen in traffic jams. This behaved indirectly as a collision system and enabled the instigation of ITD by facilitating queues. Regarding vehicle-specific behaviour, all of these vehicles—excluding buses—function identically while travelling, performing vehicle-specific functions using a *LaneType* variable to adhere to vehicle-specific restrictions, decisions, and behaviours—such as cars being unable to use bicycle paths. This *LaneType* variable is an enumerated type that indicates what lane a vehicle should use or what vehicles a lane should accept—these checks are executing within switch statements.

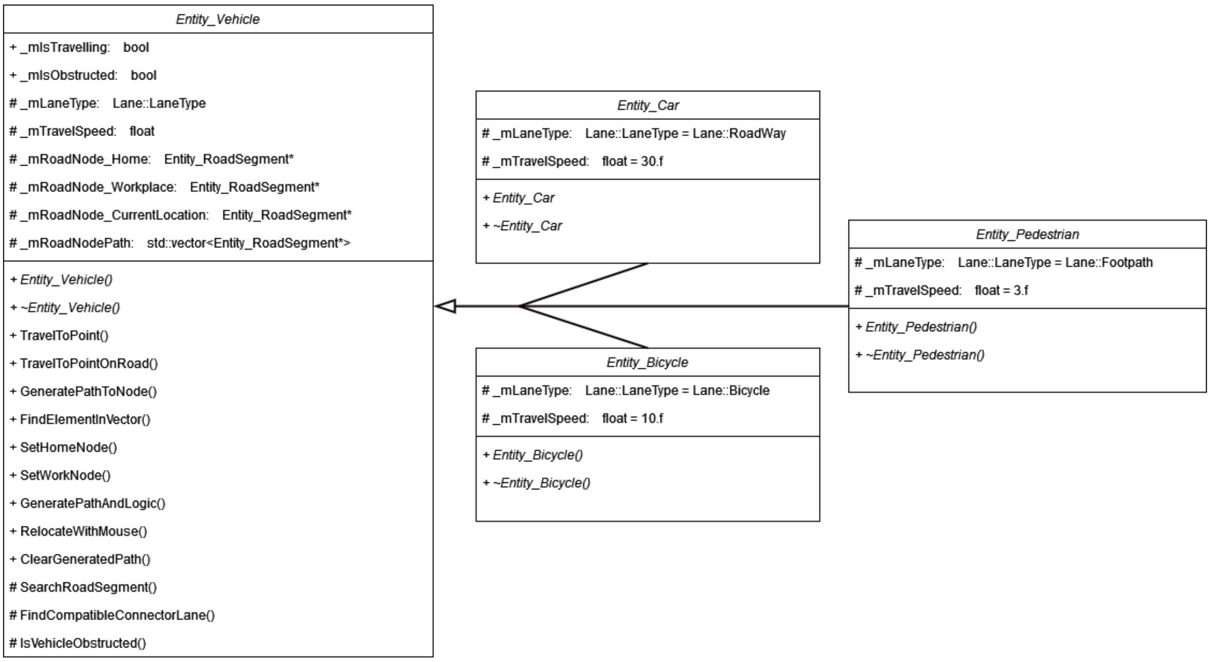


Fig. 7 A Class Diagram of Entity_Vehicle and its child classes.

As shown in *Fig. 6*, the *Lane* class defines the *LaneType* typing, allowing lanes to denote their supported travel modes. These include roads, bus lanes, bicycle paths, and footpaths. Furthermore, by possessing *_mLaneType*, a *LaneType* variable shown above in *Fig. 7*, instances of *Lane* can be compared with vehicles to determine which vehicles should access and travel within the lane. However, while this system does fully support all four vehicle types, bicycles, pedestrians, and their related lanes remain unused in the final prototype. This was due to difficulties in integrating bicycles and pedestrians into the user learning experience as a tool for helping the user understand ITD. Thus, while these vehicles are supported, they are unused, with cars and buses being the mediums for demonstration, keeping with the original design. By sharing the same transport infrastructure, cars and buses are best suited for this task, demonstrating how transport modes with higher carrying capacities influence induced travel.

5.3 | Milestone 2: Implementation of Vehicle Behaviour

Vehicles search through road segments to find valid routes, locating accessible lanes and selecting the fastest among them. This is handled within *GeneratePathToNode* and *SearchRoadSegments*, shown in *Fig. 7*, and functions *SetHomeNode* and *SetWorkNode*, which set the vehicle's origin (home) and destination (work) on initialisation. *GeneratePathToNode* is called by travelling vehicles, which calls *SearchRoadSegments* a recursive function, calling itself to iterate through road segments and find the search target. It first iterates through segments connected to the vehicle's home, named the "searching segment", comparing the distance of these segments to the work node and checking if they possess traversable lanes. Afterwards, the function selects the closest viable node to be the next "searching segment" before calling itself with this node as a parameter. This recurs until the target has been found or all nodes are searched. If found, it yields a valid commute path; the vehicle can call *TravelToPointOnRoad* using this path to travel to its destination. Otherwise, the vehicle turns red, signifying its destination is inaccessible.

This approach is similar to the Depth First Search (DFS) algorithm, conducting searches from a root node down a given branch as far as possible. Backtracking once the branch is fully explored. The software's implementation differs by prioritising nodes near the search target, locating the target more quickly, unlike DFS, which searches in an uninterrupted sequence.

Afterwards, a scheduling system was implemented to have all vehicles travel between home and work automatically, using the cycle-based system discussed in *section 4.5*. A new class, *Manager_Scheduler*, contains a value named "day counter". This value increments over time and resets upon reaching a day's length—a constant measured in seconds. Vehicles are directed to travel based on the counter's value, travelling to work in the first half of the day and returning home in the latter. *Manager_Scheduler* directs vehicles to travel by calling their *GeneratePathToNode* function, a publicly accessible function, using a pointer to *Manager_Vehicles*, which holds said vehicles. The software makes this system known to the user through a day progress meter on-screen, the same one described in the design chapter. This meter displays a rotating image of a sun moving across the meter rightward, possessing markers indicating when vehicles begin travelling. The visuals' positions correspond to the counter's current value to be informative and decluttered when communicating this system.

Implementation of this scheduling system facilitated bus-specific functionality. As public transport, buses function as containers for vehicles boarding them, stopping at locations they come across. Vehicles looking to board buses will do so when encountering a stopped bus that possesses vacant space; this excludes buses themselves—buses cannot board other buses. Once boarded, bus passengers become invisible, detached from the road environment and attached to the bus until disembarkation.

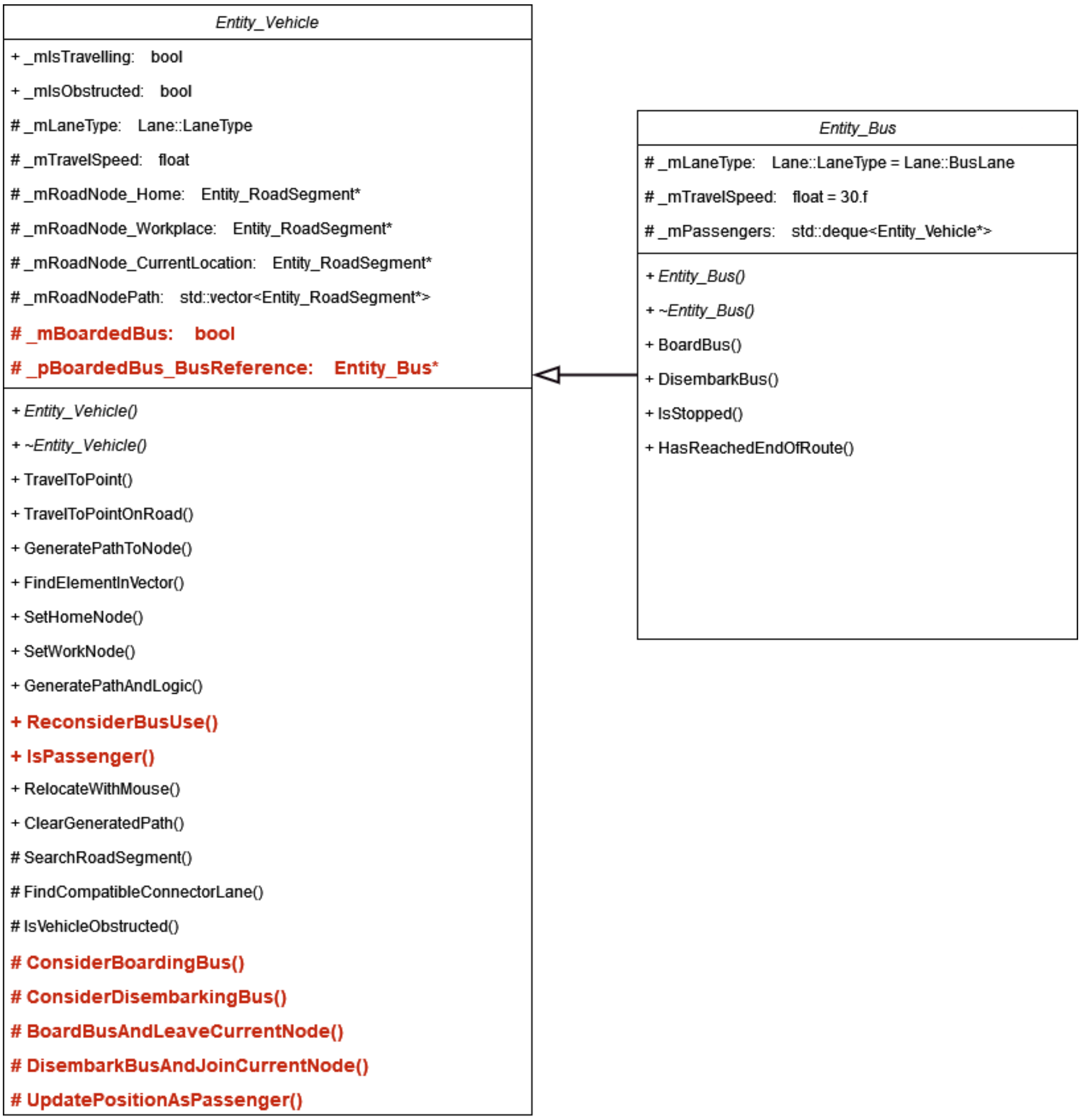


Fig. 8 A Class Diagram of Entity_Bus and its bus-specific properties.

As standard vehicles must board and disembark buses, along with knowing when to do so, *Entity_Vehicle* underwent additions (see *Fig. 8*) and *Entity_Bus* gained functions enabling passengers (non-bus vehicles) to board and disembark buses. To incorporate bus travel, communication between buses and potential passengers was required; thus, buses communicate when they're accepting passengers via the *IsStopped* function, whereas passengers possess *_mBoardedBus,* detailing whether they're a passenger, and *_mBoardedBus_BusReference* for accessing the functions of boarded buses. Additionally, passengers possess functions (shown in red) regarding embarkment and disembarkment, verifying whether they can board buses and when to disembark to avert passing their destination.

With these additions, vehicles could reconsider their travel mode, performing the decision-making algorithm described in *section 4.4*. Each morning, vehicles call *ReconsiderBusUse* before travelling, performing the flowchart of actions within *Fig. 4*. Utilising variables containing the commute times for different vehicles from *Manager_Vehicles*. These vehicles compare bus and car commutes, ranking the speed of bus travel to car travel on a scale of one to ten, decimals included. Comfort values in cars are then multiplied to matching scale, and the two rankings are compared. The comfort value ranking higher results in the vehicle travelling by car; otherwise, the vehicle commutes via bus travel.

5.4 | Milestone 3: Implementation of Direct User Interaction

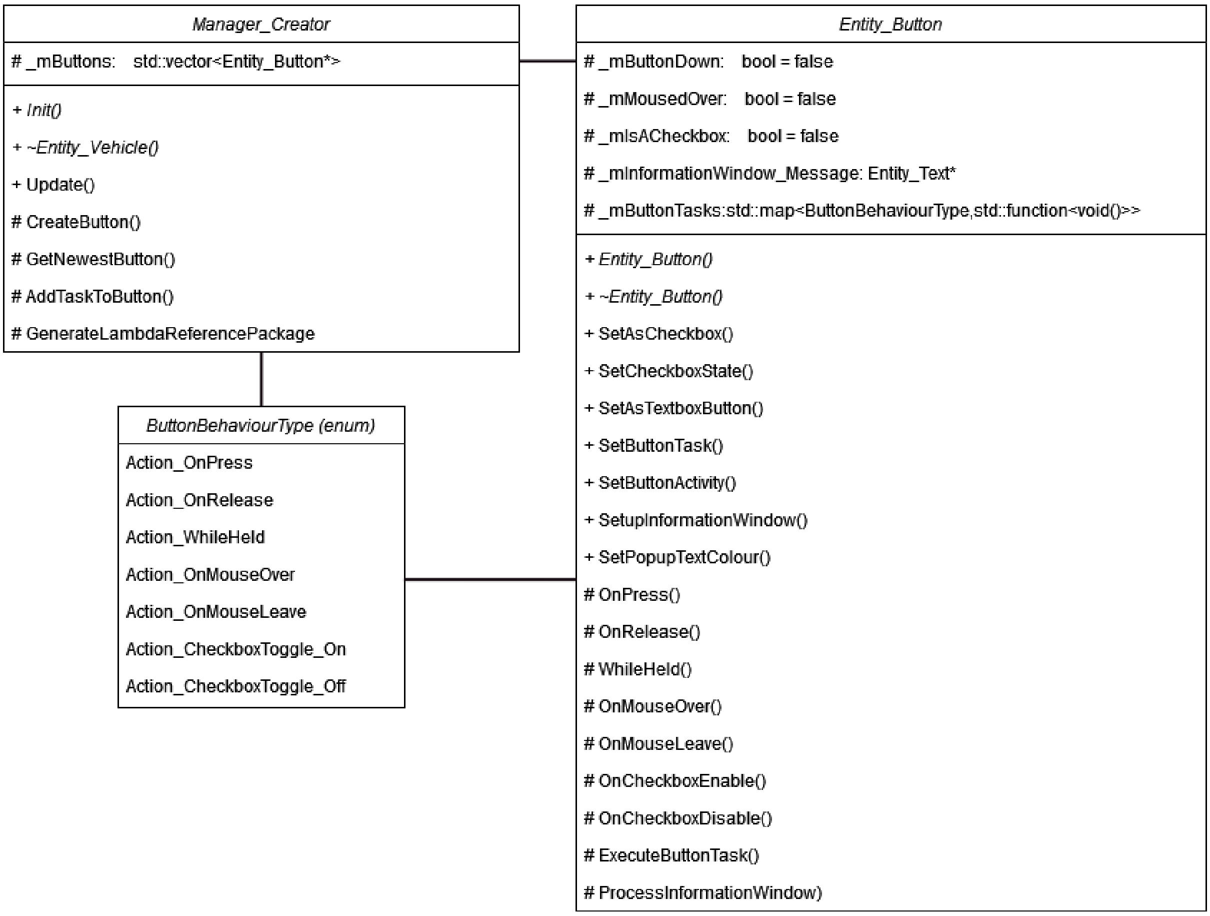


Fig. 9 A Class Diagram of Entity_Button and *Manager_Creator.*

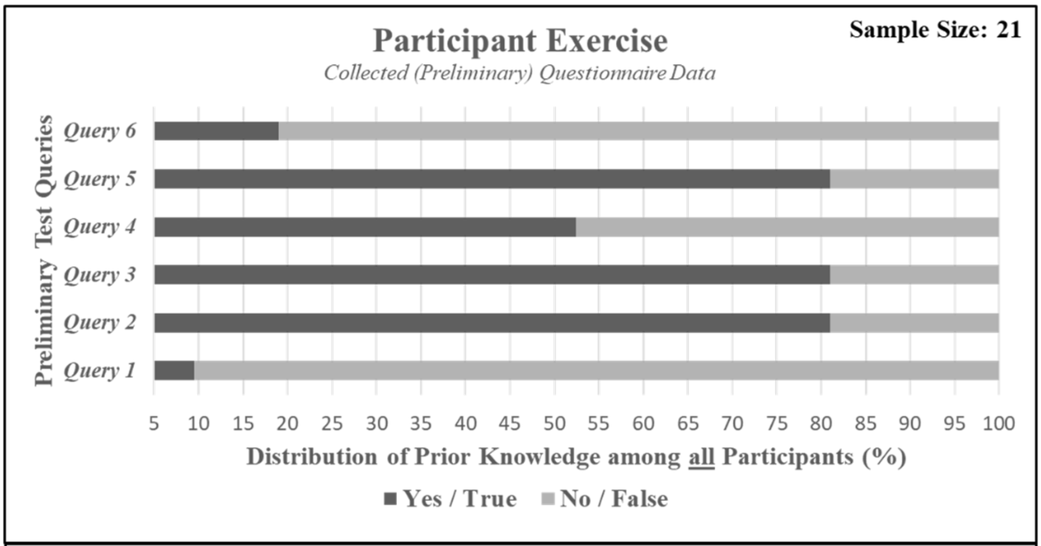
Primarily facilitating simulation interaction are button entities, managed by a "creation" manager. These buttons can be pressed, released, and held down with the mouse button; alternatively, they can be treated as checkboxes, switching between on and off states. Button functionality is assigned as lambda functions via *SetButtonTask*, allowing for different actions between pressing and releasing, etc. Users can move their cursor over a button to display a tooltip detailing its functionality, set using *SetupInformationWindow*. With these buttons, an introduction of the software's controls, via clicking buttons to advance sequences of textboxes, was created to familiarise users with interaction with the software. This introduction covers the utilisation of the statistics and lane-editing panels shown in *Appendix C*. The former displays information vehicles use in their decision-making, including the average and longest commute times of buses and cars. The latter appears when roads in the simulation environment are clicked, displaying the lanes within the road and allowing users to both view and add or remove these lanes. Together, these two panels form the backbone of the user's interaction, as they allow the user to modify the simulation environment, observing the impacts of these modifications with both moving vehicles and explicit numbers.

6. Evaluation

6.1 | Evaluating the Efficacy of the Software

Comparing the software's efficiency in communicating ITD with conventional means required collecting both qualitative and quantitative data. The flexibility of data collection methods such as questionnaires and surveys garner immediate comfort and understanding from participants, as they are often familiar with these surveys from prior experience or knowledge. Furthermore, the anonymity and informality of surveys can entail more honest answers. Therefore, by having a combination of closed-ended and open-ended questions, the survey contains respondent elaborations regarding their reasoning surrounding multifaceted questions. Despite this, data originating from opinions has a high likelihood of being subjective and thus superfluous. Yet, to evaluate interactive educational software, user experience is essential for evaluation. Hence, data collection methods that accommodate both comparative analysis and subjective experiences, especially for software lacking existing examples for comparison, become valuable for gathering informative data. This mixing of quantitative and qualitative methods warrants both statistical and thematic analysis of the collected data. Thus, these data collection approaches lead to an Experimental Research Design. These designs entail assigning groups of respondents to separate data collection assessments, enabling comparative analysis between respondent groupings. For instance, dividing respondents into interactive and non-interactive learning groups would allow for a comparison that would not be possible with a single group of participants. For this project, this interactive learning group consists of respondents assigned to use interactive education software to learn and understand ITD.

The research exercise was performed via an online website for accessibility. Participant were split into three groups, all having access to two questionnaires: one querying their ITD knowledge prior to the learning exercise, and one after. Within said exercise, all groups had access to a text explanation of ITD. However, participants within Group A additionally had access to the software solution, whereas Group C had diagrams visualising ITD. Group B included no additional material, serving as the baseline in the later comparison between the three groups. Each group was given access to the website with different weblinks; the website being structured such that participants could not access another group's resources. Upon completion, participants were instructed to email their complete questionnaires, alongside their signed consent form.



Query 1 - ***Were you aware of terms such as "Induced Traffic Demand" before this study?***
Query 2 - ***Adding lanes to a road mitigates traffic congestion on said road.***
Query 3 - ***Do you believe people choose cars over bicycles because cars are faster?***
Query 4 - ***"Traffic congestion happens due to rush-hour traffic."***
Query 5 - ***"Traffic congestion happens due to human-made decisions when driving."***
Query 6 - ***"Traffic accidents are the most impactful factor in causing traffic congestion."***

Fig. 10 Resulting data from the Preliminary Questionnaire performed prior to each group's exclusive teaching exercise.

Interestingly, the findings—illustrated by *Fig. 10*—show most participants lacking knowledge of ITD, yet, nearly all agree congestion originates from human-decisions rather than chiefly traffic accidents or rush hour; this suggests a correct consensus of congestion as a human-generated phenomenon. Additionally, when asked, nearly all participants provided adequate descriptions of traffic congestion, based upon their own understandings, yet commonly citing commuter driving habits, changes in speed and reaction times as triggers. Furthermore, responses to Query 2 insinuates that although participants view congestion as primarily human-oriented, road widening is a viable solution; likely due to being unaware of ITD, as few disagreed with Query 3.

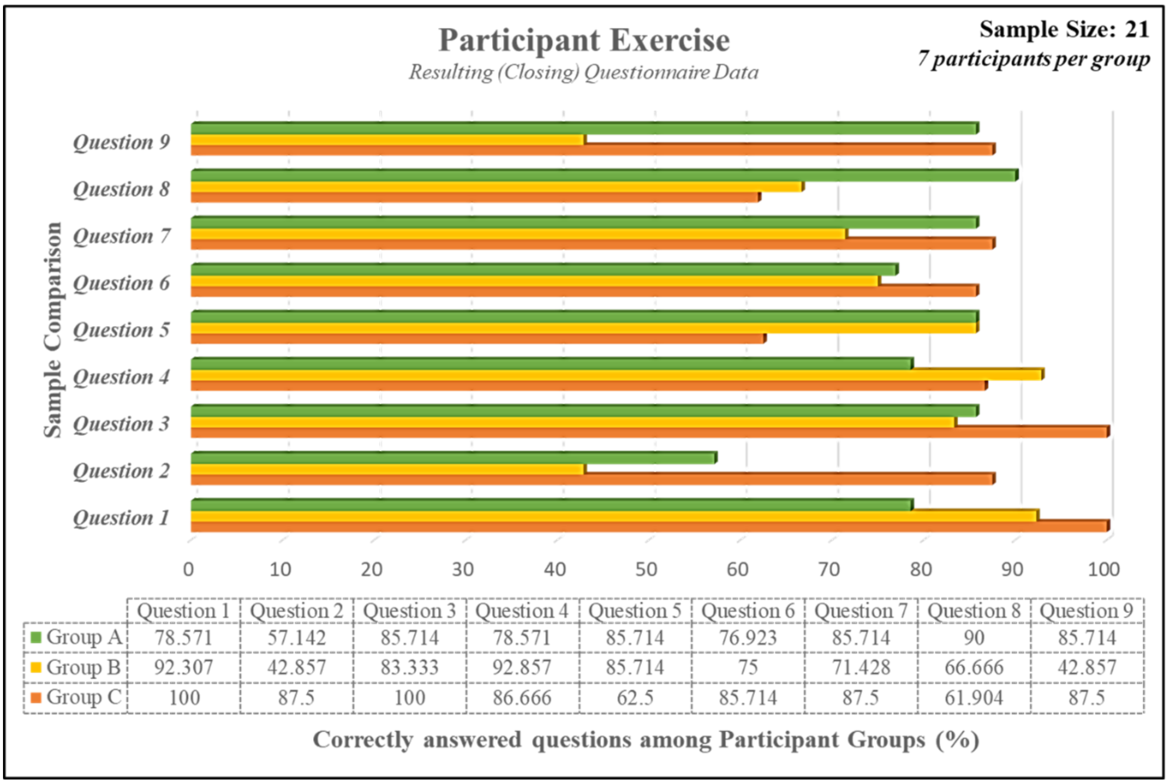


Fig. 11 Resulting data from the Closing Questionnaire performed after each group's exclusive teaching exercise.

The data illustrated in *Fig. 11*, shows an overall improvement in understanding of ITD as an outcome of all exercises. Alongside *Appendix D*, this chart suggests Group A participants exhibit superior understanding of road widening repercussions and travel modes, yet Group C exhibits superior overall understanding of ITD. Despite this, both groups broadly performed better than Group B, demonstrating that their visualisations did increase ITD understanding. When asked about their experience, 85% of participants felt they would've been unable to answer the questions within *Fig. 11* without the exercise, with all groups consequently expressing high confidence in their understanding. Nevertheless, only participants from Group A exhibited further interest in learning about ITD.

When asked, $^{1}/_{7}$ of Group A found understanding how to use the software difficult, whereas $^{4}/_{7}$ experienced difficulty using the software. Regardless, $^{5}/_{7}$ of participants agreed that the software assisted their learning, citing that visualisations outshine reading and enjoying observing their actions' consequences. These findings suggest that while Group C performed marginally better, the software utilised by Group A appears to have assisted understanding via interactive visualisations, as hypothesised. However, the total sample size likely had noteworthy sway over these results; a larger sample size could yield more definitive data.

6.2 | Project Reflections

Overall, this study was informative on the efficacy of interactive mechanisms in teaching ITD, demonstrating that these mechanisms can communicate complex mechanics comparably to conventional methods, even with prototype software. However, the software could have walked through ITD more thoroughly by reacting to the outcomes of user actions with explanations of what transpired. Additionally, cut features could have further enabled discovery learning had they been worked into the user experience. ITD demonstrations within the software could have been more realistic; however, improving this may have no clear educational yield. Regarding data collection, online forms could have served as an alternative to the website, increasing accessibility. Yet, the custom website provided flexibility, facilitating file downloads and the exercise's segmentation. More aspects of this study could have been better performed, as there were multiple development challenges. Nonetheless, this study has demonstrated the value of using interactive software for ITD communication, as utilising a software prototype to support this conclusion was the aim of this study.

6.3 | Further Research Potential

The aforementioned benefits and shortcomings of this study together serve as a valid basis for further research surrounding this topic, especially considering research regarding interactive software for communicating traffic mechanisms is scarce. Additionally, more sophisticated software, potentially modelling traffic lights and intersections, would serve as a more definitive demonstration of how such interactive software could serve in a public educational context. Approaches studying how interactive software should be designed to best communicate ITD and how these can be distributed to have an impact are also ideal continuations of this research, as promoting urban planning knowledge, including ITD, was an instigator for this study.

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Appendices

Appendix A

Pseudocode demonstrating a portion of the Decision-Making Algorithm.

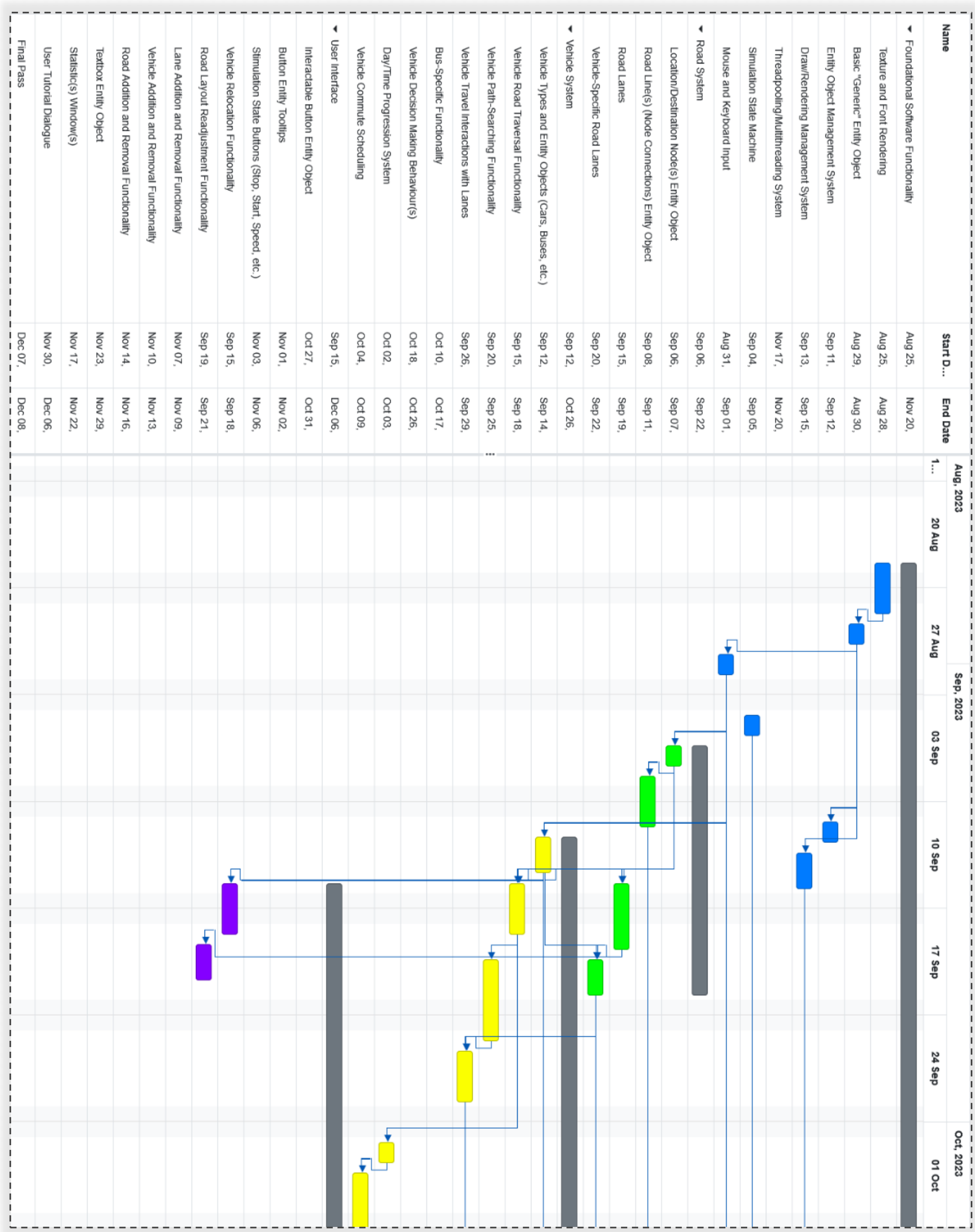
Algorithm 1: Vehicle Type Reconsideration

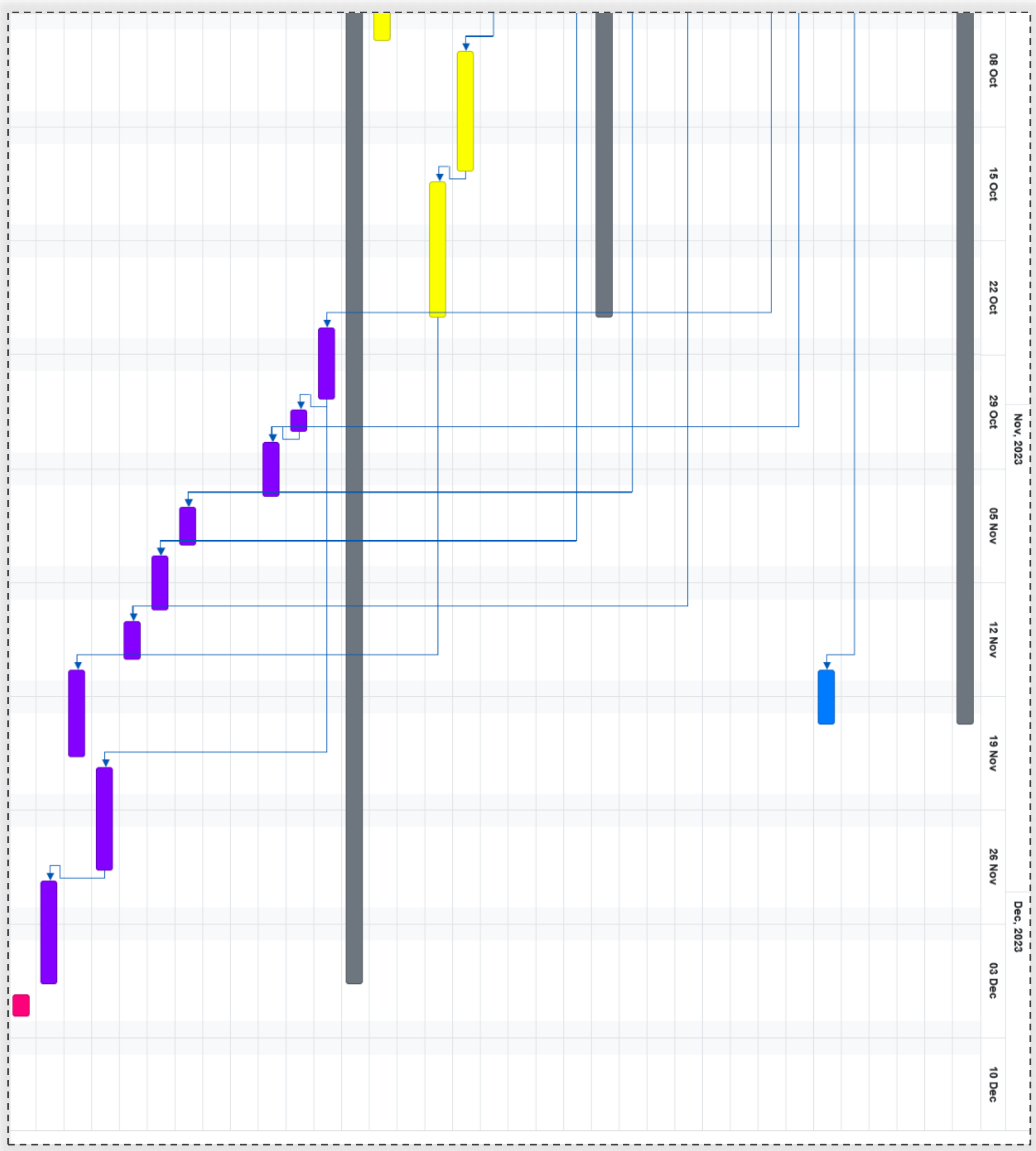
Input: *carCommuteTimes*, *busCommuteTimes*, *vehicleComfort* (all floating point numbers)
Output: *vehicleType* (an enumerated type)

```
if carCommuteTimes >= busCommuteTimes then
    C ← carCommuteTimes × (1 - vehicleComfort)
    if C >= busCommuteTimes then
        return vehicleType ← Bus
    else
        return vehicleType ← Car
    endif
else
    return vehicleType ← Car
endif
```

Appendix B

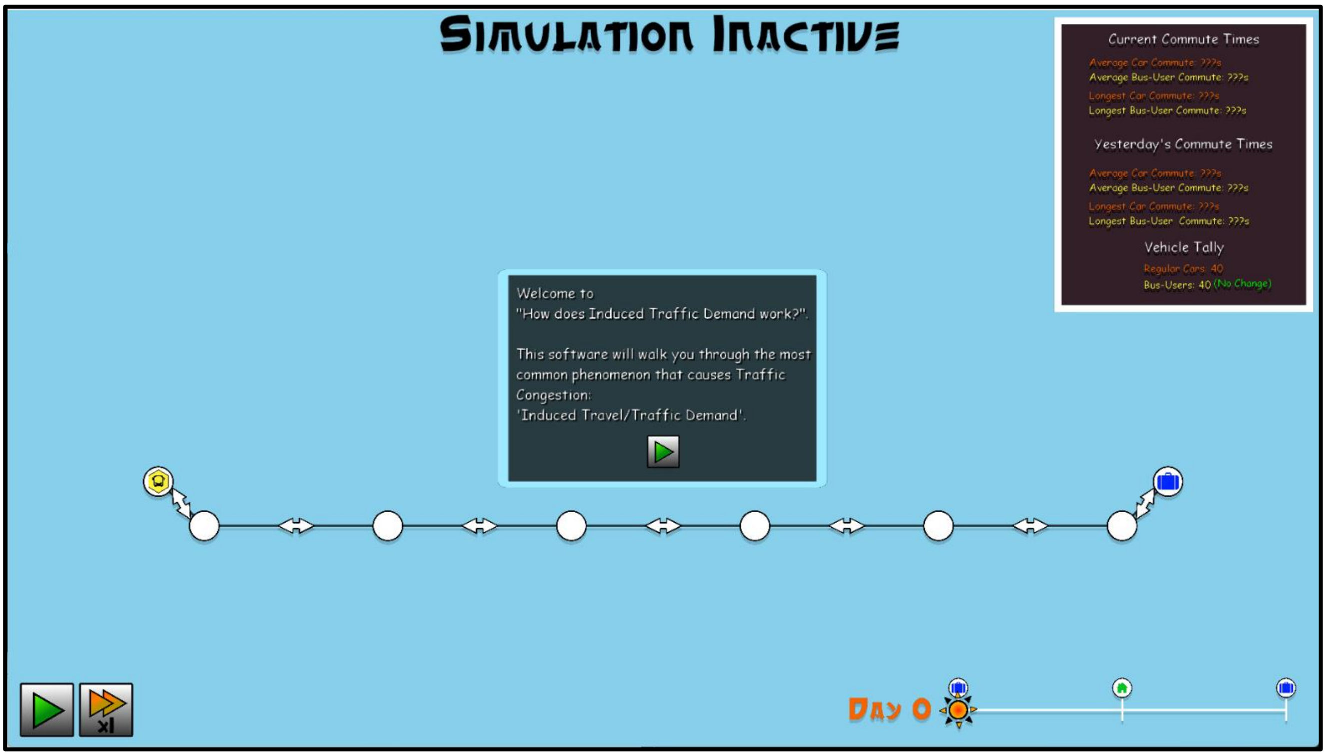
A Gantt Chart conveying the dependencies between features along with the completion dates for these features. Graphic has been outlined for readability.

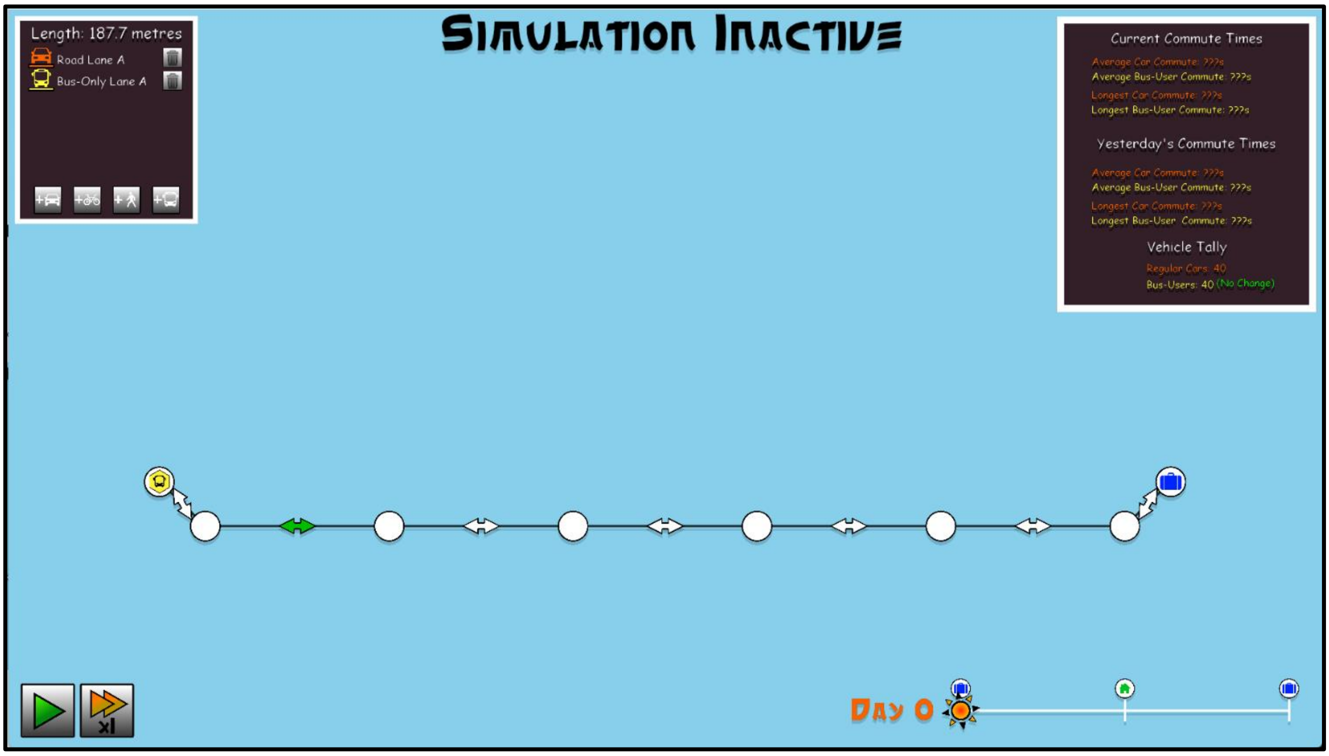



08 Oct
15 Oct
22 Oct
29 Oct
Nov, 2023
05 Nov
12 Nov
19 Nov
26 Nov
Dec, 2023
03 Dec
10 Dec

Appendix C

Screenshots of the final prototype's program window, displaying the tutorial run-through, statistics, and lane editing panels, as well as the overall layout of the simulation environment.





Appendix D

The questions which participants answered during the closing questionnaire(s) segment of their involvement. Underlined sections indicate correct answers. The results of these questions are exhibited within Fig. 11.

1) What are the main factors real-life commuters often considering when choosing their travel route?
   Choose two from: *Comfort, Travel Time, Vehicle Maintenance, Lane Count, Fuel Costs, Road Quality.*

2) When a driver (who is driving a car) changes their route to another that is faster, what is this called?
   Induced Travel, Diverted Travel or Directed Travel?

3) "■■■■■ the road capacity of a road induces more congestion, whereas ■■■■■ road capacity induces less congestion by ■■■■■ supply for this road–leading to vehicle demand not being met."
   Please write down the three words that are missing from this paragraph. Synonyms are acceptable.

4) Which of these road changes can trigger Induced Traffic Demand related phenomena?
   Choose two from: *Adding Lanes, Adjusting Speed Limit, Removing Bus Lanes, Removing Lanes, Traffic Accidents, Adding Bus Lanes.*

5) "Increasing road capacity is a harmful practice and expansion projects should never be performed."
   True *or* ***False****?*

6) What do buses, trains and trams have, that cars don't, that makes them less likely to trigger Induced Traffic Demand related phenomena?
   Check two from: Is more cost effective, Has larger carrying capacity, Has larger size, Is public transport, Bypasses congestion.

7) "Increasing road capacity has no effect in solving congestion at any point in time."
   True *or* ***False****?*

8) What other modes of transport are **NOT** influenced by traffic congestion resulting from cars?
   Choose two from: *Cycling, Tram-lines, Railways, Bus-lines, Footpaths, Automated Vehicles.*

9) "Commuters value comfort when choosing their mode of transport."
   True *or* ***False****?*

Appendix E

The project's Commit Log, exhibiting the development of the software solution.

Author	Commit	Message	Date
Joe Mumford	deadfef	Removed unused DirectXTK versions.	1 hour ago
Joe Mumford	08115c8	Moved the original source for the .dds sprites out of the bin folder.	2023-12-12
Joe Mumford	9d5d863	Removed redundant .cpp and related functions.	2023-12-10
Joe Mumford	2006026	Collated manager access into one class inside CommonVars. Finished the software tutorial segment.	2023-12-10
Joe Mumford	75d3274	Added extra flexibility to the tutorial flagging system.	2023-12-09
Joe Mumford	ce15ec5	Fixed issues with choice-weighting system, and with the current distribution it reaches equilibrium - the same equilibriu...	2023-12-09
Joe Mumford	23c2450	Began implementing the new choice-weighting system - but it too quickly and drastically changes to buses when they ar...	2023-12-08
Joe Mumford	2d51d93	Fixed aforementioned issue, but flags seem to have little to no effect for unknown reasons.	2023-12-08
Joe Mumford	6ea3a6c	Began working on the software introduction tutorial's text as well as the tutorial flagging system to disable/enable cert...	2023-12-08
Joe Mumford	d4e6446	Misc. additions and changes.	2023-12-07
Joe Mumford	2aa34fc	Added Background and Text Colour options to struct TextboxContent. Began work on the Software Introduction conten...	2023-12-06
Joe Mumford	05259cc	Successfully tested the textbox system, however functionality regarding scaling accuracy and making the text position co...	2023-12-05
Joe Mumford	457dab1	Began laying the foundation for Entity_Textbox, for future use as a teaching and tutorial system for users.	2023-12-05
Joe Mumford	b6b7dc0	Implemented an icon into the program window and updated the window text.	2023-12-04
Joe Mumford	8b74131	Implemented the speedup button's sprite and updated some fonts. Note: There seems to be input lag affecting click fun...	2023-12-04
Joe Mumford	809e9a0	Changes related to releasing resources, however D3D11 WARNINGs remain.	2023-12-04
Joe Mumford	2d46a4f	Implemented threading into renderList and entityList, but it's been disabled due to current crashes. This doesn't solve th...	2023-12-04
Joe Mumford	c4685da	Successfully solved aforementioned issues with commute time accuracy, however the vehicles becoming stuck remains.	2023-12-03
Joe Mumford	987b6a4	After displaying the longest commute times of bus-using and non-bus-using cars, it seems like commute times aren't acc...	2023-12-03
Joe Mumford	8a5901d	Implemented more clarity with a bus boarding indicator and vehicles attempting bus travel using a different colour.	2023-12-02
Joe Mumford	4344824	With the aid of the statistics window, changes were made to make ITD more apparent. A key issue at the moment contin...	2023-12-02
Joe Mumford	120ac43	Implemented statistics window that displays current and prior commute times as well as the number of vehicles; done tw...	2023-12-02
Joe Mumford	5713efa	Various simulation and QOL modifications. However, vehicles are unable to join / do not join buses waiting at the ends ...	2023-12-01
Joe Mumford	64a6b3a	Program closed without crashed, however the output flags various unreleased active objects. These must be released be...	2023-12-01
Joe Mumford	addd881	Fixed catch-22 bug and implemented various simConsts. Currently there needs to be a system/check that prevents crashe...	2023-11-30
Joe Mumford	1f84e94	Cars can fully use bus functionality, both boarding and disembarking at logical times. Catch-22 still exists, but now ...	2023-11-30
Joe Mumford	e203334	Commiting current progress with implementing vehicle interaction and use with/of buses. Issues remains.	2023-11-30
Joe Mumford	572f0d0	Implemented bus behaviour - moving between stops and waiting for a period of time on them. Key Note: The issue...	2023-11-29
Joe Mumford	f4d1580	Began laying the groundwork for bus implementation and configured the project to correctly work in release. DO ...	2023-11-29
Joe Mumford	7c02e9e	Increased car count to 100, as this will be the final number. KEY NOTES: Vehicles going in different directions on the...	2023-11-28
Joe Mumford	5363749	Created workaround to fix aforementioned vehicle queuing issues.	2023-11-28
Joe Mumford	69bfbf8	Reverted SearchRoadSegments to older version, as new changes yield different, incorrect results. Note: Vehicle que...	2023-11-27
Joe Mumford	5b6baee	Implemented more missing sprites.	2023-11-27
Joe Mumford	d7d4625	The aforementioned connector issue has been better tested while beginning the simulation in the new default lay...	2023-11-27
Joe Mumford	075def4	Rewrote SearchRoadSegements to be neater and better implemented. Filled in function body of it's LeastCongestio...	2023-11-27
Joe Mumford	a61bb5f	Info Window updates.	2023-11-26
Joe Mumford	668bc25	Implemented vehicle acceleration and decceleration. As well as the number of vehicles in a lane within the informati...	2023-11-26
Joe Mumford	34bcc0e	Tidying header.	2023-11-26
Joe Mumford	421a826	Created function declaration for SearchRoadSegments_LeastCongested(), that was unstaged in last commit.	2023-11-26
Joe Mumford	fd9f97d	Implemented new capacity system. ALBEIT, there are some key features that need to be implemented / addressed to ...	2023-11-26
Joe Mumford	09d866b	Fully implemented obstruction system, however vehicles need to search be alternative routes if they are obstructed ...	2023-11-26
Joe Mumford	bbec9d0	Added x20 as a speed multiplier option.	2023-11-25
Joe Mumford	a86ddc8	Implemented a basic "Obstruction" system to simulate congestion. As of now however, the logic behind whether a ...	2023-11-25
Joe Mumford	f990a21	Fixed road node creation ignoring maxLengthPercentage limits.	2023-11-24
Joe Mumford	e825a18	Removed ability to resize program window due to foreseen time constraints in implementing proper window resizi...	2023-11-24
Joe Mumford	0302e30	Updated random usage for gravitySprite initialisation with deconstructors to be correctly used/initialised.	2023-11-20
Joe Mumford	b171004	Make road distance and vehicle speed measurement systems consistent with each other. (1)	2023-11-20
Joe Mumford	d2ed18a	Fixed oversight where vehicles were not returning to their starting location after ending the simulation when funct...	2023-11-19
Joe Mumford	bb35a81	Implemented basic simulation speed-up functionality.	2023-11-19
Joe Mumford	0427bfe	Implemented lane addition and deletion functionality to the information window.	2023-11-19

JM	Joe Mumford	5e55b22	Fixed issued mentioned in commit [f340736].	2023-11-19
JM	Joe Mumford	27044c8	Solved a crash that resulted from Entity_Text's Constructor Parameters (specifically text list parameters) being lost; this wa...	2023-11-18
JM	Joe Mumford	60e96fc	Changed duplicate lane names to use letters ("Road Lane A" and "Road Lane B") instead of numbers ("Road Lane 1" and "...	2023-11-18
JM	Joe Mumford	f340736	Implemented more functionality for the information window, which will be used to view, edit, create and delete lanes fr...	2023-11-18
JM	Joe Mumford	412bc23	Successully implemented basic functionality for the new connector information window. However, certain issues, featur...	2023-11-18
JM	Joe Mumford	6d3e098	Fixed aforementioned issue, which resulted from one line of outdated code.	2023-11-17
JM	Joe Mumford	8461bc2	Renderlist addSprite bug quick commit.	2023-11-17
JM	Joe Mumford	f883832	Made updates to creator and button system to support more features and functionality.	2023-11-10
JM	Joe Mumford	292679c	Changes that allow the program to be developed on other PCs more smoothly. This branch will primarily be for compati...	2023-11-09
JM	Joe Mumford	8418f09	Built functionality that will enable vehicles to react to their nodes being deleted. I just need to find a method to disting...	2023-11-09
JM	Joe Mumford	3b64161	Fixed aforementioned issues: Node deletion works now, this required some combination of both iterator (++iterator) an...	2023-11-08
JM	Joe Mumford	d801847	Major Note: I've been doing inheritance wrong, and have been running duplicate code by calling both parent and child ...	2023-11-06
JM	Joe Mumford	70101c7	Fixed aforementioned issues, and deleting connectors works fine. But deleting nodes is coming with its own bug-fixing ...	2023-11-05
JM	Joe Mumford	8ee693d	Implemented connector deletion using the button, and both nodes and connectors turn red when in deletion mode an...	2023-11-05
JM	Joe Mumford	5feebd5	Fixed aforementioned crash, now the popup window works as expected - albeit with not perfect background window s...	2023-10-30
JM	Joe Mumford	35837f7	Made significant progress in developing the versitility of the button class, including the ability to pass a bundle of point...	2023-10-29
JM	Joe Mumford	0a9bd93	Updated hover windows for roads and removed unneeded information.	2023-10-28
JM	Joe Mumford	f4f37dc	Vehicles now call ClearGeneratedPath() when arriving at their destination, freeing up capacity in the connector they just ...	2023-10-23
JM	Joe Mumford	384f25a	Fixed aforementioned bug, which was due to fetching a list ID from renderList for use in entityList. This has been fixed vi...	2023-10-23
JM	Joe Mumford	ab55d89	Implemented functionality to the button class, it just needs sprites for non-checkbox button visuals. Organised header c...	2023-10-23
JM	Joe Mumford	280a8c0	Updated .gitignore to no longer exclude sprite and spritefont assets.	2023-10-20
JM	Joe Mumford	2ee7963	Fixed aforementioned issue by having the generation occur once the vehicle has reached the next node on it's path.	2023-10-16
JM	Joe Mumford	5d757da	Vehicles now travel between home and work with the day system. One major issue however is that vehicles stop their cu...	2023-10-16
JM	Joe Mumford	832319a	Implemented the day UI to display the day progress. Still finalising functionality for vehicles to return home.	2023-10-15
JM	Joe Mumford	13914be	Gave the same aforementioned ability to have shadows to Text and Text_Entity as well.	2023-10-15
JM	Joe Mumford	80c33a1	Implemented the beginning of the scheduling system and beginning tests on it. However, the UI is being developed to ...	2023-10-15
JM	Joe Mumford	3a24493	Fixed an crash with deleting all connectors of a node when the node has more than 1 connector. Notes: Observed issue...	2023-10-09
JM	Joe Mumford	1805010	Fixed the aforementioned "weird vehicle path generation issue", nodes that had a pointer to the deleted node in their _...	2023-10-09
JM	Joe Mumford	33bb59d	Nodes can now be successfully deleted, but there is still work to be done: - Vehicles on deleted nodes need to also be ...	2023-10-09
JM	Joe Mumford	7d4b427	Made significant progress in implementing deletion functionality. Currently, the hurdle is solving the mystery of an enti...	2023-10-09
JM	Joe Mumford	676dee6	Successfully fixed all compiler errors, the new entity system has been implemented. Now working on finishing deletion f...	2023-10-08
JM	Joe Mumford	c29924d	Partially implemented the node, connector and lane deletion functionality before realising that entityLists require some ...	2023-10-08
JM	Joe Mumford	abc9067	Made progress on implementing the window scaling functionality. Currently the mouse interacti... WindowResizing	2023-10-06
JM	Joe Mumford	9b08d1b	Beginning of the WindowResizing Branch for properly implementing window resizing and rescali... WindowResizing	2023-10-05
JM	Joe Mumford	ef3411b	Commented out some code that is contributing to crashes on exit.	2023-10-05
JM	Joe Mumford	bfbd2e1	The path generation function now recognises and considers two-way connectors.	2023-10-05
JM	Joe Mumford	0f1c1ad	Warning reduction related changes.	2023-10-05
JM	Joe Mumford	0f9a6c9	Misc. changes.	2023-10-05
JM	Joe Mumford	1de9271	Fixed both the issue where "vehicles can relocate to nodes that collide with their current one", as well as "connectors be...	2023-10-05
JM	Joe Mumford	8418674	Updated sprites for vehicles, but noticed that in creation mode that vehicles can relocate to nodes that collide with thei...	2023-10-03
JM	Joe Mumford	5338bd4	Successfull implemented the ability to move vehicles around with the mouse. However, there are issues with vehicles no...	2023-10-03
JM	Joe Mumford	7cbf767	Began implementation of vehicle relocation functionality, while also updating some debug messages further. The imple...	2023-10-02
JM	Joe Mumford	b4b30b0	Made the renderLayer system easier to use with enums, allowing values to be more consistent and easily changable. Ad...	2023-10-01
JM	Joe Mumford	eb40e4c	Implemented the ability to have the position of new nodes snap to a invisible grid while holding Space when dragging ...	2023-10-01
JM	Joe Mumford	0e7b39b	Updated node sprites and related code to better display destinations (instead of a blue node, the node has a blue suitc...	2023-09-30
JM	Joe Mumford	0afdf1b	Implemented checks to prevent multiple redundant connectors existing, such as having multiple connectors linking two...	2023-09-29
JM	Joe Mumford	5cbee9d	Made attempts to properly fix the opposite arrow issue for connectors. This failed, but kept the "reverseRelationship" a...	2023-09-17
JM	Joe Mumford	7d79870	Began creation of button entities and their future integration within the Creator Manager, which manages the UI the u...	2023-09-17
JM	Joe Mumford	e42db73	Fixed aforementioned issues, but I've noticed (thanks to the arrows on the connectors) that the linking dragging syste...	2023-09-16
JM	Joe Mumford	0050106	Technically fixed the tapping not working properly by moving KeyEvent_Tap inside WM_KEYUP instead of WM_KEYDOW...	2023-09-16

JM	Joe Mumford	50c85f5	Reminder commit here: Bug A - Occupants seems to jump up twice instead of once on the first traversed connector. Bug ...	2023-09-15
JM	Joe Mumford	c4822e4	Got the vector of text displaying, through this was tested with only a single lane. This will now be turned into a list with...	2023-09-15
JM	Joe Mumford	e16d7cb	Improved previous commit's implementation by moving some of the functionality into the connector itself, allow it to ma...	2023-09-15
JM	Joe Mumford	8fae03b	Implemented the body of the RemoveConnectorLane function(s). These are untested but will be tested when a delete bu...	2023-09-15
JM	Joe Mumford	c2d4d88	Introduced all of the vehicle functionality developed with the bicycle entity to cars and pedestrians, with cars now havin...	2023-09-15
JM	Joe Mumford	8a9a4c8	Fixed the text rendering issue, incorrect values were being passed due to resolution adjustments being due in the Entity...	2023-09-14
JM	Joe Mumford	20fb9ff	Made text centering more consistent after calling Entity_Text::SetTextString() on initialisation of an Entity_Text entity. Not...	2023-09-12
JM	Joe Mumford	d3e4ffd	Fixed some bugs and oversights, mainly missing intialisations as well as adding entity_text to the TextEntityList when cre...	2023-09-12
JM	Joe Mumford	2ffcf86	Implemented one-way arrow sprites to replace the circle node sprites for connectors, as well as the functionality that ma...	2023-09-11
JM	Joe Mumford	508e3c0	Set up a forking situation and performed a succesful split-road logic test. There were some bugs however such as on re-...	2023-09-11
JM	Joe Mumford	e2f6c57	Submitting aforementioned "renderMe" changes, as they were not staged.	2023-09-10
JM	Joe Mumford	76535c8	Making steps in getting text to work with the information window but currently for some reason the text isn't succesfull...	2023-09-10
JM	Joe Mumford	b7fddc2	Implemented the appearance and disappearance of the background for the information window.	2023-09-10
JM	Joe Mumford	88e0c08	Began implementation of mouse-over information panels for connectors and will likely do something similar for nodes t...	2023-09-09
JM	Joe Mumford	59c127e	Successfully implemented the node creation and node linking functionality discussed in last commit. Haven't performed ...	2023-09-09
JM	Joe Mumford	e09c73f	Implemented the line visual functionality for the future feature of the user able to make new links and nodes. It works a...	2023-09-09
JM	Joe Mumford	7769882	Fixed pathing issues but adding more new checks and adjustments to the SearchRoadSegments() function, which now s...	2023-09-08
JM	Joe Mumford	6f08c59	Fixed texture data issue by storing connectors as pointers. Pathing isn't fixed after checking, which seems to be due to n...	2023-09-07
JM	Joe Mumford	554e4b1	Pathing is fixed in theory as it was an oversight in not properly creating connectors with new nodes. However when a n...	2023-09-07
JM	Joe Mumford	9bba0f0	Implemented the following functions in Manager_Road for initialising singular nodes: CreateNewUnlinkedNode(), Link...	2023-09-07
JM	Joe Mumford	832f81e	Defined some framework functions for future user interaction and simplied calling Manager_Road's CreateRoad functio...	2023-09-06
JM	Joe Mumford	1bd5d48	For observations, previous issue due to an oversight in not setting a non-zero vehicle capacity for connector lanes on in...	2023-09-05
JM	Joe Mumford	7ade4c5	Fixed aforementioned compiler issues, but currently the lane compatibility checks are being ignored somehow.	2023-09-03
JM	Joe Mumford	b71c01c	In the process of lane functionality, adding checks that prevent vehicles for taking connectors that lack compatible rout...	2023-09-03
JM	Joe Mumford	a42101b	Introduced more colours and a "setTransparency" function for the Sprite class.	2023-08-31

JM	Joe Mumford	5cd5e14	Fixed colour issues, the namespace variables were not being correctly initialised. This led to White (1,1,1,1) (in rgba) bein...	2023-08-31
JM	Joe Mumford	94d2bb1	Fixed aforementioned issue, but learnt that the hacky Tapping Input doesn't respond to just the requested key, but all k...	2023-08-31
JM	Joe Mumford	99ad2f1	Bug fixing, has only tested a linear road without forks. Currently still fixing issue where vehicle doesn't stop after arrivin...	2023-08-31
JM	Joe Mumford	8ece847	Attempted to isolate the input of tapped input from held inputs, though held inputs still interfere. This works as is for n...	2023-08-31
JM	Joe Mumford	4688f05	Vehicles can now travel to a given target node, the path to this node is found using recursive functions. The function d...	2023-08-30
JM	Joe Mumford	13275d9	Fixed aforementioned issue in last commit. Now moving onto other previously mentioned features and issues that have...	2023-08-29
JM	Joe Mumford	15d58cb	Reworked road node connector system to allow for future full implementation of multiple connectors from one node an...	2023-08-29
JM	Joe Mumford	50d5b6c	Implemented Text functionality and ran successful tests on vehicle movement. Current challenges include fixing colours f...	2023-08-29
JM	Joe Mumford	f963db5	Implemented Entity_Text class and text rendering system, however currently text isn't displaying for unknown reasons.	2023-08-28
JM	Joe Mumford	7358d48	Initally begun to create functionality around shortest path algorithms. These algorithms will likely be used in some form ...	2023-08-27
JM	Joe Mumford	7050369	Made use of the state machine, creating the framework for the "Edit/Create" and the "Active Simulation" modes.	2023-08-26
JM	Joe Mumford	7834da9	Implemented Lane framework inside Manager_Road. Began implementation of an ActivityManager for day-to-day comm...	2023-08-26
JM	Joe Mumford	3db0985	Successful test of Vehicle Initialisation.	2023-08-26
JM	Joe Mumford	41ecd68	Finished construction of Manager_Vehicles and subsequent child entity classes of ent_vehicles.	2023-08-25
JM	Joe Mumford	c596694	W.I.P implementation and reorganisation of vehicles inside a vehicle manager. ToDo: MpH w/ Road Length Calculations ...	2023-08-25
JM	Joe Mumford	0fa8f42	Imposed a maximum connector length, limiting the distance nodes/segments can be from their neighbours.	2023-08-22
JM	Joe Mumford	781d50b	Fixed issues by revoking the segments' sprites' "OneTimeRender" status.	2023-08-22
JM	Joe Mumford	5342b34	Fixed and thus fully implemented the segment connector system. Currently the colour of the nodes isn't being successfu...	2023-08-22
JM	Joe Mumford	a0cd3e7	Made progress with segment connectors, just need to fix angle adjustment to account for non 1:1 aspect ratios.	2023-08-21
JM	Joe Mumford	6790f90	Made significant progress with getting segments to run with new system, now moving onto segment connector implem...	2023-08-21
JM	Joe Mumford	1427d75	Attempted to fix issues with line drawing, perhaps implementing the "next segment" system within segments would be a...	2023-08-19
JM	Joe Mumford	a3ed68a	Made progress in fixing previous issues by transforming ent_road into a Manager (mngr_roads). This mades more sense ...	2023-08-19
JM	Joe Mumford	cec0eb1	Attempted to fix current issue with retaining pointers to road segments within road entity, with no solutions. Must be a ...	2023-08-19
JM	Joe Mumford	65c7168	Made progress on implementing the lines that connect nodes, however it seems Entity_Road's pointers lose track of thei...	2023-08-16
JM	Joe Mumford	441b7c3	Commented out MouseEvent functionality within MainWndProc as it's now redundant.	2023-08-15

JM	Joe Mumford	d758380	Issue solved, the sleep function inside WinMain within the while loop is far too aggressive. It seems this was also causin...	2023-08-15
JM	Joe Mumford	fd5cbb9	Reclassified util_entities as group_entities within the newly created "Heading Groupings" category.	2023-08-15
JM	Joe Mumford	a62b9cc	Made attempts to fix mouse input but little progress has been made. Current changes made while attempting to fix the ...	2023-08-15
JM	Joe Mumford	ae1155a	Implemented "Only-One" functionality into more headers. Removed the usage of OrientToMouse function from the road...	2023-08-14
JM	Joe Mumford	d6bb2d7	Fixed the rotation issues from Orient to Mouse, which was due to not flipping the y-axis of the entity object's position ...	2023-08-14
JM	Joe Mumford	3d3d2d0	Fix complier errors after understanding and implmenting "Only-One Headers". Currently fixing orient to mouse issues, se...	2023-08-14
JM	Joe Mumford	0702f07	Made progress in fixing previously described issue, but it seems OrientToMouse and related functionality yields inaccura...	2023-08-12
JM	Joe Mumford	130c426	Attempting to debug mouse click detection, seems like ConvertScreenToWorldSpace doesn't 100% line up with actual w...	2023-08-10
JM	Joe Mumford	6f8304b	Fixed previous issues and made progress on implementing road system. Segment instantiation works fine, currently wor...	2023-08-10
JM	Joe Mumford	45fff82	Partially implemented road system, but there are compiler issues.	2023-08-08
JM	Joe Mumford	dc0beb7	Minor additions to ent_vehicle class.	2023-08-02
JM	Joe Mumford	212632b	Fixed various issues with inheritance, ent_vehicle currently serves as an example as too how to inherit right now. "Protec...	2023-08-01
JM	Joe Mumford	64225d6	Began working with inheritance, currently having a headache with allowing children to be stored in the same entityList. ...	2023-07-30
JM	Joe Mumford	dd38aa9	Fixed oversight with setScale being used instead of setScaleWithRules inside the generic entity update function. Now, s...	2023-07-29
JM	Joe Mumford	7beb447	Implemented SmoothToRotation functionality.	2023-07-29
JM	Joe Mumford	cbc1c6a	Implemented Scale Smoothing at a rate. Smoothing for a duration hasn't been done for any Smoothing at this point in t...	2023-07-28
JM	Joe Mumford	3a09717	Fixed aforementioned issue, was a simple (and embarassing) <= and >= instead of < and > oversight. Additionally, impl...	2023-07-28
JM	Joe Mumford	bfcf3be	Fixed angle calculation issues while smoothing with translation. However it seems like the current values being used to ...	2023-07-28
JM	Joe Mumford	5b7c52d	Fixed directional issues with smoothing, however x and y don't arrive at the point at the same time. This is due to some ...	2023-07-26
JM	Joe Mumford	c43c2c3	Made progress in implementing "Smoothing" functions for Translation (previously named incorrectly as "Interpolation"). ...	2023-07-22
JM	Joe Mumford	ae12e1e	Fixed the aforementioned issues, which were caused by using atan instead of atan2 inside GetAngleBetweenPoints. A Pr...	2023-07-21
JM	Joe Mumford	aec3f0f	Changes: Created the skeleton classes for Entity_Road. Began implementation of window resizing functionality. Introdu...	2023-07-20
JM	Joe Mumford	d46fc74	Implemented "GetAngleBetweenPoints" function in ent_generic.h.	2023-07-18
JM	Joe Mumford	977d521	Templatized the CreateEntity function. This should pave the way for alternate entity classes to be created with this functi...	2023-07-17
JM	Joe Mumford	ff00fe8	Implemented the skeleton of a Vehicle Entity class.	2023-07-16

JM	Joe Mumford	8c7afd0	Added two extra functions allowing entity children to define; these are called on Initialisation and Destruction.	2023-07-16
JM	Joe Mumford	9f238b9	Successfully implemented position, rotation and scaling functionality for Entity_Generic. This was tested during runtime ...	2023-07-16
JM	Joe Mumford	f1c1e98	Implemented scaling system that accounts for original image size. In other words: Sprites with images of different sizes (...	2023-07-15
JM	Joe Mumford	646894a	Rendering now works despite the ability to move the window still not working. (FYI: This was always an issue with the o...	2023-07-15
JM	Joe Mumford	7b40296	Changed from C++17 to C++20 as the original code seems to be compatible.	2023-07-15
JM	Joe Mumford	f24528d	FIxed compiler error, but window updating is still very bad. Now proceeding to use Performance Profiler.	2023-07-15
JM	Joe Mumford	07e9861	Implemented framework for entities. Currently has an presumably easy to fix compiler error. Did not make way in fixing a...	2023-07-09
JM	Joe Mumford	7326b3a	Fixed aforementioned crash. However the game window is unmoving and cannot be minimized or closed. This is also tru...	2023-07-09
JM	Joe Mumford	8650467	Implemented renderList system, functions correctly. There is however an unrelated crash.	2023-07-09
JM	Joe Mumford	3e50db7	Fixed Window Name uses. Unable to move program window, however this may be due to a lack of activity from Simulati...	2023-07-03
JM	Joe Mumford	fa5cd25	Solved compilation errors. Runtime errors persist however.	2023-07-03
JM	Joe Mumford	c6072e6	Minor tweaks, no changes/improvements.	2023-07-03
JM	Joe Mumford	c407620	Further progress in fixing compile-time linker errors.	2023-07-03
JM	Joe Mumford	21e8e2a	Initial Commit. Compilation errors persist however these have been significantly reduced; the initial commit is in this stat...	2023-07-03

Appendix F

The Project Specification for this study, made prior to the design of the software and thus possesses the original development milestones and schedule.
These are the milestones and schedule which were exposed to changes made during development.

MComp Individual Project: Project Specification

Student Name	Joseph Mumford	
Student Contact Details	**SHU Email**	c0006257@hallam.shu.ac.uk
	Telephone	07757168003
Course	MComp Computer Science for Games (Level 7)	
Supervisor Name	Tom Garner	
Title of Project *(Provisional)*	Evaluating the Efficacy of Educational Software in Communicating Induced Traffic Demand Concepts. Assessing the effectiveness of interactive software in increasing public awareness and understanding of induced traffic demand.	
Date	25/09/2023	

Research Question

Can Induced Traffic Demand be effectively communicated using interactive educational software to increase awareness and understanding of the topic among users?

Elaboration

Traffic congestion is a common occurrence within roads or highways, and the major contributor towards this is a phenomenon driven by human behaviour called Induced Traffic Demand *(alternatively referred to as "Induced Demand" or "Induced Travel Demand").* A phenomenon where increases in road capacity located where travel demand is high will result in more road vehicles travelling on the now widened road. This is equivalent to "Supply and Demand" within economics, and is the primary culprit for unforeseen resurgences of congestion in high-flow areas that have recently been rebuilt or reworked to reduce it. For the transportation sector, traffic demand that has been generated by improvements made to transportation infrastructure can result in the improvements made to said infrastructure either becoming invalid or exacerbating the issue they intended to solve. While fuelled by human behaviour, Induced Demand is more so a consequence of traffic planning than human driving.

For a more detailed understanding of Induced Demand, please refer to *https://en.wikipedia.org/wiki/Induced_demand*, my Literature Review, or the academic sources referenced within said review (available on request).

Traffic planners have been aware of this phenomenon for decades, and contemporary planners account for it within their designs. While implementations of these designs face slight opposition in many countries, nations such as the United States—which possesses some of the widest roads in the world—regularly exhibits public opposition towards anti-congestion measures and projects. Pushback against these projects is not limited to the United States, and can lead to disruption or outright cancellation of anti-congestion measures in order to ease public tensions. These measures have been thoroughly supported and tested by experts. However, changes made to roads, such as the reduction of lanes to reduce demand, can appear as counter-intuitive to commuters and thus prompts opposition fuelled by misinformation and misconceptions. Humanity already lives a significant portion of their lives driving within congested transportation networks, and public support of these projects can increase application of anti-congestion infrastructure and combat traffic congestion.

The root of these misconceptions likely results from a lack of awareness and knowledge regarding Induced Travel Demand and how it generates congestion. For those who live in areas whose urban planning is lacking, this is understandable, as they may be unable to picture a better system. Refined methods to mitigate congestion already exist, however their implementation will require members of the public to understand why these methods are being implemented. In other words, for solutions to be implemented and effectively combat congestion, awareness of induced demand must not only be increased, but the phenomenon itself must be understood, to allow smooth transitions towards better infrastructure. While road design in the United Kingdom follows congestion-mitigating planning principles, there are many instances where Induced Demand continues to occur. Public opposition holds back the transportation sector and urban areas from mitigating congestion in these areas as well as from improving other instances of urban infrastructure.

This study will begin with examining pre-existing studies on the shortcomings and teaching methods within education and awareness campaigns on traffic congestion, urban planning projects, induced demand and other related material. Afterwards, a software artefact will be designed and created as a learning tool for communicating what induced demand is and how it functions, with the aim of increasing awareness of induced demand as a pressing issue. This software will be a prototype to evaluate the effectiveness of software in increasing understanding of Induced Demand.

There is a large amount of evidence suggesting, supporting and confirming methods to mitigating induced demand, however there is a barrier to this knowledge for the average member of the public. Thus, the artefact and analysis of this project will aim to facilitate an increase in Induced Demand awareness via a vehicle traffic simulation designed around the visualisation of the phenomenon. This vehicle traffic simulation will consist of a network of nodes with connections between them to emulate roads; these roads will then facilitate different types of lanes for different vehicles, allowing the user to alter the simulation environment and see the impact of their changes. The focus for the project is the visualisation and education of Induced Demand, and there are many factors that influence transportation both related and unrelated to Induced Demand. Therefore, the "simulation" leans more towards emulation rather than a highly detailed and accurate simulation of traffic systems, given the scope of this study.

The hopes for this project include the ability of interactive educational software more effectively building understanding of Induced Demand being demonstrated, and future studies being able to expand on this approach and refine it for use as a public learning tool for Induced Demand. Ultimately, ending in the general public better understanding the importance of Induced Traffic Demand, rethinking how road improvements (and perhaps urban planning as a whole) can be improved to benefit those that interact with these systems, and those that rely on them.

Project objectives

To evaluate the effectiveness of interactivity as an avenue for the education of Induced Demand, a software artefact will need to be produced and evaluated against conventional teaching methods. The project objectives are as follows:

- Creation of a simple traffic simulation that users can interact with. This is the foundation of the project and will allow for the visualisation of induced demand, which is the primary objective of this project. This is implemented using C++ and Direct3D 11.
- Implementation of a decision-making algorithm to emulate the cost-related decisions that the simulated drivers make when deciding the fastest route to their location when commuting. A separate algorithm will then generate new paths to account for road capacity limitations originating from other drivers taking the same route – in other words, drivers will include their past experiences and experiences of other drivers when planning their route. This algorithm is not the focus, as the project is not aiming to flawlessly simulate reality but rather emulate it. Thus, this algorithm will be developed to be sufficient enough to demonstrate induced demand.

- Implementation of various usability features that allow the user to influence the simulated traffic environment. Such as the creation and deletion of roadways, vehicle lanes and different vehicle instances such as bicycles and pedestrians. This also includes displaying statistics, allowing the user to observe the parameters of simulation and their influence they have. These features are designed for the purpose of analysis as well as further demonstrate the existence and impact of induced demand.
- Evaluation of various traffic scenarios with differing vehicle densities and types. This data will be used to determine if this simulation can successfully emulate induced demand, in addition to any limitations or faults in the simulation's methods for emulating these scenarios. This will entail a comparison of the software against more conventional methods that communicate Induced Traffic Demand concepts and related transportation topics.

Project deliverable(s)

The deliverables for this project include a piece of software visualising Induced Demand via a traffic simulation, and an analysis determining the software's capability in conveying the concept and importance of Induced Demand visually to users.

The detailed analysis should prove or disprove the research question, and therefore the validity of the research. The software artefact will be the method of gathering data for analysis.

Ethics

No ethical issues identified.
Human participants will be necessary to assess whether the software is effective or not. However, these participants will only be required to use the software and answer questions presented to them in an anonymous survey.

Action plan

The predicted milestones and sprints for the project as well as their expected delivery dates are as follows. These predictions were made prior to the start of development on the 25th of September, and thus may change during future development.

Milestone 1 – Implementation of Simulation Features and Properties – 25/09/2023

This milestone will continue the implementation of simulation features that were started in May, prior to the start of the project. The artefact's state before this milestone will be continued to be referred to as the prototype stage (*Milestone 0 – Creation of Prototype*), but now this prototype will be polished and completed.

<u>Sprint 1 – 2 Weeks</u>

The furthering and completion of unfinished features mentioned earlier as well as the testing of these features to ensure they function as expected. This is primarily based around the interactions between vehicles and roads.

<u>Sprint 2 – 1 Week</u>

This sprint will be focused around the simulation loop of commuting back and forth between a vehicle's home and workplace, referred internally as the scheduling system. This facilitates the environment that allows vehicles to learn from past "days" of commuting (a day being designed around a work day and its related commutes).

Milestone 2 – Implementation of User Interface Features – 16/10/2023

<u>Sprint 1 – 2 Weeks</u>

This sprint will be devoted to UI implementation, allowing the user to interact with the artefact and influence the simulation with their alterations of the parameters and road layout.
This also includes work on any simulation features involving user interaction directly, such as additions and deletions of lanes to/from road lengths or designations of workplaces and homes.

Milestone 3 – Implementation of Algorithm – 30/10/2023

Sprint 1 – 1 Week

This is primarily research based, briefly ironing out the details of the algorithm through research of similar weighted path-finding algorithms and selecting the most appropriate for this project's scope as a baseline to work from.

Sprint 2 – 2 Weeks

This sprint is the aforementioned implementation of the algorithm that determines how drivers behave when plotting and driving their path.
This takes two forms: planning the route and adjusting the route while travelling.

Milestone 4 – Implementation of Remaining Functionality and Visualisation – 20/11/2023

Sprint 1 – 2 Weeks

This sprint will be the final implementation sprint and will focus on the remaining features of the simulation that can now be developed with the implementation of the algorithm. This is a general – catch-all, but the focus here is fulfilling the visualisation aspects of the project by displaying and demonstrating induced demand clearly with the factors displayed.

Sprint 2 – 1 Week

This sprint consists of time devoted to ironing out the functionality of the aforementioned simulation features such that they function flexibly (in different situations) and properly (without error) as well as fixing bugs severely impeding or hampering the functionality of the program.
This also extends to optimisation of the artefact program under heavy load (high numbers of active objects, sprites and text).
A week dedicated towards finalising the artefact before evaluation.

Milestone 5 – Evaluation – 11/12/2023

Sprint 1 – 1 Week (11/12/2023 – 18/12/2023)

This sprint will be devoted to using the simulation to run different scenarios to demonstrate induced demand, seeing how it is generated.

Milestone Interruption - Christmas Break (18/12/2023 – 01/01/2024)

Sprint 2 – 2 Weeks (01/01/2024 – 15/01/2024)

This sprint is a continuation of the previous, taking place after Christmas vacation. Although, some progress may be occasionally made prior to Christmas day during the winter holidays.

Project Completion – 25/01/2024 (Thursday 3:00pm)

The completion and submission of the project documentation, analysis, deliverable and other required work.

Appendix G

The Ethics Form regarding the ethical treatment of participants, including data collection, during this study.

UREC2 RESEARCH ETHICS PROFORMA FOR STUDENTS UNDERTAKING LOW RISK PROJECTS WITH HUMAN PARTICIPANTS

This form is designed to help students and their supervisors to complete an ethical scrutiny of proposed research. The University Research Ethics Policy should be consulted before completing the form. The initial questions are there to check that completion of the UREC 2 is appropriate for this study. The final responsibility for ensuring that ethical research practices are followed rests with the supervisor for student research.

Note that students and staff are responsible for making suitable arrangements to ensure compliance with the General Data Protection Act (GDPR). This involves informing participants about the legal basis for the research, including a link to the University research data privacy statement and providing details of who to complain to if participants have issues about how their data was handled or how they were treated (full details in module handbooks). In addition, the act requires data to be kept securely and the identity of participants to be anonymized. They are also responsible for following SHU guidelines about data encryption and research data management. Information on the Ethics Website.

The form also enables the University and College to keep a record confirming that research conducted has been subjected to ethical scrutiny.

The form may be completed by the student and the supervisor and/or module leader (as applicable). In all cases, it should be counter-signed by the supervisor and/or module leader, and kept as a record showing that ethical scrutiny has occurred. Some courses may require additional scrutiny. Students should retain a copy for inclusion in their research projects, and a copy should be uploaded to the relevant module Blackboard site.

Please note that it may be necessary to conduct a health and safety risk assessment for the proposed research. Further information can be obtained from the College Health and Safety Service.

Checklist Questions to ensure that this is the correct form

1. Health Related Research with the NHS or Her Majesty's Prison and Probation Service (HMPPS)or with participants unable to provide informed consent

Question	Yes/No
1. Does the research involve? • Patients recruited because of their past or present use of the NHS	No
• Relatives/carers of patients recruited because of their past or present use of the NHS	No
• Access to data, organs or other bodily material of past or present NHS patients	No
• Foetal material and IVF involving NHS patients	No
• The recently dead in NHS premises	No
• Prisoners or others within the criminal justice system recruited for health-related research*	No
• Police, court officials, prisoners or others within the criminal justice system*	No
• Participants who are unable to provide informed consent due to their incapacity even if the project is not health related	No
2. Is this a research project as opposed to service evaluation or audit? *For NHS definitions of research etc. please see the following website* http://www.hra.nhs.uk/documents/2013/09/defining-research.pdf	Yes

If you have answered **YES** to questions **1 & 2** then you **MUST** seek the appropriate external approvals from the NHS, Her Majesty's Prison and Probation Service (HMPPS) under their independent Research Governance schemes. Further information is provided below.
https://www.myresearchproject.org.uk

NB College Teaching Programme Research Ethics Committees (CTPRECS) provide Independent Scientific Review for NHS or HMPPS research and initial scrutiny for ethics applications as required for university sponsorship of the research. Applicants can use the IRAS proforma and submit this initially to their CTPREC.

1. Checks for Research with Human Participants

Question	**Yes/No**
1. Will any of the participants be vulnerable? *Note: Vulnerable' people include children and young people, people with learning disabilities, people who may be limited by age or sickness, people researched because of a condition they have, etc. See full definition on ethics website*	No
2. Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	No
3. Will tissue samples (including blood) be obtained from participants?	No
4. Is pain or more than mild discomfort likely to result from the study?	No
5. Will the study involve prolonged or repetitive testing?	No
6. Is there any reasonable and foreseeable risk of physical or emotional harm to any of the participants? *Note: Harm may be caused by distressing or intrusive interview questions, uncomfortable procedures involving the participant, invasion of privacy, topics relating to highly personal information, topics relating to illegal activity, or topics that are anxiety provoking, etc.*	No
7. Will anyone be taking part without giving their informed consent?	No
8. Is it covert research? *Note: 'Covert research' refers to research that is conducted without the knowledge of participants.*	No
9. Will the research output allow identification of any individual who has not given their express consent to be identified?	No

If you have answered **YES** to any of these questions you are **REQUIRED** to complete and submit a UREC 3 or UREC4). Your supervisor will advise. If you have answered **NO** to all these questions then proceed with this form (UREC 2).

General Details

Name of student	Joseph Mumford
SHU email address	c0006257@hallam.shu.ac.uk
Course or qualification (student)	MComp Computer Science for Games (Level 7)
Name of supervisor	Tom Garner
email address	t.garner@shu.ac.uk

Title of proposed research	Evaluation of educational software in demonstrating induced traffic.
Proposed start date	25/09/2023
Proposed end date	25/01/2024
Background to the study and scientific rationale for undertaking it.	Research shows that interactive software is a useful tool for effectively teaching knowledge with higher levels of retention. However, despite the difficulties that urban planners (those who plan renovations for our urban spaces, cities and transport networks) face in educating the public, there are few examples of applying interactive software in teaching the public about complex traffic mechanics, such as why congestion forms and how urban planners try to mitigate it. This research aims to see to what extent interactive software helps users understand Induced Traffic Demand: the most common factor in traffic congestion that many members of the public are unaware of.
Aims & research question(s)	Evaluating the effectiveness of educational software in demonstrating the impact of induced traffic demand on traffic travel congestion to members the public. To what extent is interactive software beneficial in communicating induced traffic demand as an education tool/method?
Methods to be used for: 1. recruitment of participants, 2. data collection, 3. data analysis.	1. Word-of-mouth, Inquiring those who work in fields either related to, or tangentially related to Urban Planning or Software Development. 2. Surveys / Questionnaires. 3. Comparison with non-interactive forms of learning/teaching on the same topic.
Outline the nature of the data held, details of anonymisation, storage and disposal procedures as required.	Email addresses, which will be removed/wiped upon the project's completion. If not, then when data collection for a participant has finished, that participant's data is removed/wiped.

3. Research in Organisations

Question	Yes/No
1. Will the research involve working with/within an organisation (e.g. school, business, charity, museum, government department, international agency, etc.)?	No

2. If you answered YES to question 1, do you have granted access to conduct the research? *If YES, students please show evidence to your supervisor. PI should retain safely.*	N/A
3. If you answered NO to question 2, is it because: A. you have not yet asked B. you have asked and not yet received an answer C. you have asked and been refused access. *Note: You will only be able to start the research when you have been granted access.*	N/A

4. Research with Products and Artefacts

Question	Yes/No
1. Will the research involve working with copyrighted documents, films, broadcasts, photographs, artworks, designs, products, programmes, databases, networks, processes, existing datasets or secure data?	Yes
2. If you answered YES to question 1, are the materials you intend to use in the public domain? *Notes: 'In the public domain' does not mean the same thing as 'publicly accessible'.* • *Information which is 'in the public domain' is no longer protected by copyright (i.e. copyright has either expired or been waived) and can be used without permission.* • *Information which is 'publicly accessible' (e.g. TV broadcasts, websites, artworks, newspapers) is available for anyone to consult/view. It is still protected by copyright even if there is no copyright notice. In UK law, copyright protection is automatic and does not require a copyright statement, although it is always good practice to provide one. It is necessary to check the terms and conditions of use to find out exactly how the material may be reused etc.* *If you answered YES to question 1, be aware that you may need to consider other ethics codes. For example, when conducting Internet research, consult the code of the Association of Internet Researchers; for educational research, consult the Code of Ethics of the British Educational Research Association.*	Yes
3. If you answered NO to question 2, do you have explicit permission to use these materials as data? *If YES, please show evidence to your supervisor.*	N/A
4. If you answered NO to question 3, is it because: A. you have not yet asked permission B. you have asked and not yet received and answer C. you have asked and been refused access. *Note You will only be able to start the research when you have been granted permission to use the specified material.*	~~A/B/C~~

Adherence to SHU policy and procedures

Personal statement	
I can confirm that: • I have read the Sheffield Hallam University Research Ethics Policy and Procedures • I agree to abide by its principles.	
Student	
Name: Joseph Mumford	Data: 10/12/2023
Signature:	
Supervisor or other person giving ethical sign-off	
I can confirm that completion of this form has not identified the need for ethical approval by the FREC or an NHS, Social Care or other external REC. The research will not commence until any approvals required under Sections 3 & 4 have been received and any necessary health and safety measures are in place.	
Name: Tom Garner	Date: 30.12.2023
Signature:	
Additional Signature if required by course:	
Name:	Date:
Signature:	

Please ensure the following are included with this form if applicable, tick box to indicate:

	Yes	No	N/A
Research proposal if prepared previously	☐	☒	☐
Any recruitment materials (e.g. posters, letters, etc.)	☐	☒	☐
Participant information sheet	☒	☐	☐
Participant consent form	☒	☐	☐
Details of measures to be used (e.g. questionnaires, etc.)	☒	☐	☐
Outline interview schedule / focus group schedule	☐	☒	☐
Debriefing materials	☐	☐	☐
Health and Safety Project Safety Plan for Procedures	☐	☐	☐