TØI report 1391/2015

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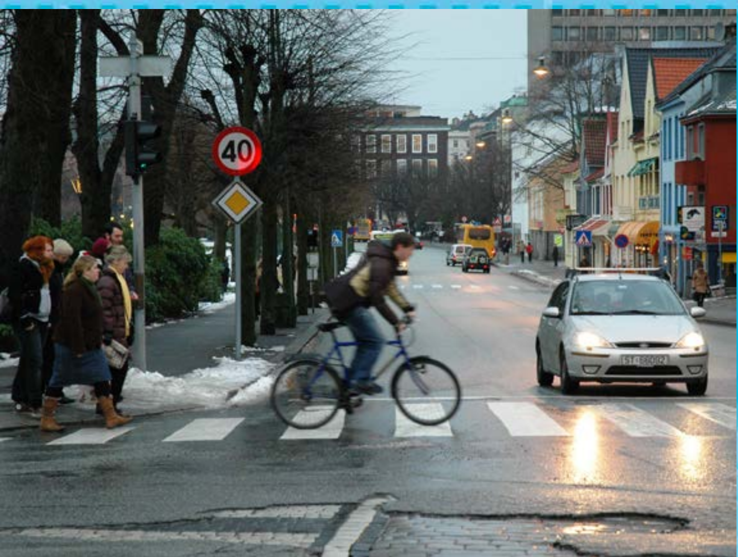
Institute of Transport Economics
Norwegian Centre for Transport Research

An assessment of the available simulation models for the planning and design of safe urban intersections for pedestrians and cyclists



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Sammendrag:

Den norske transportplanleggingsagendaen ønsker å skape gode forhold for fotgjengere og syklister. Bærekraftige transportmidler, dvs. kollektivtransport, sykling og gange skal også, ifølge politiske målsetninger, stå for all fremtidig trafikkvekst i byregionene. Statens vegvesen ønsket på bakgrunn av dette å ta i bruk verktøy for effektiv modellering av fotgjengere og syklister ved trafikkerte gatekryss i byene for å redusere trafikkulykker. Denne rapporten presenterer detaljert informasjon om tilgjengelige (og fremtidige) simuleringsverktøy som kan tas i bruk ved planlegging og utforming av veikryss. Vi har identifisert viktige hensyn som kapasitet og egenskaper som må vurderes dersom verktøyene skal brukes til effektiv utforming av gatekryss hvor fotgjengere, syklister og kjøretøy møtes.

Prosjektet er finansiert av Statens vegvesen gjennom FOU-programmet BEST – Bedre sikkerhet i trafikken.

Summary:

The Norwegian transport planning agenda is moving towards creating supportive conditions for pedestrians and cyclists. It is also a policy directive that all future growth in traffic in the urban regions should be absorbed by sustainable transport modes i.e. public transport, cycling and walking. In light of these developments, the Norwegian Public Roads Administrationis keen on adopting tools to model the flow of pedestrians and cyclists in the urban intersections to effectively minimise traffic accidents. This report presents detail information on the available (and forthcoming) simulation tools which may be used for the planning and design of road junctions and crossings. We identify key considerations for the capability of software tools if they are to be used for effective junction design involving (potentially large numbers of) pedestrians and cyclists, together with motor vehicles.

The Norwegian Public Roads Administration (NPRA) funded this study through the BEST project, which looks into traffic safety issues in Norway.

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Preface

This report on assessment of the available simulation models for the planning and design of safe urban intersections for pedestrians and cyclists is part of a larger research program "BEST – Bedre sikkerhet i trafikken *(better safety in the traffic)"*. The project was financed by the Norwegian Public Roads Administration (NPRA). Our contact person at NPRA has been Guro Berge.

The main aim of the project has been to detail out the various micro-simulation tools available in the market suitable for simulating pedestrians and cyclists in both normal road conditions and in various types of road junctions to provide a knowledge base that can be used to develop measures against accidents affecting pedestrians and cyclists.

The study is based on data collected from different originations involved in developing and selling simulation tools. David Taylor, Head of Consulting from Movement Strategies AS was our partner in this project. He has close to 15 years of experience and a rich insight in the world of micro-simulation. Some parts of the report where comparisons have been drawn between the various simulations tools draws on his insight and hands on experience with the various tools.

We are thankful to the members of the reference group of the project for their valuable comments on an initial version of the current report.

Tanu Priya Uteng and David Taylor have written the report. Michael Sørensen has been responsible for the quality assurance of the report, while Trude Rømming has prepared the report for publication.

Oslo, December 2015
Institute of Transport Economics

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Content

Summary

An assessment of the available simulation models for the planning and design of safe urban intersections for pedestrians and cyclists

TØI Report 1391/2015
Authors: Tanu Priya Uteng (TØI) and David Taylor (Movement Strategies)
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The Norwegian society faces a complex set of challenges in form of striking a balance between decreasing car usage and increasing usage of sustainable modes of transportation – public transport, bicycling and walking. A common denominator underlying all these growth trends is traffic safety, which needs to be filtered out and presented as one of the most important keystones for a balanced growth in the future. This necessitates a long term strategy which is aligned both with the transport structure and needs of future transport users. This report gives a systematic outlook on the relations that is considered important for make informed decisions on the design of urban junctions in the future.

Pedestrian modelling

A key overarching point is that pedestrian models are fundamentally different from vehicular models in that where road traffic can be defined as a stand-alone system with prescribed behaviours, formed by some system of links for instance, pedestrian movement is 'free'. Pedestrian simulation models are therefore based upon the entire *area* available for walking, with origins, destinations, waypoints and various behaviours defined over relevant parts of the total area.

In addition to the accurate modelling of pedestrian 'desire lines' of movement, key aspects to be tested include the areas available for comfortable, safe movement of pedestrians along pavements and when waiting at crossings – together with potential delays and waiting times. Measures of walking times, waiting times, people counts, the use of space and densities of people per m² are outputs common to all pedestrian simulation models and form key metrics in the assessment of pedestrian experience at junctions. Video outputs, combined with vehicle micro-simulation models where relevant, can be powerful tools in demonstrating anticipated outcomes, problems and benefits to a wide range of stakeholders.

The following three theoretical models have driven the development of pedestrian simulation modelling till date:

Social Force modell

The model is based on the primary purpose of pedestrians being to accelerate towards making progress towards a destination at a desired speed. This primary goal is influenced by physical and social factors; agents will respond to 'repulsive' forces as a result of the boundary of physical objects (walls, other obstacles) and of the presence of other agents (i.e., people).

The Social Force Model was successful in recreating real-world 'emergent' behaviours such as the formation of lanes in opposing flows of people (at certain densities) and the 'shockwaves' that propagate through crowds of people at narrow openings and similar situations.

Legion / 'OMCA' modell

The model which is the basis for the software tool *Legion* was developed by Keith Still (Still, 2000) on the premise that a simpler mathematical approach than the Social Force Model could be used to create results that were just as well validated. The basis for this model is based on four key behavioural rules: Objective, Motility, Constraint, and Assimilation (OMCA). In more detail, these are described by Still (2000) as:

- *Objective*: Try to move to a desired or intended end point
- *Motility*: Try to maintain your optimum velocity
- *Constraint*: Try to maintain a minimum distance between yourself and the other objects in the environment
- *Assimilation*: Delay time taken to read and react to the environment.

Behavioural heuristics modell

More recently, the cognitive science approach taken by Moussaïd et al (2011) seeks, as with the Legion model, to simplify the mathematical basis of the movement model. Specifically, a model based on the distance of obstructions in agents' 'line of sight' is proposed, which uses two simple heuristics (simple cognitive procedures and rapid decision making).

Bicycle (and vehicle) modelling

The three main elements of vehicle micro-simulation modelling, which would also apply in some form to bicycle modelling, are:

- Car-following models describe the interaction between a vehicle and the vehicle in front
- Lane-changing models describe the timing and urgency of changing lane
- Gap-acceptance models determine the timing and safety of movements at intersections.

The algorithms to perform these functions vary by software tool, and have various strengths and weaknesses in different circumstances, but the broad concepts are common.

State of development of bicycle models

A key differentiator for bicycles is their width, and the associated more complex lane behaviour. Generally speaking, model development for bicycles is therefore in the process of moving from simplistic lane adherence that is appropriate for motor vehicles to more advanced modelling of 'lateral' movement appropriate for bicycles (and their interaction with motor vehicles). When combined with the ability to model dedicated bicycle lanes, this additional capability should provide the basis for modelling the majority of conceivable bicycle routes. This is a step change from past modelling of bicycles, which considered them only nominally, based purely on the vehicle model.

The industry as a whole is not there yet. Different tools are at different stages of development. However, the overall direction is towards suitable adaptations to the car-following models to enable relatively sophisticated and accurate modelling of bicycles. PTV Group are currently notably strong in this area.

Key considerations for junction design

Simulation of junction designs with a focus on pedestrians and cyclists – both to accommodate large numbers of those users and to provide optimal, safe route choices for them – requires various capabilities of the modelling software. A summary of key considerations are given below, to be used as a basis for assessment and comparison of the different software tools.

These considerations are given further context by giving a brief overview of some trends in the US, the Netherlands and the UK – with a particular focus on bicycle use; arguably the least well understood and provided-for user group.

Key considerations for software tools

General

- *Model validation:* Technical and real-world validation of model outputs to ensure outputs are a credible representation of the situation modelled and therefore have the potential to form an accurate basis for decision-making (including applicability to pedestrians, cyclists and vehicles).
- *Fully integrated interactions between modes*: Exchange of position and speed data between pedestrians, cyclists and motor vehicles at each time step.
- *Integration with signal timing software:* Ability to optimise signal timings is critical, through fixed and vehicle actuated timings, as well as LISA+, RBC, SCATS, SCOOT, Siemens VA, VS-Plus, etc.
- *Quality and clarity of outputs:* Options to produce both high-level and detailed numerical and graphical outputs suitable for not only technical assessment and conclusions but also stakeholder communication (e.g., to include 3D rendering).
- *Cost:* Indicative costs of software licences and training, together with broad appreciation of modelling time/cost.

Cyclists

- *Road position and overtaking:* Ability to model vehicles using road space 'freely' (not restricted to one vehicle per lane) to enable realistic modelling of cyclists in particular (thus having the potential to have an appropriate impact on junction layout/geometry in the design process). To include interaction between bicycles and other road users (e.g., a car and bicycle sharing a lane) and dedicated cycle paths.

- *Classification of speed and acceleration:* Ability to take account of the wide range of speed and acceleration characteristics of different bicycle user types, in the context of surface gradient.
- *Dealing with obstructions*: Ability to take account of obstructions that may have a direct bearing on cyclist behaviour and knock-on impacts in relation to movement and capacity (e.g., narrowing of route, bus stops etc).
- *Behaviour at traffic signals:* Ability to simulate waiting behaviours in 'forward stop zones'; encroachment on pedestrian crossings[1]; the use of cycle-specific signal timings; and red-light violations (full violation or early start), especially for right turns.

Pedestrians

- *Route choice flexibility*: Combination of modelled shortest-path choices and imposed navigational routes required with sufficient control to model the pedestrian environment effectively.
- *Realistic pedestrian model*: Appropriate mathematical basis to recreate pedestrian behaviours relating to individual movement and aggregate, crowded movement.
- *Conflict areas*: Ability to define (freely) areas of conflict between pedestrians and vehicles, to include modelling crossings at places other than formally marked crossings. Flexibility is required to ensure that the modelling reflects real-world 'desire lines' of movement for pedestrians (including for planned schemes such as extended central reservations).
- *Crossing behaviour*: Capability to model realistic behaviours of pedestrian crossing choices (gap acceptance, right of way, etc) and vehicle responses
- *Response to traffic signals:* Control over pedestrian adherence to signal timings and 'jaywalking'.

Simulation modelling tools overview

A brief overview of relevant simulation tools is given for context and to illustrate potential future developments. The most promising are identified for specific assessment, against the key considerations described.

The information given here is based on a combination of information from suppliers, use of trial versions and review of relevant material (e.g., other publicly-available research/project work that has used a particular tool).

Paramics / UAF

Summary: Micro-simulation vehicle model with sophisticated pedestrian module ('Urban Analytics Framework' or UAF) allowing for full interaction between vehicles and agents. Note that two 'versions' of Paramics software exist (stemming from the same original software) – one owned by Quadstone Paramics / Pitney Bowes and the other by SIAS.

1 encroachment on pedestrian crossings means cycles blocking pedestrian crossings (which they are not meant to do but sometimes take advantage of that space)

Given the inclusion of UAF within the Quadstone product, it is that software tool that is considered here.

Key benefits

- Autodesk and GIS integration.
- Proven micro-simulation vehicle model.
- High-quality pedestrian module.

Key limitations

- Bicycles modelled only as another vehicle type similar to motor vehicles; lacks detail of within-lane movement and related behavioural characteristics. No information on planned development of lateral movement modelling.

InControl Pedestrian Dynamics

Summary: Sophisticated pedestrian simulation tool, but currently lacking integration with a vehicle micro-simulation tool.

Key benefits

- Sophisticated pedestrian simulation with dynamic route choice based on emerging pedestrian conditions.

Key limitations

- Currently not integrated with a vehicle simulation tool.

Aimsun / Legion

Summary: Proven micro-simulation model by TSS, paired with pedestrian simulation module using Legion.

Key benefits

- Proven micro-simulation vehicle model with fast run times.
- Ability to build hybrid vehicle simulation – mesoscopic model of larger area, micro-simulation of smaller area of key interest.
- High-quality pedestrian module.
- Integrated model: Allows for assessment of interaction between vehicles and pedestrians.

Key limitations

- Bicycles not currently modelled with lateral movement (though actively in development).
- No Norwegian language option (English supported).

Vissim / Viswalk

Summary: Established micro-simulation vehicle model.

Key benefits

- All-in-one solution to model vehicles, bicycles and pedestrians.
- Bicycles modelled with lateral movement and greater level of development overall for bicycles, including recent developmental project experience in Copenhagen. Parameter settings identified (albeit research/revision for Norwegian context might be required).
- Much-improved pedestrian module which allows complex algorithmic basis to be relatively well controlled.
- Potential to model detailed scenarios involving complex behaviours of both bicycles and pedestrians.
- PTV have a strong record of innovation and research (e.g., Kretz, 2014).

Key limitations

- Pedestrian module remains complex mathematically, though a competent practitioner should be able to produce reliable results.

Commuter / InfraWorks 360 Traffic

Summary: Innovative all-in-one solution considering person-trips as the primary basis for analysis, rather than being mode-led.

Key benefits

- Potential to be a sophisticated multi-modal tool, including dynamic mode choice and 'layering' of walkways/roads/crossings to allow for complex priorities and crossing behaviour.
- Non-lane based modelling of vehicles and bicycles – allows for vehicles to pass where there is sufficient width (e.g., including bicycles overtaking stopped buses).
- Potential to incorporate the influence of public transport modes on junction design, e.g., a rush of pedestrian demand from people disembarking from a bus or train close to junction.

Key limitations

- Currently in beta testing following takeover by Autodesk; undergoing integration into the InfraWorks tool.
- Release plan not yet public.

MassMotion

Summary: Sophisticated natively 3D pedestrian simulation tool, but currently lacking integration with a vehicle micro-simulation tool.

Key benefits

- Advanced control over pedestrian class types, with unique 'agendas' en route.
- Autonomous agent route choice.
- Ability to plot line-of-sight of agents, demonstrating their field of view when walking.

Key limitations

- Currently not integrated with a vehicle simulation tool.
- Requires Autodesk Softimage.

Massive Insight

Summary: Advanced simulation tool based on 'artificial intelligence'.

Key benefits

- Potential to implement different type of mathematical model from the more typical vehicle and pedestrian models.

Key limitations

- Not yet available for commercial use; development appears to have stalled since 2009 beta testing programme.

Software assessed in greater detail

On the basis of the state of the market at the time of writing, the following tools are further assessed in this report:

- *Aimsun / Legion*
- *Vissim / Viswalk*
- *Commuter / InfraWorks 360 Traffic*

Conclusions and recommendations

In recent years, the development of micro-simulation tools has been rapid and complex multi-model environments have been modelled. Specific high-profile projects such as Oxford Circus in London, together with in-depth studies such as the Copenhagen bicycle modelling study, have shown that it is feasible to assess complicated junction design for all road users.

That said, because these developments are new – and on-going – there remain challenges in refining some model features and behaviours (notably for bicycles), and not all software developers are at the same stage of development, despite moving towards similar goals.

The recommendations given below are therefore presented in the context of our best understanding of both the current and future position of the software market. We anticipate that these timings could have a bearing on the most appropriate software choice, depending on the precise requirements and timescales of forthcoming projects.

Recommendations: Software tool selection

Based on our understanding of the requirement, trends in junction design for pedestrians and cyclists, and the review of simulation tools presented in this report, we recommend the possible use of three software tools. They are presented here in priority order based on *current functionality at the time of writing*. Note that the relative merits of these software tools may change substantially within the next 12 months, given our understanding of the development priorities and broad timescales of the software developers.

1. **Vissim/Viswalk (PTV)**
   - Excellent integration of vehicles, bicycles and pedestrians. Allows testing of features such as bicycle lanes/paths; signal timings, including 'green scramble' and 'green waves'; forward stop zones, including feeder bicycle lanes; narrowing lanes; and a range of priority and gap acceptance behaviour for vehicles, bicycles and pedestrians.
   - Most developed bicycle model, incorporating lateral movement and including recent developmental experience in Copenhagen.
2. **Aimsun/Legion (TSS)**
   - Currently almost as capable as *Vissim/Viswalk*, but lacking lateral movement for bicycle modelling. Also slightly more complex integration between vehicles and pedestrians because of separate companies' collaboration.
   - Within approximately the next year, likely to have developed lateral movement (based on a specific, major, funded project) and become a relatively even competitor for *Vissim/Viswalk*.
   - Potential efficiencies given existing use of *Aimsun* by the Norwegian Public Roads Administration and City of Oslo.
3. **Commuter/InfraWorks (Autodesk)**
   - Not currently commercially available.
   - However, is multi-modal from conception and would offer (arguably) the greatest flexibility of the three recommended tools.
   - Early indications suggest that conflict between vehicles, bicycles and pedestrians may be the better implemented of the tools (though note the more limited information freely available).
   - Potentially well integrated with Autocad CAD and BIM tools.
   - Proven in a range of past projects, though currently unavailable during integration with InfraWorks.

Sammendrag

Simuleringsverktøy for planlegging og utforming av sikre gatekryss for gående og syklende

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Forfattere: Tanu Priya Uteng (TØI) and David Taylor (Movement Strategies)
Oslo 2015 55 sider

Det norske samfunnet møter komplekse utfordringer når det gjelder balansegangen mellom redusert bilbruk og økende bruk av bærekraftige transportmidler som kollektivtrafikk, sykling og gange. Trafikksikkerhet er en underliggende fellesnevner når det er snakk om veksttrender. Derfor er det behov for å trekke frem sikkerhet som en av de viktigste byggesteiner for balansert fremtidig vekst. Trafikksikkerhet forutsetter en langsiktig strategi som legger til rette for at infrastruktur kan imøtekomme de behovene transportbrukere har i framtiden. Denne rapporten gir et systematisk perspektiv på sammenhenger som antas å være viktige i forhold til informerte fremtidige beslutninger rundt modellering av gatekryss i byer og tettsteder.

Design av fotgjengermodeller

Et hovedpoeng er at fotgjengermodeller fundamentalt skiller seg fra kjøretøymodeller. Veitrafikk kan defineres som et frittstående system med forhåndsbestemte atferder, som er utformet av et system av lenker med bestemte regler. Fotgjengere er frigjort fra disse forhåndsbestemte atferdene; bevegelsen er "fri". Simuleringsmodeller for fotgjengere baserer seg derfor på hele det tilgengelige *området* man kan bevege seg innenfor. Dette inkluderer startpunkt, sluttpunkt og forskjellig atferd definert ved relevante deler av det totale området.

Fotgjengeres "ønskelinje" for bevegelse må modelleres nøyaktig. I tillegg må grunnleggende aspekter ved området, som komfortabel og trygg fotgjengerbevegelse langs fortauer og venting på å få krysse veien, testes. Det samme gjelder for eventuelle forsinkelser og ventetid. Måling av gangtid, ventetid, telling, bruken av rom og folketetthet per m² er output som er felles for alle simuleringsmodeller. Disse målingene ligger til grunn for viktige beregninger i vurderingen av fotgjengeres opplevelse ved veikryss. Videoopptak, kombinert med mikrosimulerings-modeller for biler hvor det er relevant, kan være gode verktøy for å demonstrere forventede utfall samt fordeler og ulemper ved alternative løsninger for et vidt spekter av interessenter.

Social force modell

Denne modellen baserer seg på fotgjengeres primære formål – å komme seg fra A til B med en viss hastighet. Dette formålet påvirkes av fysiske og sosiale faktorer; agenter (dvs. mennesker) vil respondere på "motvirkende" krefter som et resultat av fysiske objekters begrensninger (vegger og andre hindringer) og tilstedeværelsen av andre agenter.

Modellen lyktes i å gjenskape virkelighetens atferd som for eksempel dannelse av motgående baner/felt (med en viss folketetthet) og "sjokkbølger" som forplanter seg i folkemengder ved smale åpninger og lignende situasjoner.

Legion/ ´OMCA´ modell

Denne modellen er utviklet av Keith Still (Still, 2000) og danner grunnlaget for verktøyet *Legion*. Premisset her er at det er mulig å oppnå resultater av samme kvalitet med en enklere matematisk tilnærming enn ved Social Force Modellen. Grunnlaget for denne modellen baserer seg på fire viktige atferdsregler beskrevet i detalj av Stills (2000);

- *Objective:* Å forsøke å bevege seg mot det ønskelige eller intenderte målet
- *Motility:* Å forsøke å opprettholde optimal hastighet
- *Constraint:* Å forsøke å opprettholde så liten distanse som mulig mellom deg selv og de andre objektene i miljøet
- *Assimilation:* Forsinkelser som oppstår når man leser og reagerer på miljøet

Adferdsbasert heuristisk (Behavioural heuristics) modell

Den kognitive forskningstilnærmingen som Moussaïd et al (2011) forfekter har i senere tid, i likhet med Legion modellen, ønsket å forenkle det matematiske grunnlaget for bevegelsesmodellen. Nærmere bestemt har en modell basert på avstanden mellom hindring i agentens synsfelt og som bruker to enkle heuristikker (enkle kognitive prosedyrer og raske beslutninger) blitt foreslått.

Sykkel (og kjøretøy) modellering

De tre hovedelementene ved mikrosimulering av biler - som også delvis gjelder sykkelmodellering - er som følger;

- Car-following modeller beskriver samhandlingen mellom et kjøretøy og kjøretøyet foran
- Modeller som illustrerer skifte av kjørefelt beskriver timing og hastverket ved kjørefeltskifte
- Gap-acceptance modeller avgjør timing og sikkerhet ved bevegelse i veikryss.

Algoritmene som utfører disse funksjonene varierer ut i fra programvareverktøyet som brukes og har forskjellige styrker og svakheter i forskjellige kontekster – men de overordnede konseptene er like.

Utvikling av sykkel-modeller

En viktig distinksjon når det gjelder syklister er bredden og den mye mer komplekse kjørefeltatferden. Generelt sett beveger derfor utviklingen av sykkel-modeller seg fra en forenklet tilknytning til kjørefelt, som er tilpasset motoriserte kjøretøy, til en mer avansert modell for "sidelengs" bevegelse, som er mer tilpasset syklister (og syklisters interaksjon med biler). Når dette kombineres med evnen til å modellere tildelte sykkelfelt burde det danne grunnlaget for modellering av de fleste tenkelige sykkelruter. Dette er et stort steg i utviklingen av sykkelmodeller i og med at de tidligere modellene anså sykkelmodellering som ubetydelig og utelukkende baserte det på kjøretøy-modeller. Foreløpig mangler området imidlertid helhet. De ulike verktøyene er på forskjellige utviklingsnivåer. Den generelle utviklingen virker allikevel å bevege seg i retningen av anvendbare tilpasninger til «car-following» modeller som innebærer å muliggjøre relativt sofistikert og nøyaktig modellering av syklister. PTV Group er for tiden spesielt sterk på dette området - delvis som et resultat av utviklingen av prosjekt i København.

Viktige hensyn ved design av veikryss

Simulering av veikryss-design med fokus på fotgjengere og syklister – både for å få plass til en høy andel av disse brukerne og for å forsørge optimale og sikre rutevalg – stiller krav til modellerings-verktøyets forskjellige egenskaper. En sammenfatning av hovedhensyn er gitt nedenfor, og brukes som grunnlag for vurdering og sammenligning av programvare-verktøy.

Hensynene nedenfor er supplert med en kort oversikt over noen trender i USA, Nederland og Storbritannia – med særskilt fokus på sykkelbruk, som uten tvil er den minst forståtte trafikantgruppen.

Hovedhensyn for programvareverktøy

Generelt

- *Modellvalidering:* Teknisk- og virkelighetsvalidering av modell-output for å sikre output som er en troverdig representasjon for den modellerte situasjonen, og som derfor har potensiale til å forme et nøyaktig beslutningsgrunnlag (inkluderer anvendbarhet til fotgjengere, syklister og kjøretøy).
- *Fullstendig integrert samhandling mellom transportmidler:* Utveksling av data om posisjon og fart mellom fotgjengere, syklister og kjøretøy ved hvert tidstrinn.
- *Integrering med signaltiming-verktøy:* Evnen til å optimalisere signaltiming er avgjørende – både gjennom faste og kjøretøy-aktiverte timinger så vel som LISA+, RBC, SCATS, SCOOT, Siemens VA, VS-PLUS og så videre.
- *Output kvalitet og tydelighet:* Valg av produksjon av høyt nivå og detaljert numeriske og geografiske output som egner seg for, ikke kun teknisk vurdering og konklusjoner, men også kommunikasjon mellom interessenter (For eksempel for gjengivelse i 3D).
- *Kostnad:* Indikativ kostnad for programvareverktøy når det gjelder lisens og opplæring sammen med bred forståelse av modellerings-tid/kostnad.

Syklister

- *Veiposisjon og forbikjøring:* Evnen til å modellere kjøretøy ved å bruke veirommet "fritt" (ikke begrenset til ett kjøretøy per felt) for å muliggjøre realistisk modellering av syklister og dermed potensialet til å ha en passende innvirkning på veikryssets oppsett/geometri i designprosessen. Inkludere samhandling mellom syklister og andre veibrukere for eksempel en bil og en sykkel som deler felt, og for å tilegne sykkelstier.
- *Klassifisering av hastighet og akselerering:* Evnen til å ta hensyn til hele spekteret av karakteristikker knyttet til forskjellige typer syklisters hastighet og akselerasjon i forhold til stigningsgrad.
- *Håndtering av hinder:* Evnen til å ta hensyn til hindre som kan ha direkte innvirkning på sykkelatferd og konsekvenser av det å møte på hindre for eksempel innsnevring av ruten og bussholdeplasser.

- *Atferd ved trafikksignaler:* Evne til å simulere venteatferd ved `forward stop zones`; inngrep på gangfelt[2]; bruk av sykkelspesifikke signaltiminger og overtramp ved rødt lys, spesielt ved høyresvinger.

Fotgjengere

- *Rutevalg og fleksibilitet:* Kombinasjon av det modellerte korteste rutevalg og pålagt navigeringsrute nødvendig for å oppnå tilstrekkelig kontroll når det gjelder effektiv modellering av fotgjengeres miljø.
- *Realistisk fotgjengermodell:* Passende matematisk grunnlag for å gjenskape fotgjengeratferd når det gjelder individuell bevegelse og folkemengders bevegelse.
- *Konfliktområder:* Evnen til å definere konfliktområder mellom fotgjengere og kjørende, og å inkludere veikryssmodellering på andre steder enn ved formelt markerte veikryss. Fleksibilitet er nødvendig for å garantere at dette reflekterer virkelighetens `ønske-linjer` for fotgjengere. Dette inkluderer planlagte ordninger som for eksempel utvidede midtdelere.
- *Atferd ved kryssing av vei:* Evnen til å modellere realistisk atferd når det gjelder fotgjengeres kryssvalg som aksept av avstand, forkjørsrett, og kjøretøy-responser.
- *Respons ved trafikksignaler:* Kontroll over hvorvidt fotgjengere følger signaltiming og eventuell `rågjengeri`.

Oversikt over simuleringsverktøy for modellering

Et kort sammendrag av relevante simuleringsverktøy er gitt nedenfor for å belyse potensielle fremtidige utviklinger. Verktøy med størst potensiale blir identifisert og konkret vurdert opp mot de viktigste hensynene beskrevet foran.

Informasjonen som gis her er basert på en kombinasjon av informasjon fra leverandører, bruk av prøveversjoner og gjennomgang av relevant materiale som annen forskning og andre prosjekter som er offentlig tilgjengelig og som har brukt et spesifikt verktøy.

Paramics/UAF

Sammendrag: Mikrosimulerings-verktøy og kjøretøymodell med sofistikert fotgjenger-modul (`Urban Analytics Framework` eller UAF) som muliggjør fullstendig interaksjon mellom kjøretøy og agenter. Legg merke til at to `versjoner` av Paramics-programvaren eksisterer, de stammer fra samme originale programvare – en eies av Quadstone Paramics/Pitney Bowes og den andre av SIAS. Ettersom UAF er inkludert i Quadstone produktet, er det denne versjonen av programvareverktøyet som vurderes her.

[2] Inngrep på gangfelt betyr at sykler blokkerer gangfelt (noe som de i utgangspunktet ikke skal gjøre, men enkelte ganger likevel utnytter).

Viktige fordeler

- Autodesk og GIS-integrering.
- Velprøvd mikrosimulerings-modell for kjøretøy.
- Høy kvalitet på fotgjengermodulen.

Viktige begrensninger

- Sykler modelleres kun som et kjøretøy på lik linje med motoriserte kjøretøy; mangel på detaljert bevegelse innenfor kjørefelt og relaterte atferds-karakteristikker. Ingen informasjon om planlagt utvikling når det gjelder modellering av sidelengs bevegelse.

InControl Pedestrian Dynamics

Sammendrag: Sofistikert simulerings-verktøy for fotgjengere, men mangler foreløpig integrering med mikrosimulerings-verktøy for kjøretøy.

Viktige fordeler:

- Sofistikert fotgjengersimulering med dynamisk rutevalg basert på fotgjenger-forhold.

Viktige begrensninger:

- Foreløpig ikke integrert med simuleringsverktøy for kjøretøy.

Aimsun/Legion

Sammendrag: Velutprøvd mikrosimulerings-modell fra TSS, sammenkoblet med fotgjengersimulerings-modul som bruker Legion.

Viktige fordeler

- Rask og velutprøvd mikrosimulerings-modell for kjøretøy.
- Evne til å bygge hybridsimulering av kjøretøy – mesoskopisk modell av et større område, mikrosimulering av mindre områder av interesse
- Høy kvalitet på fotgjengermodulen.
- Integrert modell: muliggjør vurdering av interaksjon mellom kjøretøy og fotgjengere.

Viktige begrensninger

- Sykler er foreløpig ikke modellert med sidelengs bevegelse, men dette er under utvikling.
- Ikke tilgjengelig på norsk (engelskspråklig).

Vissim/Viswalk

Sammendrag: Etablert mikrosimulerings-modell for kjøretøy.

Viktige fordeler

- Alt-i-ett løsning for å modellere kjøretøy, syklister og fotgjengere.
- Syklister modellert med sidelengs bevegelse. Generelt høyt nivå på utviklingen av hvordan modellen oppfører seg når syklister blir simulert, inkludert erfaringer fra nylige utviklingsprosjekter i København. Parametersettinger er identifisert selv om det kanskje vil være behov for forskning/revisjon for å tilrettelegge for norske forhold.
- Forbedret fotgjengermodul som muliggjør kontrollerbar og kompleks algoritmisk basis.
- Potensial for å modellere detaljerte scenarioer som tar hensyn til komplekse atferder når det gjelder både syklister og fotgjengere.
- PTV Group, som utvikle modellene, har et godt rykte når det kommer til innovasjon og forskning, for eksempel Kretz, 2014.

Viktige begrensninger

- Fotgjengermodulen er fremdeles matematisk kompleks, men en kompetent utøver burde være i stand til å produsere pålitelige resultater.

Commuter/ InfraWorks 360 Traffic

***Sammendrag*:** Innovativ alt-i-ett løsning som behandler personreiser som hovedgrunnlag for analyse i stedet for å være styrt av transportmiddel.

Viktige fordeler

- Innehar potensialet til å være et sofistikert multimodus-verktøy. Inkluderer dynamisk modusvalg og ´lagdeling´ av gangstier/veier/veikryss for å tilrettelegge for kompleks atferd og prioriteter ved veikryss.
- Modellering av kjøretøy og sykler som ikke innebærer kjørefelt – tilrettelegger for forbikjøring der det er tilstrekkelig med plass inkluderer for eksempel sykler som kjører forbi busser som har stoppet.
- Innehar potensiale til å innlemme kollektivtrafikks innvirkning på design av veikryss.

Viktige begrensninger

- Foreløpig, som følger av overtagelse av Autodesk, i betatesting-fasen; gjennomgår integrering inn i InfraWorks-verktøyet.
- Slipplanen er enda ikke offentliggjort.

MassMotion

Sammendrag: Sofistikert 3D-simuleringsverktøy for fotgjengere, men mangler foreløpig integrering med mikrosimulerings-verktøy for kjøretøy.

Viktige fordeler

- Avansert kontroll over fotgjengertyper med unike `agendaer` underveis.
- Selvstyrende valg av agenters rute.
- Evne til å planlegge agenters `visuelle linje`, demonstrering av synsfeltet mens agenten går.

Viktige begrensninger

- Foreløpig ikke integrert med simuleringsverktøy for kjøretøy.
- Krever Autodesk Softimage.

Massive Insight

Sammendrag: Avansert simuleringsverktøy basert på `kunstig intelligens`.

Viktige fordeler

- Innehar potensialet til å implementere forskjellige typer matematiske modeller fra mer vanlige kjøretøy- og fotgjengermodeller.

Viktige begrensninger

- Foreløpig ikke tilgjengelig for kommersiell bruk. Utviklingen har tilsynelatende stagnert etter beta-testingen i 2009.

Vurdering av programvare i nærmere detalj

Følgende verktøy er ytterlige vurdert - på grunnlag av markedstilstanden i skrivende stund:

- *Aimsun/Legion*
- *Vissim/Viswalk*
- *Commuter/InfraWorks 360 Traffic*

Konklusjon og anbefalinger

Mye har skjedd i løpet av kort tid de seneste årene når det gjelder utviklingen av mikrosimulerings-verktøy, komplekse multimodemiljøer har blitt modellert. Velprofilerte prosjekter som Oxford Circus i London har, sammen med dybdestudier som sykkelmodellerings-studien i København, vist at det er mulig å vurdere komplisert veikryssdesign for alle veibrukere.

Når det er sagt, er det fortsatt utfordringer når det kommer til raffinering av enkelte modellfunksjoner og atferd spesielt når det gjelder syklister, ettersom disse utviklingene er nye og pågående. Selv om de alle beveger seg i samme retning, er ikke alle utviklere på samme utviklingsstadium.

Anbefalingene nedenfor er derfor presentert ut i fra vår beste forståelse av både nåværende og fremtidige utvikling av programvaremarkedet. Vi forventer at disse kan ha innvirkning på det programvarevalget som passer best – avhengig av de nøyaktige krav og tidsskala for kommende prosjekter.

Anbefalinger: Valg av programvareverktøy

Basert på vår forståelse av krav, trender i veikryssdesign for fotgjengere og syklister, og gjennomgang av simuleringsverktøyene presentert i denne rapporten kan vi anbefale tre programvareverktøy. De er rangert her etter funksjonalitet. Merk at ut i fra vår forståelse for utviklingsprioriteter når det gjelder utviklere av programvareverktøy, kan disse programvareverktøyenes verdi forandre seg vesentlig i løpet av de neste 12 månedene.

1. **Vissim/Viswalk (PTV)**
   - Utmerket integrering av motoriserte kjøretøy, syklister og fotgjengere. Muliggjør testing av egenskaper som sykkelstier/felt; signaltiming, inkludert "green scramble" og "green waves"; forward stop zones, inkludert midtstilte sykkelfelt; innsnevrende felt; og et utvalg av atferd knyttet til prioritet og aksept av mellomrom når det gjelder kjøretøy, syklister og fotgjengere.
   - Den mest velutviklede sykkelmodellen, inkluderer sidelengs bevegelse og de erfaringene fra København.

2. **Aimsun/Legion (TSS)**
   - Foreløpig nesten like god som Vissim/Viswalk, men den mangler sidelengs bevegelse når det kommer til sykkelmodellering. Noe mer kompleks integrering av kjøretøy og fotgjengere grunnet samarbeid mellom forskjellige bedrifter.
   - Får antakeligvis utviklet sidelengs bevegelse i løpet av 2016 baserer seg på et større, mer spesifikt og finansiert prosjekt og kan fort bli en enda større konkurrent til Vissim/Viswalk.
   - Potensielt effektivt fordi Aimsun allerede brukes av Statens vegvesen og flere kommuner i Norge.

3. **Commuter/InfraWorks (Autodesk)**
   - Foreløpig ikke tilgjengelig for kommersiell bruk.
   - Sett bort i fra dette, er den i utgangspunktet multi-modal og hadde antakeligvis kunnet tilby størst fleksibilitet av de tre anbefalte verktøyene.
   - Tidlige tegn på konflikt mellom kjøretøy, syklister og fotgjengere implementeres bedre i dette verktøyet.
   - Integreringspotensiale med Autocad CAD og BIM verktøy.
   - Uttestet og velfungerende i tidligere prosjekter, men er foreløpig ikke tilgjengelig for integrering med InfraWorks.

1 Introduction

This report details research into the available (and forthcoming) simulation tools which may be used for the planning and design of road junctions and crossings where it may be expected that pedestrians and cyclists are critical user groups. From the work cited by Statens vegvesen (Sagberg & Sørensen, 2012), it is the quality of design and planning for efficient and comfortable junctions for all users which is likely to result in fewer accidents, by virtue of reducing potentially dangerous conflicts between disparate road users.

Modelling of motor vehicle behaviours is outside the scope of this report per se, but micro-simulation of vehicles is both a well-established approach and we understand that Statens vegvesen are familiar with two of the major tools: *Vissim* and *Aimsun*.

In this report, we identify key considerations (Section 2.5) for the capability of software tools if they are to be used for effective junction design involving (potentially large numbers of) pedestrians and cyclists, together with motor vehicles. This list of considerations is supportive of the overarching aim of creating safer junctions through appropriate provision for all road users.

The key considerations are listed as 'general' or specific to pedestrians or cyclists - and not motor vehicles per se. However, the treatment of pedestrians and cyclists implicitly provides suitable handling of interactions with motor vehicles as part of a multi-modal simulation model.

2 Theoretical, practical and international context

This report is written in the context that the client has a working knowledge of the vehicle micro-simulation tools *Aimsun* and *Vissim* – and therefore an appreciation of their theoretical basis, benefits and key features.

In this chapter, we have given an overview of the modelling theories and approaches applied to pedestrians and cyclists, together with consideration of the interaction with vehicles.

Some example are identified to demonstrate the current state of the art.

Finally, key considerations are identified, to be used as a basis for comparison of the available tools in Chapter 4.

2.1 Pedestrian modelling

2.1.1 Introduction

The last 15-20 years has seen the emergence of various pedestrian models, based on differing theoretical backgrounds – though ultimately with the shared capacity to simulate realistic pedestrian movement in a variety of contexts and numbers of pedestrians. The major theoretical models are presented briefly here for context.

A key overarching point is that pedestrian models are fundamentally different from vehicular models in that where road traffic can be defined as a stand-alone system with prescribed behaviours, formed by some system of links for instance, pedestrian movement is 'free'. Pedestrian simulation models are therefore based upon the entire *area* available for walking, with origins, destinations, waypoints and various behaviours defined over relevant parts of the total area.

In addition to the accurate modelling of pedestrian 'desire lines' of movement, key aspects to be tested include the areas available for comfortable, safe movement of pedestrians along pavements and when waiting at crossings – together with potential delays and waiting times. Measures of walking times, waiting times, people counts, the use of space and densities of people per m^2 are outputs common to all pedestrian simulation models and form key metrics in the assessment of pedestrian experience at junctions. Video outputs, combined with vehicle micro-simulation models where relevant, can be powerful tools in demonstrating anticipated outcomes, problems and benefits to a wide range of stakeholders.

Note that the terms 'agent' and 'entity' are typically used (interchangeably) to describe the depiction of individual pedestrians within a model.

2.1.2 Social Force model

The Social Force Model was first developed by Dirk Helbing (e.g., Helbing & Molnár, 1995) through his work in the 1990s. The model is based on the primary purpose of pedestrians being to accelerate towards making progress towards a destination at a desired speed. This primary goal is influenced by physical and social factors; agents will respond to 'repulsive' forces as a result of the boundary of physical objects (walls, other obstacles) and of the presence of other agents (i.e., people).

The modelled area is thus evaluated based on the shortest distance from any point to the destination in question to provide the route to be followed, ideally, at the desired speed. The interaction with obstacles and other agents is then added based on algorithms that deal with the relative physical position and speed. This process also reflects the differing propensity of people to move depending on the surrounding density of people. A key parameter of the algorithm affects the extent to which agents consider obstacles/agents in front of them, to the sides and behind; for the model to be realistic, clearly agents must consider objects in 'sight' in front of them much more strongly than those behind.

The Social Force Model was successful in recreating real-world 'emergent' behaviours such as the formation of lanes in opposing flows of people (at certain densities) and the 'shockwaves' that propagate through crowds of people at narrow openings and similar situations.

One of the Model's weaknesses is its mathematical complexity, which places it beyond the understanding of most likely practitioners of a simulation model based on the theory (Still, 2000). However, in practice, this problem can be largely overcome by well-designed software which carefully controls which parameters of the algorithms can be edited.

2.1.3 Legion / 'OMCA' model

The model which is the basis for the software tool *Legion* was developed by Keith Still (Still, 2000) on the premise that a simpler mathematical approach than the Social Force Model could be used to create results that were just as well validated. The basis for this model is based on four key behavioural rules: Objective, Motility, Constraint, Assimilation (OMCA). In more detail, these are described by Still (2000) as:

- Objective: try to move to a desired or intended end point
- Motility: try to maintain your optimum velocity
- Constraint: try to maintain a minimum distance between yourself and the other objects in the environment
- Assimilation: delay time taken to read and react to the environment

As with the Social Force Model, the application of the (simpler) set of calculations relating to these four principles results in emergent behaviour in groups or crowds of people as would be expected in real life: lane formation and so on.

Note that the OMCA approach was also the basis for the development of a tool called *Myriad II* – also from Keith Still – which was subsequently integrated into the *Urban Analytics Framework* module of *Paramics*.

2.1.4 Behavioural heuristics model

More recently, the cognitive science approach taken by Moussaïd et al (2011) seeks, as with the Legion model, to simplify the mathematical basis of the movement model. Specifically, a model based on the distance of obstructions in agents' 'line of sight' is proposed, which uses two simple heuristics (simple cognitive procedures and rapid decision making).

The first considers the angle of movement, optimising between the overall destination and local obstacles. The second assesses the optimum speed to make desired progress while avoiding collisions on the chosen path. A third factor, considering physical contact, is included to account for behaviour at higher densities (and *only* at higher densities), not covered by the two main choices.

2.2 Bicycle (and vehicle) modelling

2.2.1 Overview

Comprehensive consideration of bicycles is a relatively new (and growing) priority for the design of urban roads, pavements and 'shared spaces'. Similarly, the inclusion of detailed modelling of bicycles within simulation models is also relatively new.

The use of bicycle models is strongly linked to vehicle models, because of the need to understand capacity for both bicycles and motor vehicles (and impacts on each other) when designing roads and, particularly, junctions. Bicycle behaviour is also ostensibly similar to motor vehicle behaviour – with the major difference (apart from different values for speed, acceleration etc) being the importance of lateral movement within and between lanes.

In this context, bicycle micro-simulation has grown as an extension to existing motor vehicle simulation models. The basic concept therefore follows the use of car-following (or bicycle following), gap-acceptance and lane-changing model algorithms, as described in the following section (2.2.2). Section 2.2.3 discusses the state of development of bicycle models, most notably with respect to the inclusion of lateral movement.

2.2.2 Relevant vehicle micro-simulation theory

The three main elements of vehicle micro-simulation modelling, which would also apply in some form to bicycle modelling, are:

- car-following models describe the interaction between a vehicle and the vehicle in front;
- lane-changing models describe the timing and urgency of changing lane; and
- gap-acceptance models determine the timing and safety of movements at intersections.

The algorithms to perform these functions vary by software tool, and have various strengths and weaknesses in different circumstances, but the broad concepts are common.

Of the five types of model defined by Brackstone and McDonald (1999), three are currently in limited or no use because of problems such as difficulties with calibration or subjectivity. The two main types which form the basis of the widely accepted and market-leading tools are listed below.

"Psychophysical" or "Action Point" Based on the use of thresholds which define driver behaviour, such as braking actions, spacing to the vehicle in front and judgement of changing gaps between vehicles. Greater algorithmic complexity means greater difficulty in calibration. Two main examples: Fritzsche (1994) and Wiedemann (1974, 1991) – these form the basis of *Paramics* and *Vissim* respectively.

"Collision Avoidance" or "Safety Distance" Based on calculation of safe following distances given vehicle speeds, driver reaction times and distances between the vehicles. Relatively easily calibrated based on relatively few, more intuitive parameters: desired speed and headway, reaction time and both normal and maximum acceleration/deceleration speeds. Example: Gipps (1981) – a variant of which is used by *Aimsun*.

Previous studies have gone some way to establishing and discussing these strengths and weaknesses (e.g., Panwai & Dia, 2005; Gibson, 2012; Olstam & Tapani, 2004; Bloomberg et al, 2003). Note that a caveat to such studies is the specific basis for comparison and evidence used (e.g., country-specific), and the divorce from other practical considerations such as cost and institutional experience. The author is also aware of broad industry opinion. Generally speaking, *Paramics* may be considered more suitable for higher-speed roads, whereas *Vissim* and *Aimsun* could be considered better in urban situations.

For junction design, it is also important to note that *Paramics*, *Vissim* and *Aimsun* all have links to traffic signal software to allow the representation of realistic (and optimised) signal timings/behaviour.

2.2.3 State of development of bicycle models

A key differentiator for bicycles is their width, and the associated more complex lane behaviour. Generally speaking, model development for bicycles is therefore in the process of moving from simplistic lane adherence that is appropriate for motor vehicles to more advanced modelling of 'lateral' movement appropriate for bicycles (and their interaction with motor vehicles). When combined with the ability to model dedicated bicycle lanes, this additional capability should provide the basis for modelling the majority of conceivable bicycle routes. This is a step change from past modelling of bicycles, which considered them only nominally, based purely on the vehicle model.

The industry as a whole is not there yet. Different tools are at different stages of development. However, the overall direction is towards suitable adaptations to the car-following models to enable relatively sophisticated and accurate modelling of bicycles. PTV are currently notably strong in this area, as discussed in Chapter 4 – partly as a result of the development project in Copenhagen (Section 2.4.2).

Amongst the changes implemented by PTV, and it is reasonable to assume that similar adaptations will be forthcoming from other software companies (though with uncertain timing), some of the key aspects are:

- Lateral lane position and overtaking behaviours – with differences on cycle lanes, dedicated cycle paths, merges between the two, and on approach to junctions.
- Specific signalling of lanes and vehicles, including multiple signal heads on a single lane with different vehicle class settings so that motor vehicles and cyclists can receive and react to different signal timings.
- Signal compliance rates, including differences at smaller and larger junctions, and for straight-on and right-turn movements in particular.

Further detail, taken from the PTV/COWI Copenhagen study, is given in Section 2.4.2.

We note that some tools, which are not currently appropriate for detailed bicycle modelling, will be much better suited within relatively a short timescale (e.g., approximately 6 months to 1 year). This inevitably complicates the pros and cons in this one-off comparison study.

2.3 Interaction between vehicles/bicycles and pedestrians

Interaction is possible at junctions – both signalised and non-signalised – and at other points of the road network where 'informal' crossing may occur, particularly at points crossing a desire line of pedestrian movement.

In addition to the modelling of vehicles and bicycles based on car-following models, and pedestrians based on free-space models using models such as Social Force or OMCA, the conflict points between these road users have a great influence on the capacity of junctions – and their safety.

Key aspects for modelling are that the vehicles/bicycles and pedestrians can be simulated with genuine interaction within a single model environment, and that a range of conflict areas and associated behaviours can be defined. Parameters are needed to enable control of road crossings through priority rules, gap acceptance, range of sight and signal adherence/violation probabilities. Priority rules need to be able to accommodate vehicle priority, bicycle priority or pedestrian priority – or a first-come-first-served situation.

2.4 Theoretical, practical and international context

Various example cases are available from the software companies. Here we present two illustrative examples to help demonstrate the potential.

2.4.1 Oxford Circus, London

A relatively early yet ambitious example of the combination of vehicle and pedestrian modelling was done for Oxford Circus in London. The project actually used a combination of *Vissim* and *Legion* – so not a single modelling environment, but a combination of two distinct studies. Even with this restriction, well-designed testing of options, scenarios and sensitivities demonstrates what can be done. The intersection is high-volume, with up to in excess of 43,000 people and 2,000 vehicles per hour – and with 23,000 people accessing the London Underground station beneath the junction.

The problems at the junction (Figure 1) included overcrowding at sections where pavement design was poorly aligned to pedestrians' goals – or desire lines of movement. This also led to safety problems through people jumping barriers and jaywalking in relatively dangerous parts of the busy junction.

Figure 1: Oxford Circus before implementation of the scheme. Source: TfL, 2010a.

The solutions – modelled for both vehicles and pedestrians – involved:

- clearing away street furniture and barriers to pedestrian movement;
- adjusting kerb lines to widen pavements
- reorienting the pedestrian crossings to align better with desire lines;
- extending median islands to allow for more safe informal crossing points; and
- adjusting signal timings including introducing a 'green scramble' phase to allow pedestrians to cross freely with no vehicle movements – including across the diagonal.

The modelling of these solutions demonstrated both the benefits to pedestrians and very little change to traffic and bus journey times. The scheme (Figure 2) was opened in 2009 and has widely been considered a success.

Figure 2: Oxford Circus pedestrian crossing scheme after opening. Source: TfL, 2010a.

In the first lessons learned report, it was noted that many iterations of modelling were required, responding to the changing brief and the requirement for detailed modelling around London Underground entrances (TfL, 2010a). The value for money of modelling was also noted as a positive, though with a lesson learned being the benefit of building a bespoke model from scratch rather than using an old *Vissim* model.

2.4.2 Copenhagen "Cykelflow" scheme

The City of Copenhagen has been looking to increase capacity for cyclists on bicycle lanes in recent years – including initiatives such as introducing fast and slow lanes, green waves of signals and better waiting zones. To support this work, an investigation was conducted into the potential for modelling accurate bicycle behaviour within a micro-simulation model (COWI, 2013). The study was done using *Vissim*.

Through the collection of new data, the study created an updated and validated set of parameters to be used to simulate cyclists within *Vissim*. The ten parameters examined were (COWI, 2013):

- Basic parameters
  - Vehicle characteristics
  - Speed distributions
  - Acceleration distribution

- Relevant to cycle paths
  - Following parameters
  - Overtaking parameters
  - Behaviour at narrowing section
  - Behaviour at bus stops

- Relevant to intersections
  - Behaviour in waiting zones
  - Behaviour at stop lines
  - Behaviour at right turns

These parameters relate to various elements of the model that were identified, such as illustrated in Figure 3.

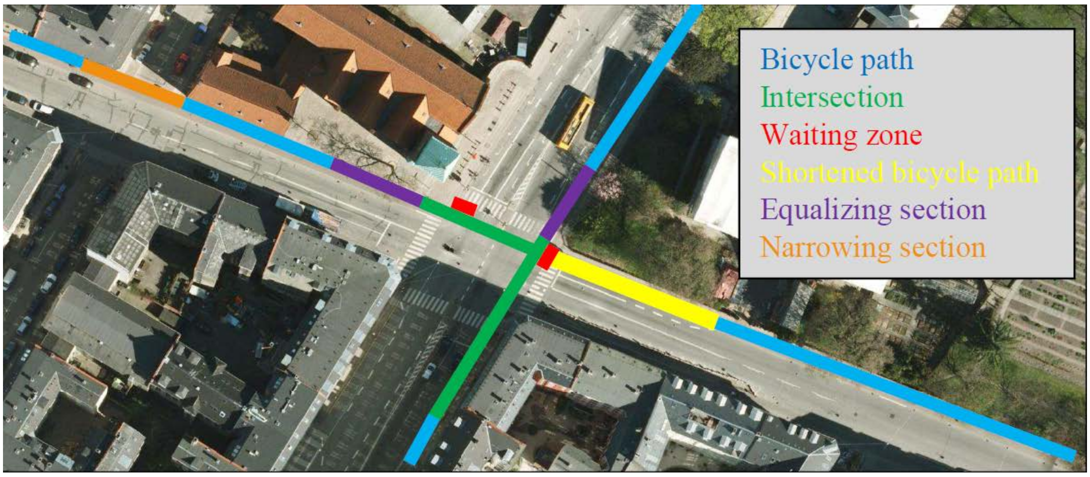

Figure 3: COWI sketch of modelled elements for cyclists in Vissim. Source: COWI, 2013.

The basic parameters included new 'vehicle' types to represent a range of bicycles, together with new speed distributions that together describe level, uphill and downhill riding and turns for normal, carrier and electric bicycles. This is supported by acceleration distributions which reduce bicycles' acceleration relative to motor vehicles – potentially prolonging conflict between different vehicle types at intersections.

The study also made adjustments to the 'Wiedemann 99' car-following model, optimising parameters for situations involving bicycle paths and intersections. Among the bicycle flow parameters, control over the speed, lateral position and the closeness and 'aggression' of overtaking manoeuvres are key.

Special attention was given to narrowing sections of bicycle path – with a new link type defined. This allows for the definition of lateral weaving manoeuvres in sections of reduced width (e.g., reducing the number of overtaking manoeuvres) – and for up to 50m in advance of those narrowings.

For bus stops where passengers embarking/disembarking could block the cycle path, a detector at the bus stop is used to activate reduced speeds on the bicycle path and control the number of cyclists making a full stop. This functionality made use of the *VAP* programming tool within *Vissim*.

At intersections, the behaviour in waiting zones was identified as important – with cyclists feeding through to waiting zones and commonly blocking pedestrian crossings. Notional signals were used to control this stopping forward of the vehicle stop line and adjust signal timings to reflect cyclists' behaviour (e.g., early starts prior to green). Further parameters control lateral movement and the shape of queuing – with cyclists packing together in the waiting zone.

In addition to waiting zone behaviour, the treatment of stop lines was examined. This demonstrated the increased lateral movements on approach to a stop line, as cyclists find the optimal path. Also the adherence to red lights – with more violations at smaller junctions and hardly any at large intersections. These observations led to advice for a particular link behaviour on approach to the junction (for about 75m – the 'shortened bicycle path in Figure 3).

For the red light violations, PTV introduced a new function to allow a proportion of road users to ignore the red signal – not reliant on vehicle types or classes. This can therefore be used with a separate signal head for bicycles.

For the transition from bicycle paths to lanes on the road, an additional link behaviour was introduced. This handles overtaking and keep-right behaviour to ensure capacity problems are not overstated. Such links are particularly important (and may need to be longer) where the volume of cyclists is high.

As is suggested by the level of detail in this summary, the Copenhagen study is a very useful reference for some of the technical challenges that need to be overcome to ensure realistic modelling of cyclist behaviour, and its impact on intersection capacity.

2.5 Key considerations for junction design

2.5.1 Some thoughts on design

Simulation of junction designs with a focus on pedestrians and cyclists – both to accommodate large numbers of those users and to provide optimal, safe route choices for them – requires various capabilities of the modelling software. A summary of key considerations are given below in Section 2.5.2, to be used as a basis for assessment and comparison of the software tools in Chapter 4.

These considerations are given further context by the discussion below, giving a brief overview of some trends in the US, the Netherlands and the UK – with a particular focus on bicycle use; arguably the least well understood and provided-for user group.

US

The National Association of City Transportation Officials (NACTO) in the US published their first Urban Bikeway Design Guide in 2011 – regarded as some of the most forward-thinking advice in the US, a country known for the primacy of the car. Notably, this first edition was revised just a year and a half later with the release of the Second Edition (available online at http://nacto.org/cities-for-cycling/design-guide/) – including features such as 'bike boulevards'. This update reflected the desire by NACTO to include the latest options regarding bicycle design.

Some of the guidance in the first edition gave rise to debate in the industry about the quality of the advice – and whether it included the latest and best options. One such example was the advice on through-bike-lane design (Figure 4). This was criticised by those familiar with junction design in the Netherlands, with particular problems cited including the mixing of cycles with motor vehicles in the middle of the intersection, and the unsighted lane changes required for bicycles or cars (e.g., requiring cars to check their blindspot to assure avoidance of bicycles). A different illustration was included for the second edition (Figure 4), illustrating the potential importance of modelling lateral bicycle and vehicle movement accurately.

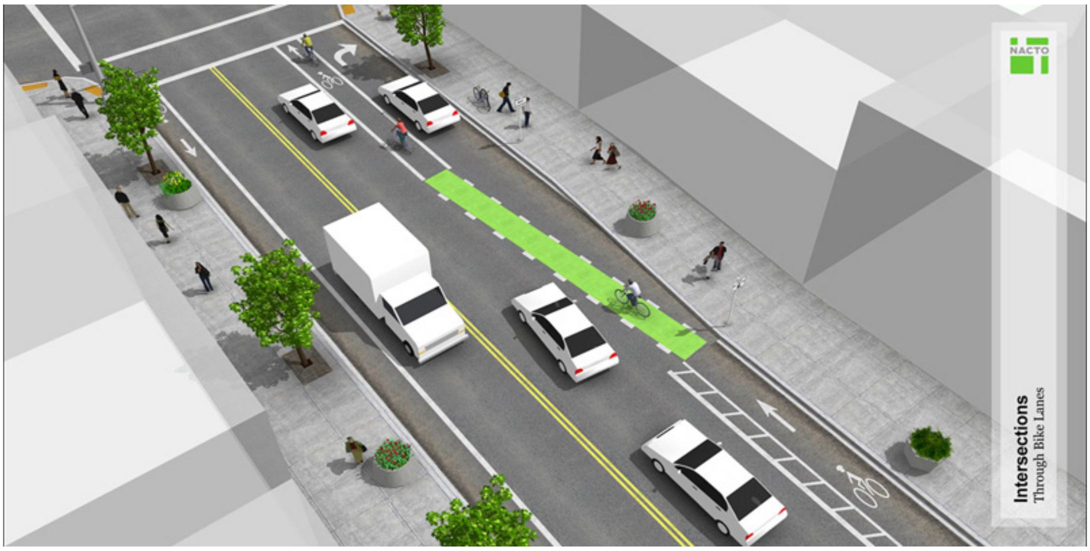

Figure 4: NACTO through-bike-lane design advice, Urban Bikeway Design Guide, First Edition. The design has received criticism for encouraging cars to change lanes while potentially unsighted from bicycles – and for leaving bicycles to negotiate left turns at risk from motor vehicles. Source: NACTO Urban Bikeway Design Guide, First Edition.

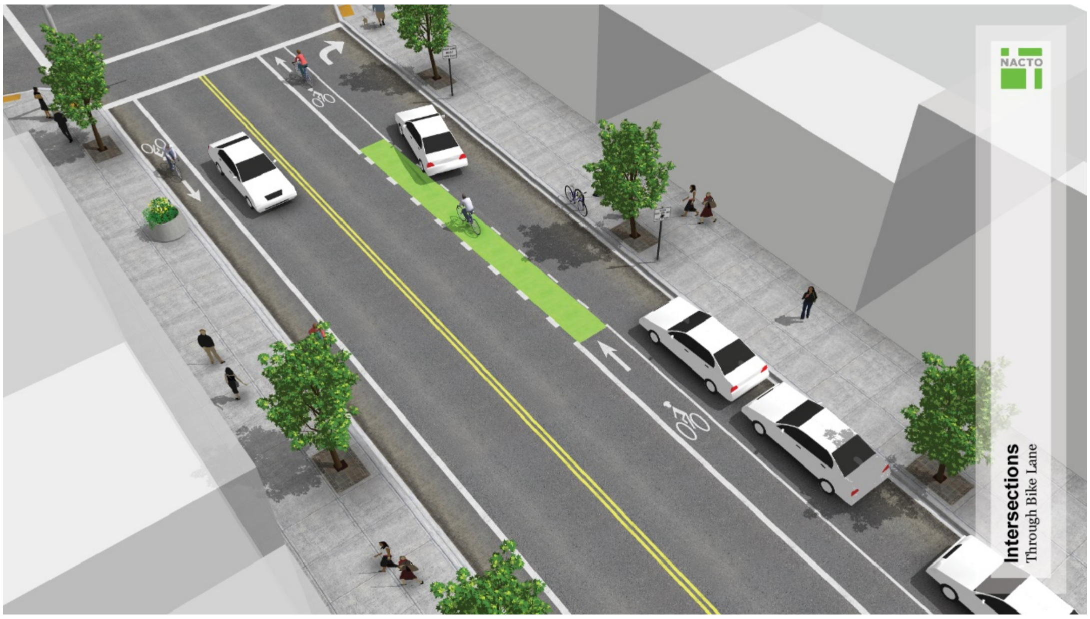

Figure 5: Revised through-bike-lane design advice, NACTO Urban Bikeway Design Guide, Second Edition. Source: NACTO Urban Bikeway Design Guide, Second Edition.

This has led to some advocating an approach more in line with designs common in the Netherlands. Some further thoughts are given below.

Netherlands
Examples from the Netherlands promote keeping cyclists to the right, segregated from motor vehicles (e.g., illustration in Figure 6 from Mark Wagenbuur). This requires different treatment of the junction itself to create 'protected intersections' for cyclists (e.g., for possible implementation in the US, see http://www.protectedintersection.com/).

Figure 6: Illustration of common (though not only) Dutch junction design, incorporating 'protected' cycle lanes which allow for two-stage left turns, increase the separation between bicycles and vehicles, and create clear sightlines for points of conflict between bicycles and vehicles. *Source: Mark Wagenbuur (https://bicycledutch.wordpress.com/).*

More recently, the use of 'simultaneous green' or 'scramble green'[3] phases has been used in the Netherlands to afford bicycles complete priority for all movements for one phase of the traffic signals cycle (sometimes more than one phase within the cycle). This approach removes the major safety hazard of vehicle/bicycle conflicts, while creating conditions that can in principle allow for rapid movement of large numbers of cyclists.

This is the case in part because of the lack of conflicting movements and in part because of the ability to follow direct desire lines – even diagonally across a junction (Figure 7). This takes advantage of the natural curves followed by cyclists, rather than sharp turns, meaning that conflicts are relatively few within the space of the junction – and those that occur have space to be negotiated. The basic principles can be applied at all junction scales, though there is not a one-size-fits-all design solution to accompany the signal phasing.

3 'scramble green' is the use of a traffic light phase in which all vehicles are stopped and all pedestrians have green - including the ability to cross diagonally (as in the new Oxford Circus design in London f.eks).

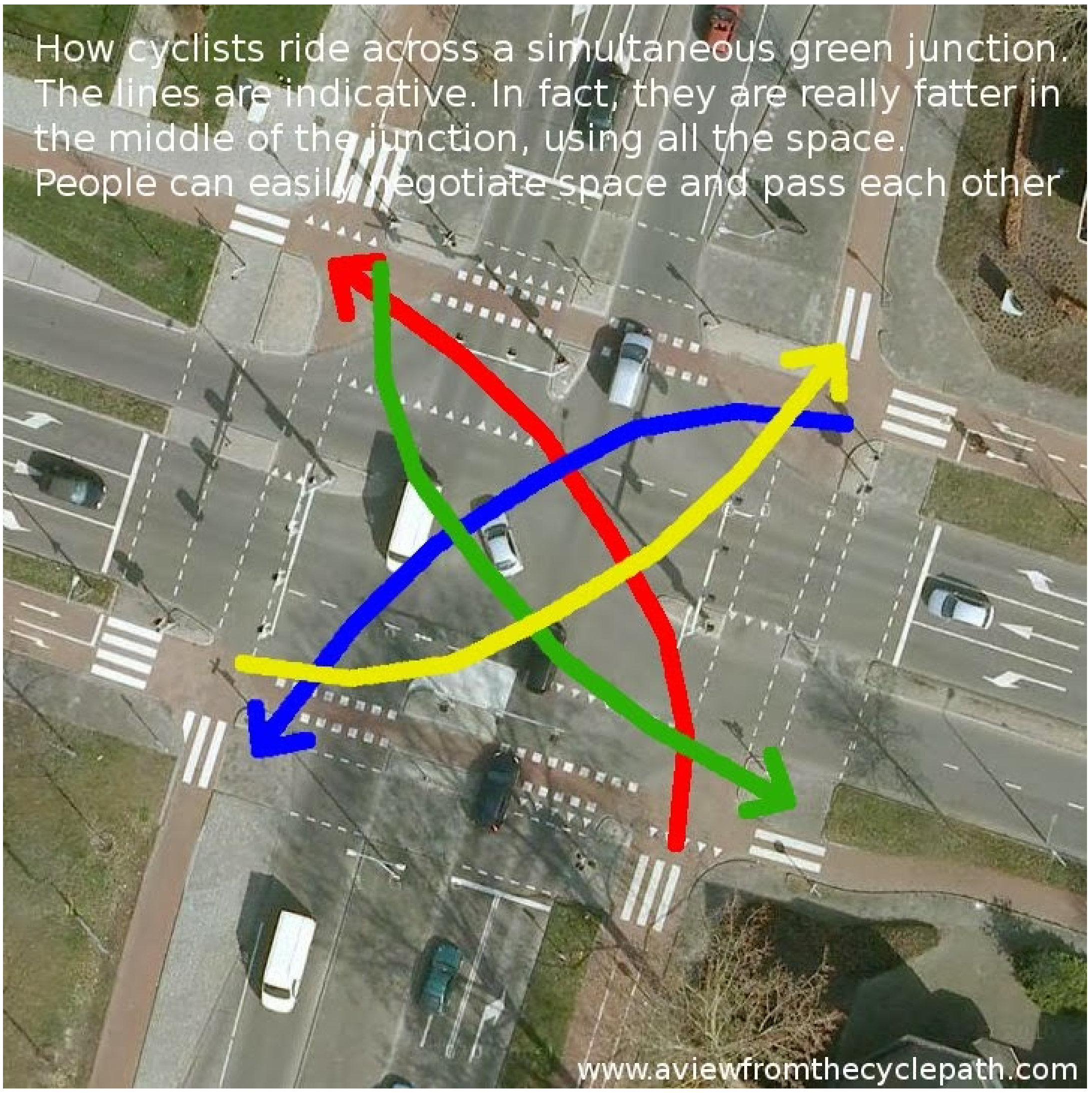

Figure 7: Indicative cyclists' turning movements across a junction during a simultaneous green phase. Source: www.aviewfromthecyclepath.com.

Further options and details according to road type are given in the influential CROW "Design manual for bicycle traffic" (CROW, 2007); Section 6 of the manual covers intersections.

UK

In recent years the UK has seen a growing push towards increasing the number of bicycle trips – but also providing for cyclists' safety. This has arguably been most prominent in London, though with limited success so far. In June 2014 a consultation version of the updated London Cycling Design Standards (LCDS) were published.

Amongst the proposals are plans to introduce a Cycling Level of Service (CLoS) assessment– scoring streets out of 100 and junctions out of 36 against best practice standards. In addition, junction design advice has been updated to take much greater advantage of experience in places like the Netherlands. For instance, one of the concepts included in the LCDS is for a junction with island protection for cyclists (Figure 8) – similar to that shown above from the Netherlands and being implemented in the US. A TfL / Transport Research Laboratory real-life trial of a similar roundabout design type is on-going in 2014.

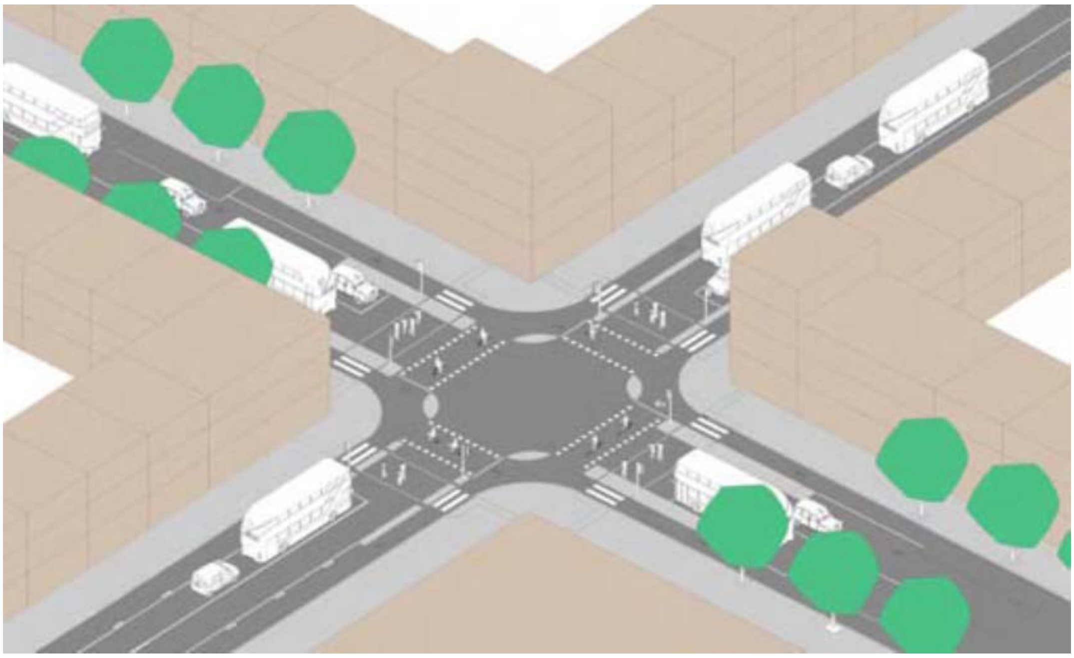

Figure 8: London Cycling Design Standards illustration of possible junction design based on Dutch 'protected intersection' concept. Source: Transport for London Draft Cycling Design Standards (TfL, 2014).

There is also consideration of 'shared space' as a workable solution – though the guidance is that bicycles should be considered as vehicles and the highest levels of service for them come with dedicated facilities rather than shared spaces. Nonetheless, this can be an option – particularly where there are mixed uses of the space naturally, such as in town-centre settings. Examples include Poynton in the UK (modelled using *Aimsun/Legion*) and Graz in Austria.

The new guidance for London marks a potential step change in provision, though influential groups such as the London Cycling Campaign are in the process of preparing comments. Arguments for further strengthening the guidance will include calls for: better advice on where and why different junction design options should be selected; more detail on traffic signal timings and innovations; consideration of a 'green scramble' phase for cyclists and pedestrians – as discussed briefly above.

For London, this advice is set in the context of Transport for London modelling advice (Tfl, 2010b). The modelling guidelines discuss both empirical, deterministic models and micro-simulation tools. There is recognition of the additional value of micro-simulation modelling in representing driver behaviour rather than the aggregate representation used by deterministic models. For complex junctions involving pedestrians and cyclists, this benefit is particularly pronounced.

The TfL guidance advocates used of *Vissim*, with the capability of the organisation to audit and manage modelling work from consultants part of the consideration. However, the limitations of this approach have also been recognised and there is an on-going process in 2014 to re-assess the modelling capability and approach, with *up to 3* software providers expected to be chosen.

The TfL modelling guidance also discusses pedestrian considerations (TfL, 2010b Section 6). The advice promotes the need to understand pedestrian 'desire lines' of movement as well as the volume of movements for accurate modelling. The need to plan for the impact of pedestrians on vehicle capacity is also recognised, with the expectation that micro-simulation modelling should be used to test options. These may include a range of signalised, request and priority crossings – and, if signalised, either full pedestrian phases or parallel phases combining vehicle and pedestrian movements. Further guidance on modelling with *Legion* specifically is given in TfL's "Street Level Modelling with Legion Best Practice Guide" (TfL, 2008) – though the guide predates the current level of interaction between *Legion* and *Aimsun*.

The TfL guidance also suggests that when bicycle volumes exceed approximately 20% of the total traffic volume on any one approach to a junction, they may have a disproportionate effect on the results of modelling and thus require additional consideration. That said, we note that the guidance was written before the latest adaptations for bicycle representation (e.g., in *Vissim*) were introduced.

Summary

The brief discussion above serves to highlight some of the aspects of junction design that can be important where pedestrians and cyclists are to the fore, such as:

- Advanced stop lines (ASLs) for bicycles (and feeder lanes to the ASL)
- Widened carriageways
- Dedicated bicycle lanes, including protected lanes for crossings
- Two-stage left turn boxes for bicycles
- Roundabouts with cycling priority lanes
- Intersection bicycle crossing markings
- Median refuge islands
- Through bicycle lanes
- 'Protected intersections' for bicycles (segregated bicycle lanes using corner islands)
- 'Green scramble' signal phases for pedestrians and/or bicycles
- 'Shared space'

With junction design elements such as these in mind, the following section gives key considerations of modelling software tools to allow for testing such options.

2.5.2 Key considerations for software tools

A. General

A.i. Model validation: technical and real-world validation of model outputs to ensure outputs are a credible representation of the situation modelled and therefore have the potential to form an accurate basis for decision-making (including applicability to pedestrians, cyclists and vehicles).

A.ii. Fully integrated interactions between modes: exchange of position and speed data between pedestrians, cyclists and motor vehicles at each time step.

A.iii. Integration with signal timing software: ability to optimise signal timings is critical, through fixed and vehicle actuated timings, as well as LISA+, RBC, SCATS, SCOOT, Siemens VA, VS-Plus, etc.

A.iv. Quality and clarity of outputs: options to produce both high-level and detailed numerical and graphical outputs suitable for not only technical assessment and conclusions but also stakeholder communication (e.g., to include 3D rendering).

A.v. Cost: indicative costs of software licences and training, together with broad appreciation of modelling time/cost.

B. Cyclists

B.i. Road position and overtaking: ability to model vehicles using road space 'freely' (not restricted to one vehicle per lane) to enable realistic modelling of cyclists in particular (thus having the potential to have an appropriate impact on junction layout/geometry in the design process). To include interaction between bicycles and other road users (e.g., a car and bicycle sharing a lane) and dedicated cycle paths.

B.ii. Classification of speed and acceleration: ability to take account of the wide range of speed and acceleration characteristics of different bicycle user types, in the context of surface gradient.

B.iii. Dealing with obstructions: ability to take account of obstructions that may have a direct bearing on cyclist behaviour and knock-on impacts in relation to movement and capacity (e.g., narrowing of route, bus stops etc).

B.iv. Behaviour at traffic signals: ability to simulate waiting behaviours in 'forward stop zones'; encroachment on pedestrian crossings[4]; the use of cycle-specific signal timings; and red-light violations (full violation or early start), especially for right turns.

C. Pedestrians

C.i. Route choice flexibility: combination of modelled shortest-path choices and imposed navigational routes required with sufficient control to model the pedestrian environment effectively.

C.ii. Realistic pedestrian model: appropriate mathematical basis to recreate pedestrian behaviours relating to individual movement and aggregate, crowded movement.

C.iii. Conflict areas: ability to define (freely) areas of conflict between pedestrians and vehicles, to include modelling crossings at places other than formally marked crossings. Flexibility is required to ensure that the modelling reflects real-world 'desire lines' of movement for pedestrians (including for planned schemes such as extended central reservations).

C.iv. Crossing behaviour: capability to model realistic behaviours of pedestrian crossing choices (gap acceptance, right of way, etc) and vehicle responses

C.v. Response to traffic signals: control over pedestrian adherence to signal timings and 'jaywalking'.

4 encroachment on pedestrian crossings means cycles blocking pedestrian crossings (which they are not meant to do but sometimes take advantage of that space)

3 Simulation modelling tools overview

3.1 Introduction

In this section, a brief overview of relevant simulation tools is given for context and to illustrate potential future developments. The most promising are identified for specific assessment in Chapter 4, against the key considerations identified in Section 2.5.

This section concerns a high-level overview only; not a thorough assessment. A full assessment of all tools against specific criteria was necessarily outside the budget/time scope of the review project. The information given here is based on a combination of information from suppliers, use of trial versions and review of relevant material (e.g., other publicly-available research/project work that has used a particular tool).

As this is only a brief overview of relevant products, that is why some currently do not warrant further testing (e.g., as stated, Pedestrian Dynamics). Similarly, the differences in length of content reflect (at least in part) the relevance/importance of each tool.

3.2 Software tools

3.2.1 Paramics / UAF

Summary

- Micro-simulation vehicle model with sophisticated pedestrian module ('Urban Analytics Framework' or UAF) allowing for full interaction between vehicles and agents.
- Note that two 'versions' of Paramics software exist (stemming from the same original software) – one owned by Quadstone Paramics / Pitney Bowes and the other by SIAS. Given the inclusion of UAF within the Quadstone product, it is that software tool that is considered here.

Model theory/approach

- Vehicle micro-simulation based on car-following model developed by Fritzsche (1994).
- Pedestrian simulation model based on OMCA, as described in Section 2.1.3.

Key Benefits

- Autodesk and GIS integration.
- Proven micro-simulation vehicle model.
- High-quality pedestrian module.

Key Limitations

- Bicycles modelled only as another vehicle type similar to motor vehicles, lacks detail of within-lane movement and related behavioural characteristics. No information on planned development of lateral movement modelling.

3.2.2 InControl Pedestrian Dynamics

Summary

- Sophisticated pedestrian simulation tool, but currently lacking integration with a vehicle micro-simulation tool.

Model theory/approach

- Exploites the recently developed behavioural heuristics model, as described in Section 2.1.4.

Key benefits

- Sophisticated pedestrian simulation with dynamic route choice based on emerging pedestrian conditions.

Key limitations

- Currently not integrated with a vehicle simulation tool.

3.2.3 Aimsun / Legion

Summary

- Proven micro-simulation model by TSS, paired with pedestrian simulation module using *Legion*.

Model theory/approach

- Vehicle micro-simulation based on car-following model developed by Gipps (1981).
- Pedestrian micro-simulation based on Legion/OMCA model as described in Section 2.1.3.

Key benefits

- Proven micro-simulation vehicle model with fast run times.
- Ability to build hybrid vehicle simulation – mesoscopic model of larger area, micro-simulation of smaller area of key interest.
- High-quality pedestrian module.
- Integrated model: allows for assessment of interaction between vehicles and pedestrians.

Key limitations

- Bicycles not currently modelled with lateral movement (though actively in development).
- No Norwegian language option (English supported).

3.2.4 Vissim / Viswalk

Summary

- Established micro-simulation vehicle model

Model theory/approach

- *Vissim* micro-simulation based on car-following model developed by Rainer Wiedemann, Karlsruhe University 1974 and 1999. The model describes 4 states: free driving; approaching a vehicle in front; following a vehicle in front; and braking.
- Lane changing in Vissim is implemented to account for navigational lane changes and overtaking manoeuvres.
- Road behaviour is non-lane based. This allows for road positions wherein two vehicles occupy space within the same lane – such as cars and bicycles in a road lane, or bicycles on a cycle path. This potentially allows for better modelling of, e.g., bicycles approach a forward stop zone by laterally avoiding cars within the same lane on approach to the stop line.
- The Viswalk model is based on the Social Force Model described in Section 2.1.2.
- The combined *Vissim/Viswalk* model is operated from a single user interface.

Key Benefits

- All-in-one solution to model vehicles, bicycles and pedestrians.
- Bicycles modelled with lateral movement and greater level of development overall for bicycles, including recent developmental project experience in Copenhagen. Parameter settings identified (albeit research/revision for Norwegian context might be required).
- Much-improved pedestrian module which allows complex algorithmic basis to be relatively well controlled.
- Potential to model detailed scenarios involving complex behaviours of both bicycles and pedestrians.
- PTV have a strong record of innovation and research (e.g., Kretz, 2014).

Key Limitations

- Pedestrian module remains complex mathematically, though a competent practitioner should be able to produce reliable results.

3.2.5 Commuter / InfraWorks 360 Traffic

Summary

- Innovative all-in-one solution considering person-trips as the primary basis for analysis, rather than being mode-led.

Model theory/approach

- Powerful options to use any of the three most commonly adopted vehicle micro-simulation algorithms: Fritzsche (1994, used in Paramics), Gipps (1981, used in Aimsun) and Wiedemann (1974/1999, used in Vissim).
- Pedestrian simulation model TBC (limited information available during beta testing).

Key benefits

- Potential to be a sophisticated multi-modal tool, including dynamic mode choice and 'layering' of walkways/roads/crossings to allow for complex priorities and crossing behaviour.
- Non-lane based modelling of vehicles and bicycles – allows for vehicles to pass where there is sufficient width (e.g., including bicycles overtaking stopped buses).
- Potential to incorporate the influence of public transport modes on junction design, e.g., a rush of pedestrian demand from people disembarking from a bus or train close to junction.

Key limitations

- Currently in beta testing following takeover by Autodesk; undergoing integration into the InfraWorks tool.
- Release plan not yet public.

3.2.6 MassMotion

Summary

- Sophisticated natively 3D pedestrian simulation tool, but currently lacking integration with a vehicle micro-simulation tool.

Model theory/approach

- Modified Social Force Model (on which see Section 2.1.2), incorporating agents' awareness of 3D space (incorporating work by Kuffner, 1998 and Dijkstra, 1959).

Key benefits

- Advanced control over pedestrian class types, with unique 'agendas' en route.
- Autonomous agent route choice.
- Ability to plot line-of-sight of agents, demonstrating their field of view when walking.

Key limitations

- Currently not integrated with a vehicle simulation tool.
- Requires Autodesk Softimage.

3.2.7 Massive Insight

Summary

- Advanced simulation tool based on 'artificial intelligence'.

Model theory/approach

- Developed initially from movie-animation beginnings, Massive Insight was designed to be a sophisticated simulation tool for pedestrians and vehicles (of all types) based on an implementation of artificial intelligence exploiting simulated senses of sight, hearing and touch. Potential for greater sophistication in the interaction of agents and their responses.

Key benefits

- Potential to implement different type of mathematical model from the more typical vehicle and pedestrian models.

Key limitations

- Not yet available for commercial use; development appears to have stalled since 2009 beta testing programme.

3.3 Software to be assessed in greater detail

On the basis of the state of the market at the time of writing, we recommend considering the following tools:

- *Aimsun / Legion*
- *Vissim / Viswalk*
- Co*mmuter / InfraWorks 360 Traffic*

These are assessed further in Chapter 4.

4 Detailed software assessments

For the purpose of evaluation, we have adopted the following methodology for each tool: manuals/guidance (including online resources) were reviewed; latest trial versions (at the time of writing) were used (within the time/budget constraints of the review); information was collated from each supplier and relevant documents were reviewed (as stated throughout).

4.1 Aimsun / Legion [TSS]

4.1.1 Overview

Aimsun is effectively a suite of simulation modelling tools, incorporating microscopic, mesoscopic and hybrid vehicle modelling tools, together with a micro-simulation pedestrian plugin (a version of *Legion*) and four-stage (trip generation, distribution, mode choice and route assignment) travel demand modelling tools.

It is understood that Statens Vegvesen are already familiar with *Aimsun* for vehicle modelling and are actively using the tool. *Aimsun* is also being used in the city of Oslo. *Aimsun* micro-simulation is considered here – the tool which allows for integration with *Legion* pedestrian simulations.

There are three main options for with *Aimsun* and *Legion*, explained further in Section 4.1.3 below. Effectively these are:

- A markedly limited *Aimsun* plug-in for *Legion*.
- A somewhat limited *Legion* plug-in for *Aimsun*.
- Separate fully-featured model builds in *Legion* and *Aimsun*, combined for simulation within *Aimsun*.

Python (and C++) can be used for custom programming within *Aimsun*.

Note that model import from *Paramics* and *Vissim* is possible.

4.1.2 Theory

Motor vehicles

The vehicle micro-simulation model is based on the collision avoidance car-following model developed by Gipps (1981) and is a proven model with fast run times. The model is highly regarded in the context of urban road modelling and has been implemented successfully around the world. The successful application of the model for urban traffic suggests that the potential to model bicycles well is also good (i.e., more so than if the core model was better suited to higher-speed roads).

There is also the ability to build hybrid vehicle simulations which use a mesoscopic model of a larger area together with micro-simulation of a smaller area of key interest.

Bicycles
The modelling of bicycles is currently a key limitation of *Aimsun*. Although bicycles can be included using the existing lane-based model, the key capability to model the lateral movement of vehicles (including bicycles) is not yet implemented. Bicycles can therefore use dedicated bicycle lanes, with modelling based on 'vehicles' approaching the behaviour of cyclists and can interact with signal phases and use gap acceptance – but they cannot use lateral movement to progress realistically along congested streets. This is likely to mean that it is not suitable for testing detailed design of infrastructure for cyclists.

However, we understand that a keystone project is currently under development for a client in a challenging environment which incorporates motor vehicles, bicycles, mopeds, rickshaws etc. Dynamic links and nodes are to be developed to deal with the complexity of intersections and the conflicts in that space.

The high-profile nature of this project and its timescale suggests that *Aimsun* will implement lateral movement and address more detailed aspects of bicycle modelling within the next 6 to 12 months. No public announcements have been made, but the nature of this development gives confidence that the functionality will be forthcoming in that timeframe.

Pedestrians
Pedestrian micro-simulation is based on the Legion/OMCA model as described in Section 2.1.3. *Legion* software has been widely and successfully used for projects both inside and outside buildings, including complex pedestrian crossings (e.g., Oxford Circus in London). Its implementation within *Aimsun* allows exploitation of the strengths of a proven model together with integration with vehicles to allow awareness and reaction at formal and informal road crossings.

The model allows for definition of pedestrian types with specific speed and size profiles. Pedestrian demand is given origins and destinations within the model based on 'pedestrian centroids' (entrances and exits), to which an O/D matrix can be applied. Level changes can be used to model grade-separated pedestrian crossings (e.g., foot bridges).

Specific to *Legion* within *Aimsun* (as opposed to stand-alone) is the ability to model boarding and alighting from public transport vehicles such as buses – controlled by parameters such as boarding and alighting times (including timetable-based demand) and vehicle capacity.

Traffic signals
Comprehensive support for traffic signal definition is included in *Aimsun*, including links with TRANSYT, SYNCHRO, VS-PLUS, UTOPIA, SCATS and SCOOT, and use of fixed or vehicle/pedestrian actuated signals.

Vehicle/bicycle/pedestrian conflicts
Aimsun with Legion is an integrated model: pedestrians and vehicles are aware of each other and the model allows for a range of interactions. For instance, pedestrian crossings are possible with fixed signals, pedestrian actuated signals, non-signalised but formalised crossings with pedestrian priority, and – more recently available – gap acceptance and priority models where people cross but check for vehicles.

4.1.3 Approach and interface

We do not give a discussion of *Aimsun*'s interface as a whole here, as we understand the client to be familiar with the software.

Aimsun/Legion integration options

Of the three approaches to modelling with *Aimsun* and *Legion* introduced in Section 4.1.1, the first is '*Aimsun for Legion*', which allows *Legion* licence holders to build simple, small *Aimsun* models (e.g., to include a pedestrian crossing outside a railway stations) within their *Legion* pedestrian model. However, this tool is likely to be too limited for junction design as it would not allow for testing the impact on vehicles sufficiently well.

The second option is the *Legion* plug-in for the full *Aimsun* software. The plugin is a fully integrated part of *Aimsun*, run from within the main interface. It therefore complements the vehicle modelling within *Aimsun*, allowing some interaction between vehicles and pedestrians at crossings. However, this solution is limited to 30,000 pedestrians and does not include the full functionality of *Legion*. It does, however, allow for representing pedestrians using 3D shapes within the overall 3D model environment (something not possible natively within stand-alone *Legion* software).

The third option is to build pedestrian and vehicle models separately, in *Legion* and in *Aimsun* respectively, and then combine the two within the *Aimsun* environment for simulation. It is the 'ORA' file from *Legion* which is imported into *Aimsun* – this file contains the compiled model, but not the simulated results. The two models are linked with placeholder objects that provide the spatial link. Although the models are built separately, this therefore allows for the full functionality of *Legion* while still allowing the simulation itself to be run concurrently in *Aimsun* – with full interaction between vehicles and pedestrians.

This third method provides maximum complexity in the model. For instance, it could be used to model the detail of pedestrian movement around a complex transport hub, together with interactions with vehicles at surrounding street junctions and road crossings.

Modelling of pedestrians

Pedestrian types can be defined with speed and size profiles, based either on *Legion's* default data (based on extensive observations) or custom profiles. Unlike stand-alone *Legion* software, agents can be shown in 3D (e.g., male, female or child) within the software itself. The areas for pedestrian movement may be defined by drawing areas within the *Aimsun* interface, or by importing CAD plans (as in *Legion SpaceWorks*). Obstacles to pedestrian movement may also be created from the *Aimsun* objects (e.g., Figure 9) or drawn within pedestrian areas.

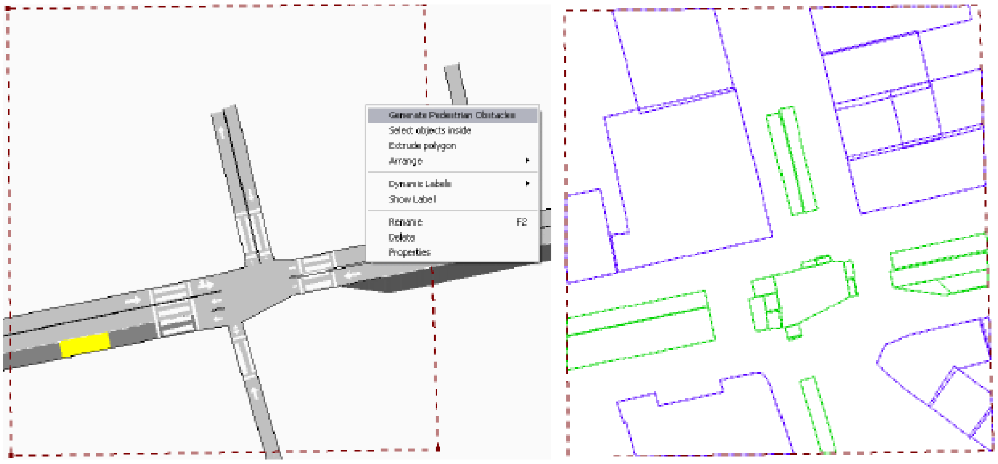

Figure 9: Example pedestrian obstacles (on the right) created from Aimsun network objects (on the left)
Origins, destinations and routes[5] *Source: Aimsun Dynamic Simulators Users' Manual v8 (TSS, 2014).*

'Pedestrian centroids' are used to define entrances and exits to/from the model for pedestrians (e.g., Figure 10). These can be drawn within *Aimsun*, or imported as part of a full *Legion* model. Origin-destination routes can then be defined (Figure 11).

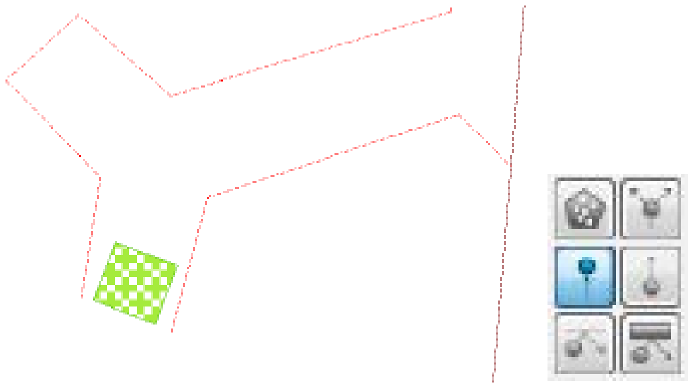

Figure 10: Pedestrian centroid in Aimsun: defining an entrance to the model. Entrance object shown on the left, with entrance centroid tool on the right. Source: Aimsun Dynamic Simulators Users' Manual v8 (TSS, 2014).

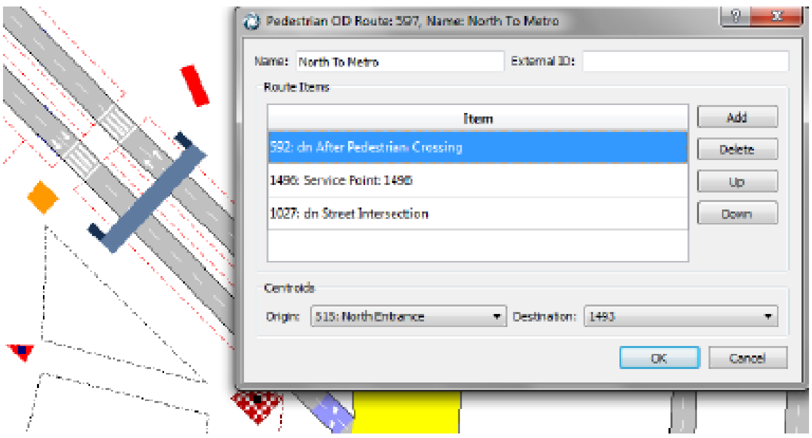

Figure 11: Example definition of origin-destination routes for pedestrians in Aimsun. Source: Aimsun Dynamic Simulators Users' Manual v8 (TSS, 2014).

5 The green objects are associated with controlling vehicle movement, while the purple objects are 'physical' barriers for pedestrians.

Further objects ('decision nodes' or 'focal nodes') can be used to provide intermediate destinations and decision points for pedestrians. This gives detailed control over route choice for example.

Public transport boarding/alighting

Boarding and alighting of public transport vehicles can be controlled through the definition of centroids at a stop. Parameters include the boarding and alighting time per passenger and demand, including through timetable-based data.

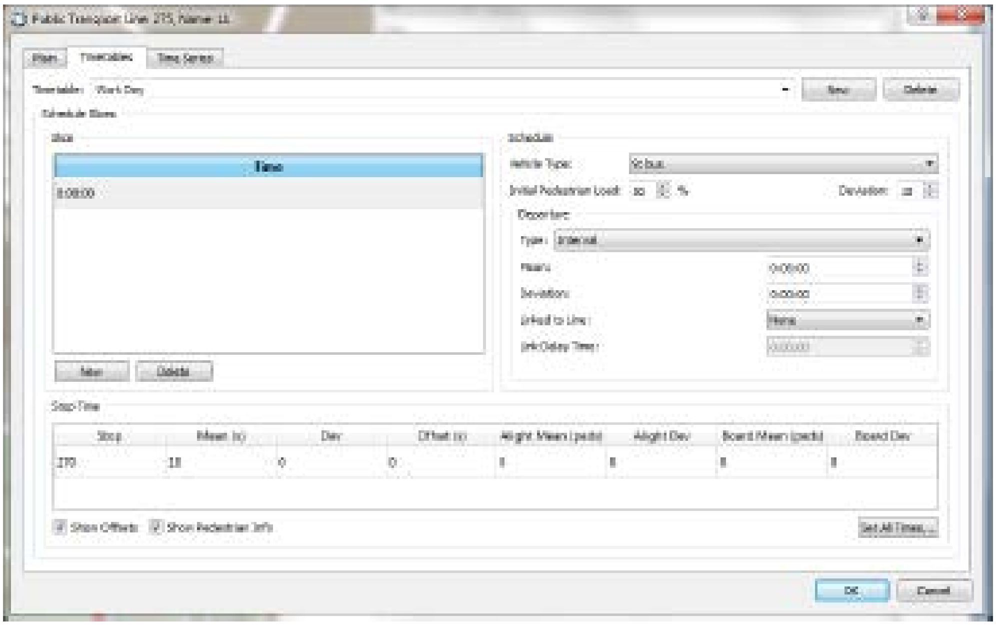

Figure 12: Example timetable information input for pedestrian demand on public transport vehicles in Aimsun.
Source: Aimsun Dynamic Simulators Users' Manual v8 (TSS, 2014).

Pedestrian crossings

Crossings are defined at the start or end of a section, as an extension of the node. Once added, the length can be defined, together with pedestrian movements (e.g., Figure 13) and signals (e.g., Figure 14).

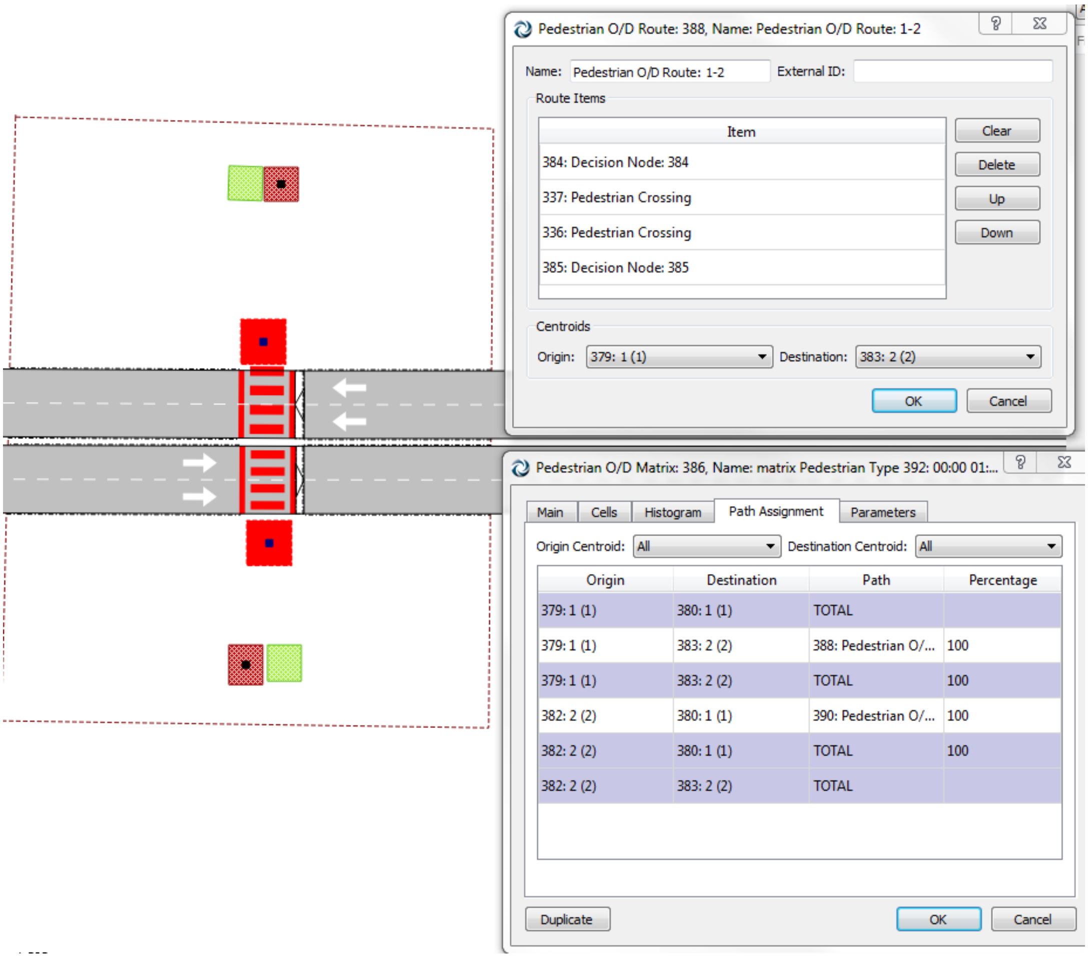

Figure 13: Example percentage routing for pedestrians at a road crossing in Aimsun. Source: Aimsun Technical Note #7 (TSS, 2014b).

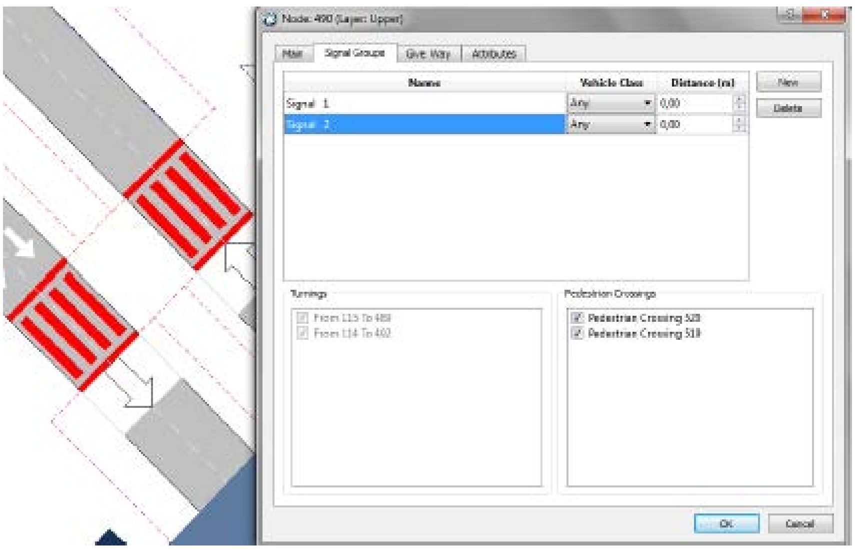

Figure 14: Example signal group editing for a pedestrian crossing in Aimsun. Source: Aimsun Dynamic Simulators Users' Manual v8 (TSS, 2014).

For pedestrian actuated signals (i.e., push-buttons), the detectors for pedestrians arriving at the crossing are created and defined automatically (Figure 15). This ensures that the pedestrian signal phase is called when a pedestrian reaches the crossing.

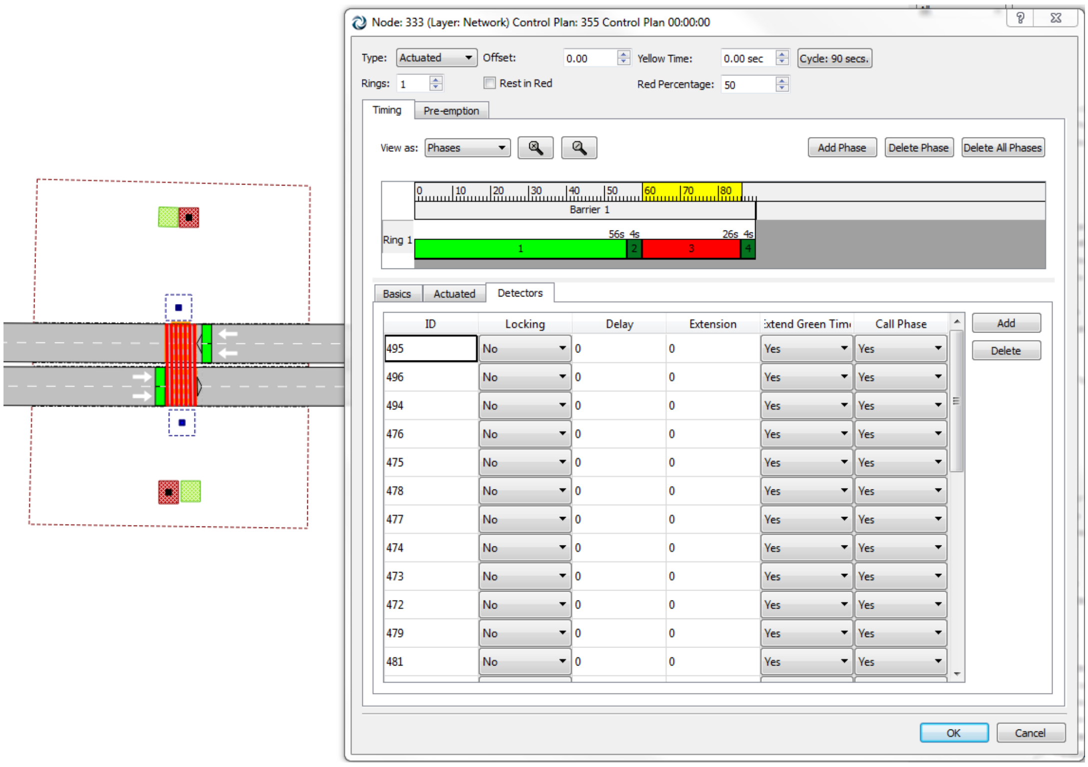

Figure 15: Example of automatic creation and definition of pedestrian detectors at crossings in Aimsun. Source: *Aimsun Technical Note #7 (TSS, 2014b).*

Openness and third-party tools

Aimsun uses modular architecture and includes programming capabilities (e.g., through the Python scripting language or C++, an Application Programming Interface and a microscopic simulator Software Development Kit) which allow for a range of third-party tools. These include functions such as signal optimisation through a TRANSYT-Aimsun Link.

4.1.4 Licensing and training

Licensing

Aimsun

Aimsun 8 (the latest version) is offered in a range of 'Editions' (details available here at the time of writing: http://www.aimsun.com/wp/?page_id=29), with basic pricing as follows:

- Aimsun Small Edition: €3,000 (€300/year software updates)
- Aimsun Standard Edition: €8,000 (€800/year software updates)
- Aimsun Professional Edition: €14,000 (€1,400/year software updates)
- Aimsun Advanced Edition: €23,000 (€2,300/year software updates)
- Aimsun Expert Edition: €32,000 (€3,200/year software updates)

In the case of multiple simultaneous purchases, TSS apply volume discounts: the first licence costs the full price but thereafter 25% discount is applied to licences #2-#4; a 50% discount to licences #5-#9; and a discount of 75% to licences #10 onwards.

Aimsun's 'Software Update Subscription' is available free of charge for one year and optionally renewable for an annual fee of 10% (as indicated in the price list above). This subscription guarantees access to all major software upgrades without further charges.

The pricing includes membership of the *Aimsun Forum* and all bug fixes. Technical support is also available in 8-hour packages at €620 per package.

These editions offer a range of capabilities and scales of modelling, up to the fully featured model in the Expert Edition incorporating static and dynamic traffic assignment; mesoscopic, microscopic and hybrid modelling; origin/destination matrix manipulation; and travel demand modelling.

Aimsun advise that "the Professional, Advanced and Expert editions have no limitations on the number of junctions and kilometres of lanes you can model, while the Standard edition is limited to 100 junctions and 200 kilometres of lanes and the Small edition is limited to 20 intersections and 40 kilometres of lanes".

Licence purchases in Norway would be handled through the TSS head office in Barcelona. Two types are available: stand-alone and network. Stand-alone licences are dongle-based, limiting its use to whichever machine has the dongle inserted (from any number of machines with the software installed). Network licences are server-based and automatically limit the number of concurrent instances running. Pricing is the same for either, though network licences require a minimum of 2 users.

In addition to the main licence cost, various additional modules are optionally available:

- Planning software interfaces (EMME and Saturn): €2,000 (not available for the Small edition)
- Adaptive control interfaces (ETRA, SCATS, SCOOT, SICE, Telent, Telvent, UTOPIA, VS-Plus and ZGZ Pro): €2,500 for the Standard edition and €5,000 for the Professional, Advanced and Expert Editions.
- Application Programming Interface (API): €2,500 for the Standard edition and €5,000 for the Professional, Advanced and Expert Editions.
- MicroSDK: €2,500 for the Standard edition and €5,000 for the Professional, Advanced and Expert Editions.
- Additional thread support: €2,000 for each additional pair of threads. Only available for the Professional, Advanced and Expert Editions

Legion for Aimsun

Legion for Aimsun is activated within *Aimsun* using a separate licence. Prices and options, as received from Legion, are as in Table 1 (as of 11 December 2014):

Table 1: Legion for Aimsun options and pricing summary.

Legion for Aimsun options (differing restrictions)	Peds / hour	Activities	'RES' results file saved	Licence cost (perpet-ual)	Technical support (payable annually)
Legion for Aimsun Base	1,000	- Import of Image Files & CAD - OD Matrix input in Aimsun format - Entrances, Exits and Decision Points - Shortest Path Auto-navigation - Pedestrian crossing objects - Public Transport stop objects	No	€0	-
Legion for Aimsun Lite	10,000	As above plus: - 5 level changes (e.g., footbridge) and service point objects	Yes	€6,400 (approx. based on conversion from £5,000)	€1,000 (approx. based on conversion from £750)
Legion for Aimsun Extra	30,000	As above plus: - Unlimited level changes and service point objects	Yes	€12,750 (approx. based on conversion from £10,000)	€2,000 (approx. based on converstion from £1,500)
Space-Works	No limit	No limit	Yes	To be quoted	To be quoted

Legion (stand-alone)
Stand-alone *Legion* licences, for their '*SpaceWorks*' software suite, which includes *Aimsun for Legion*, are quoted individually for customers. Typically, an annual licence arrangement is preferred, but shorter-term licences and other agreements have been made in the past.

Training
Aimsun organise frequent training courses in their offices in Barcelona, Spain; Paris, France and New York City, USA. They also offer on-site training; in the last twelve months courses have been held in Shanghai, China; Moscow, Russia; Brisbane, Australia; Bogotá, Colombia; Amersfoort, The Netherlands; and Stockholm, Sweden. The vast majority of courses are taught in English.

4.1.5 Assessment against key considerations

Table 2: Key considerations: Aimsun / Legion.

Ref	Key consideration	Comments & assessment
A	General	
A.i.	Model validation	Both vehicle (Gipps) and pedestrian (Still) models are well established and proven against a wide range of real-world projects, with documented model validation (e.g., Barceló, 2003; Berrou *et al*, 2005). Bicycle simulation not yet included fully (no lateral movement).
A.ii.	Fully integrated interactions between modes	Yes – within a single interface. Some complications arise from different versions of *Aimsun* and *Legion*, adding some complexity to the use of the software. However, all functionality is available within the final simulation.
A.iii.	Integration with signal timing software	Well integrated with all major signal timing software, together with native definition of fixed or vehicle-actuated signals.

Ref	Key consideration	Comments & assessment
A.iv.	Quality and clarity of outputs	Natively 3D – allows for good quality animations within the software itself. Very high quality animations can be achieved (at significant extra cost) by using the FZP Exporter to allow specialist animation companies to render simulations in 3DS Max.
A.v.	Cost	Small and Standard editions may offer significant licence cost savings relative to *Vissim*/*Viswalk*. For more substantial projects, Professional or Advanced edition may be needed – at costs more comparable with *Vissim*/*Viswalk*. *Legion* plug-in costs broadly in line with *Viswalk,* though includes cheaper options for smaller jobs. Interface well established – would expect benefits/problems to be largely determined by modellers (i.e., software users). Some need to split between *Aimsun* and *Legion* interfaces may increase time spent somewhat.
B	Cyclists	
B.i.	Road position and overtaking	Not yet modelled realistically; no account taken of lateral movement within/between lanes. *Likely, not guaranteed, to be within 6-12 months.*
B.ii.	Classification of speed and acceleration	Parameters largely existing already for the required adaptations of the car-following model for bicycles, but full review and modification of this is expected to follow development of lateral movement for bicycle simulation.
B.iii.	Dealing with obstructions	Obstacles which require lateral movement behaviours are not currently realistically simulated. See consideration B.i.
B.iv.	Behaviour at traffic signals	Broad functionality available, but full review and modification of this is expected to follow development of a lateral movement based implementation of bicycle simulation.
C	Pedestrians	
C.i.	Route choice flexibility	*Legion* implementation within *Aimsun* allows for easy definition of origin-destination routes, and intermediate decision points, between entrances and exits defined by area within the model. Additional functionality is also available within *Legion SpaceWorks*; ORA output files can be imported for concurrent simulation with vehicles.
C.ii.	Realistic pedestrian model	The Legion model has been widely adopted over the last decade, in a variety of contexts including street-level modelling and major transport hubs. Detailed guidance is available from a variety of sources (e.g., Transport for London).
C.iii.	Conflict areas	Good ability to define conflict areas between different agents. Allowance made for range of priority and signal options.
C.iv.	Crossing behaviour	For non-signalised junctions, *Aimsun* gives priority to pedestrians over vehicles – though a give way or stop can be placed to control pedestrians.
C.v.	Response to traffic signals	Pedestrians can be added to signal groups to control vehicle-pedestrian interactions at intersections, or combine crossings with turnings in the same signal group.

4.2 Vissim / Viswalk [PTV Group]

4.2.1 Overview

Vissim and *Viswalk* are both standalone programs, but for streets and junction design work including both vehicles and pedestrians, *Vissim* must be used together with the *Viswalk* module. Both tools are thus available from a single graphical user interface.

As PTV themselves state, the combined tool allows for modelling of "pedestrian crossings, roundabouts with pedestrian crossings, signalized pedestrian crossings, arbitrarily complex "normal" intersections and urban traffic situations with some shared space aspects". Vehicles and bicycles are modelled on a road/path network, while pedestrians are modelled over defined areas.

Control over input data, detailed parameters and the network (roads and pedestrian spaces) allows for comprehensive option testing and optimisation of designs. Outputs can be numerical or graphical – both fixed maps and animated videos. More sophisticated visualisations can be accomplished (usually through collaboration with a specialist computer animations company) by using the output data file of vehicle and pedestrian locations.

Vissim is capable of multi-threading and can therefore take advantage of multi-processor machines to allow faster model run times.

VAP allows for custom programming within *Vissim*.

4.2.2 Theory

Motor vehicles

Vissim is based on the Wiedemann psychophysical car-following model (see Section 2.2.2), with up to 20 simulation steps per minute. The car-following model relies on the point at which a driver perceives themselves to be following the vehicle in front and, similarly, the gap acceptance model relies on drivers' perception of the speed and distance between vehicles the driver intends to move between (Gibson, 2012).

For European conditions, *Vissim* enables the modeller to select rules reflecting overtaking on the left (right in the UK), with a return to slower lanes after overtaking. Perceptions of speed differences are important in both the car-following and lane-changing models, involving parameters such as minimum headway and acceptable deceleration rates for lane-changing vehicles.

Bicycles

The bicycle element of the model is also part of the car-following model, but there is the capability to adjust parameters to represent the speed and acceleration behaviours of bicycles better, as in the Copenhagen study (see Section 2.4.2). Just as importantly for junctions where bicycles are considered to play a large role, is the fact that both motor vehicles and bicycles are not necessarily positioned centrally within a lane. Rather, there is free choice of lateral position on the road, which allows for behaviours such as bicycles being overtaken within a lane, bicycles overtaking buses at bus stops, or bicycles feeding through stationary traffic to reach advanced stop lines.

Pedestrians

Viswalk is based on the Social Force Model. Dirk Helbing, who developed the model, is a scientific adviser to PTV. The implementation of the theoretical model includes options for 'dynamic potential' (PTV's term). This is based on the use of optional parameters for controlling the sensitivity of agents to distance vs travel time.

While this is a strength of the model, it implies understanding of the underlying algorithms that is unlikely to be understood well by the modeller. In practice, a good modeller would do either or both of increasing their understanding and testing different options thoroughly to observe the emergent result. There is nonetheless the risk that a poor modeller could introduce 'error' by badly implemented use of these options.

Traffic signals
PTV advise that: "Traffic signals can be modelled according to all established signal control methods (fixed time, vehicle actuated, LISA+, RBC, SCATS, SCOOT, Siemens VA, VS-Plus, plus six more as well as entirely externally controlled). Pedestrians (also vehicles) can be defined to obey traffic signals class-dependent and/or according to a probability".

Vehicle/bicycle/pedestrian conflicts
A range of priority, request/actuated and fixed signalled crossings can be modelled within *Vissim*, including some degree of 'shared space' behaviour. This range of managing conflicts is achieved using signal timings, "conflict areas" and priority rules. The rules can determine which road users yield to others, or if there is a first-come-first-served type of priority. Conflict areas (e.g., Figure 16) may be used to define which agents in the model yield priority – and how they consider the first and subsequent gaps to make a decision to proceed (or not). For instance, cars may adapt their speed to pass through a second gap of other cars or pedestrians.

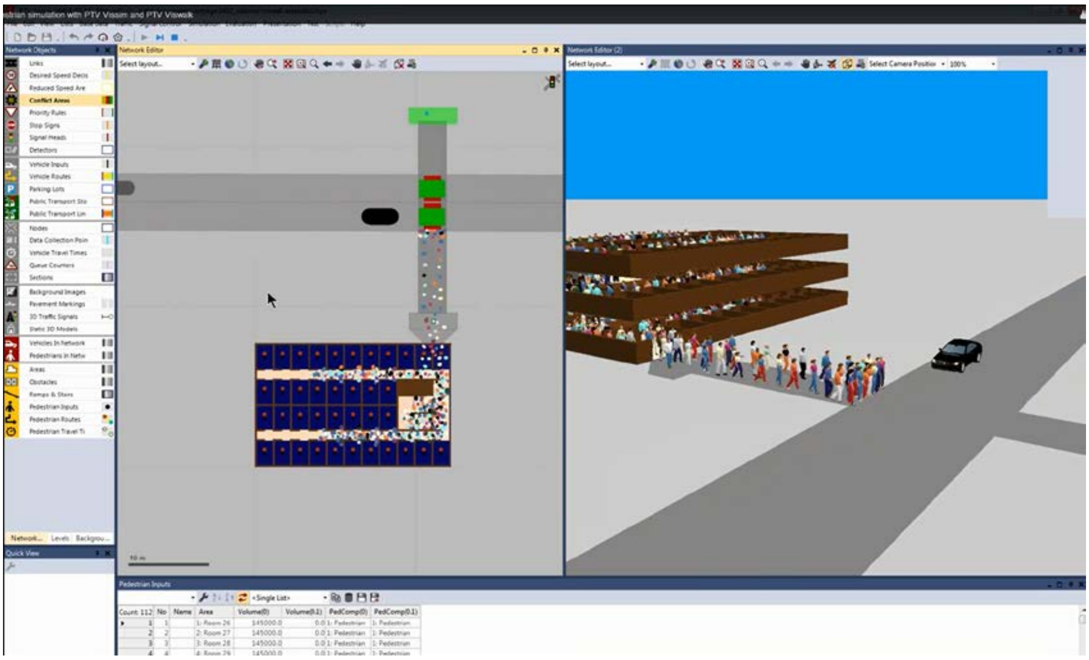

Figure 16: Vehicle/pedestrian "conflict areas" defined in a simple example in Vissim. The green and red areas shown at the crossing point in the left screen demonstrate the allocation of priority to cars over pedestrians in this case. Pedestrians will cross only if there is sufficient gap from any vehicles within their range of sight. Source: PTV.

Vissim's functionality can therefore allow for complex models involving signalised and non-signalised crossings and complex priorities between a variety of modes (e.g., Figure 17 and Figure 18).

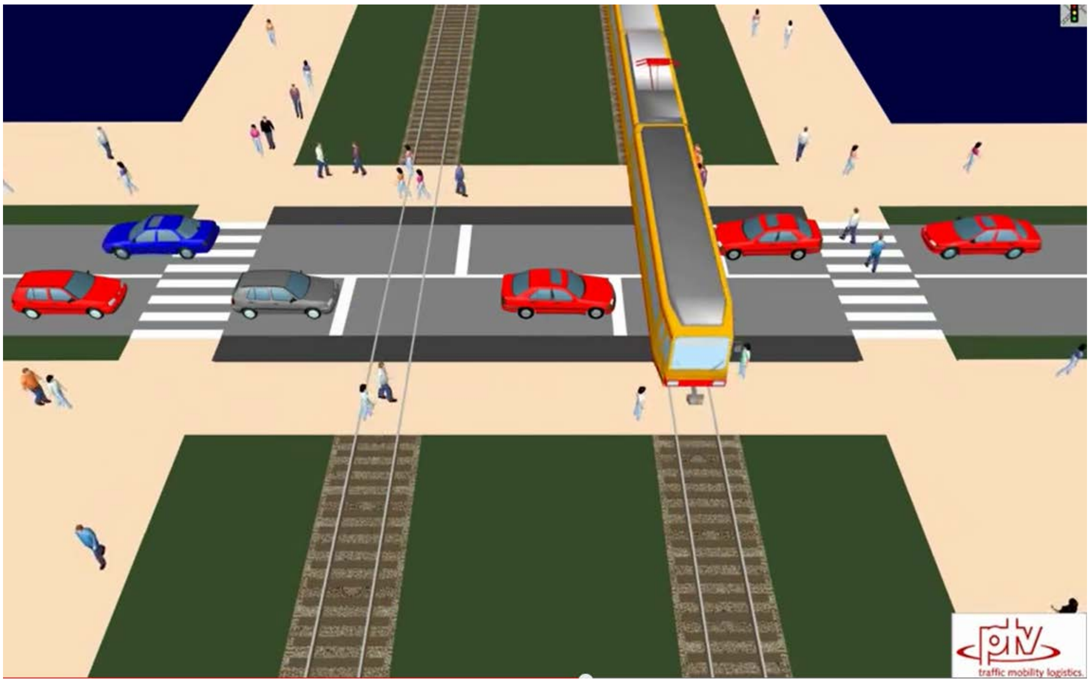

Figure 17: Example Vissim model demonstrating a variety of crossings in a multi-modal context. Source: PTV (https://www.youtube.com/watch?v=VShyFd7kafM).

Figure 18: Vissim/Viswalk simulation of traffic, bicycles and pedestrians around Pont Kuss in Strasbourg – involving both formal and informal crossings. Source: PTV (https://www.youtube.com/watch?v=YzPYwfHe0VU).

Further information on the Pont Kuss project in Strasbourg is available in a review report by PTV (Kretz et al, 2013).

4.2.3 Approach and interface

We do not give a discussion of *Vissim*'s interface here as we understand the client to be familiar with the software. However, it is worth noting that for the modelling of bicycle behaviour, *Vissim* is used as for motor vehicles, but with the specific definition of bicycles lanes and paths, together with features such as advanced stop lines, as defined in the PTV/COWI Copenhagen study (COWI, 2013). The study demonstrates that in addition to the relevant link types, locations and dimensions, a series of parameters needs to be set appropriately for cyclists.

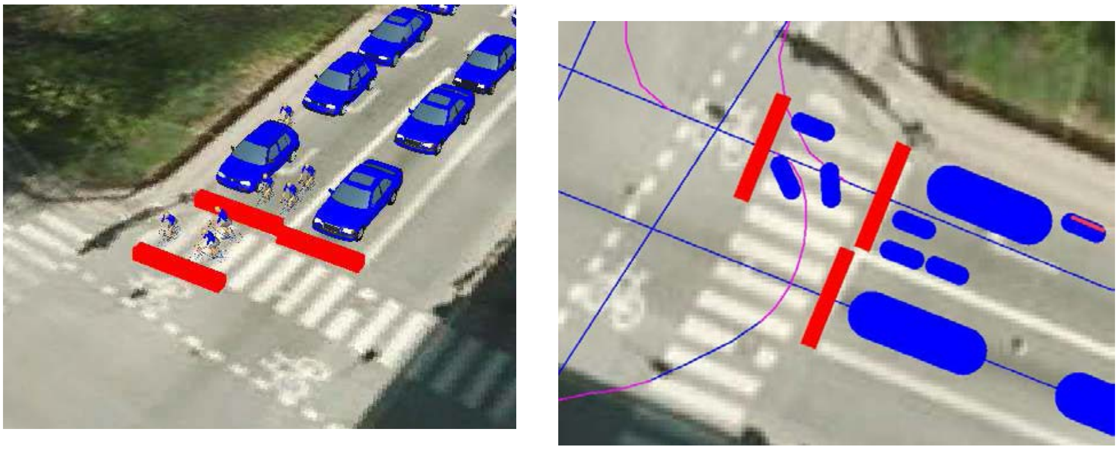

Figure 19: Example waiting zone modelling for bicycles within Vissim, in which bicycles use the pedestrian crossing as a waiting zone. The forwardmost signal is used to control the early start of cyclists in relation to signal timings. *Source: COWI, 2013.*

For *Viswalk,* as with *Vissim,* the model is natively 3D; the model network and simulation runs can readily be shown in 3D as well as 2D. The interface allows for multiple network windows showing either 2D or 3D views of the model (e.g., Figure 20). 2D may be used for convenience and/or speed, but the 3D functionality very usefully allows for the presentational benefits of showing animations in 3D.

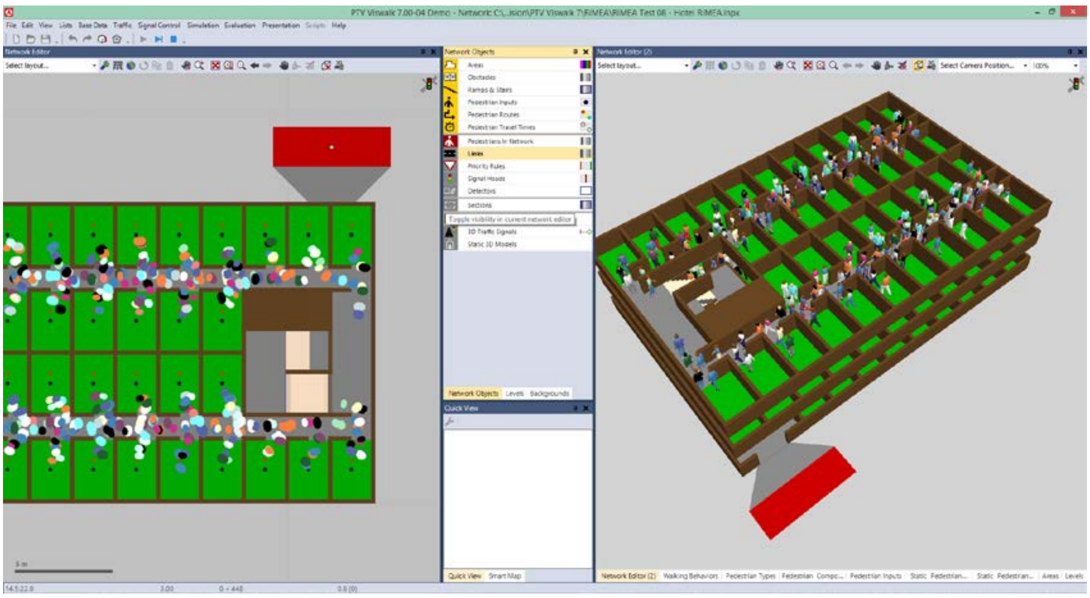

Figure 20: Screenshot of Viswalk graphical user interface. Source: PTV Viswalk Trial Version.

Model sections in *Viswalk* can be combined easily, for example through overlapping areas within the model and defining the way in which those areas are to be used (e.g., as a waiting area for a crossing). Routes are defined simply between different areas of the model, allowing easy implementation of origin-destination matrices. The overall route choice can then be refined using 'partial routes', which allow for deviations and diversions for particular route choices or activities en route to the final destination. Such options can be made dependent on particular classes of agents.

In relation to the interaction between vehicles and pedestrians, the right of way can be defined at 'conflict areas', as mentioned above. This ensures that the vehicles and pedestrians take account of each other, and that the appropriate priority and gap acceptance behaviours are set.

Analysis of areas and so on is easily accomplished, with counts and measures of density flexibly designed. A further strength is the ability to set up analyses based on averages of multiple runs, ensuring results are not one-off occurrences, but statistically reliable.

4.2.4 Licensing and training

Licensing

Two types of licence are available: single-user licence and network licence.

Single-user licences use a USB dongle to allow any PC with the software installed to work only with the dongle inserted. Local use only is supported; no remote connection.

Network licences use server-based software to hold the licence(s), with a USB dongle required for the server itself (not the local PCs). When a PC starts the software, it will access the server to determine whether a licence is available for use, up to the maximum number of simultaneous uses permitted by the network licence. These licences do support the use of remote connections and 'virtual machines'.

Indicative current pricing is as follows (as of 1 December 2014):

Option 1

- *Vissim* and *Viswalk* package: *Vissim* with VAP and 3D package (limited to 10km x 10km extent and up to 20 signalised intersections); *Viswalk* (limited to 10,000 pedestrians simultaneously in the system).

1 single-user licence: €21,500 (€3,225/year maintenance)
1 network licence: €26,950 (€4,043/year maintenance)

Option 2

- *Vissim* and *Viswalk* package plus VisVAP: *Vissim* with VAP and 3D package (limited to 10km x 10km extent and up to 20 signalised intersections); *VisVAP*; *Viswalk* (limited to 10,000 pedestrians simultaneously in the system).

1 single-user licence: €23,500 (€3,525/year maintenance)
1 network licence: €29,450 (€4,418/year maintenance)

Option 3

- *Viswalk* stand-alone: *Viswalk* (limited to 10,000 pedestrians simultaneously in the system).

1 single-user licence: €9,915 (€1,487/year maintenance)
1 network licence: €12,500 (€1,875/year maintenance)

Option 4

- Software maintenance: continuous software updates and hotline support services (at 15% of licence fee).

Example costs given above against each option

Note that there is a multiple licence discount, consisting of 30% discount for the second license, 40% for the third, and 50% for the fourth and beyond.

Training

Standard training courses are available in Karlsruhe in Germany: introduction (€340 / day) or advanced (€390 / day) – with 10% discount for booking at least four weeks in advance.

Standard courses include a one-day pedestrian simulation course ("Realistic pedestrian simulation"), which covers: fields of application; modelling stairs and escalators; interaction between pedestrians and vehicles; calibration and validation; and evaluation of pedestrian simulations.

Bespoke courses can also be arranged for up to four people at a cost of €1,100 per day plus travel expenses.

4.2.5 Assessment against key considerations

Table 3: Key considerations: Vissim / Viswalk.

Ref	Key consideration	Comments & assessment
A	General	
A.i.	Model validation	Both vehicle (Wiedemann) and pedestrian (Helbing) models are well established and proven against a wide range of real-world projects, with documented model validation (e.g., Fellendorf & Vortisch, 2001; Kretz et al, 2008). Comprehensive default parameter values are supplied - though may require adjustment for the best validation. Bicycle simulation is less well developed and is likely to require a greater degree of local research/testing, building on the PTV/COWI study in Copenhagen (COWI, 2013).
A.ii.	Fully integrated interactions between modes	Yes – within a single interface. As all model components are built by PTV, integration is excellent – and additional developments which may be required have been shown to be possible in previous work.
A.iii.	Integration with signal timing software	Well integrated with all major signal timing software, together with native definition of fixed or vehicle-actuated signals.
A.iv.	Quality and clarity of outputs	Natively 3D – allows for good quality animations within the software itself. Very high quality animations can be achieved (at significant extra cost) by using the output data to allow specialist animation companies to render simulations in software such as 3DS Max.
A.v.	Cost	Limited reduced-cost options; licences are expensive. However, combination of Vissim/Viswalk remains relatively good value. Integrated, single interface which is well established and widely used - would expect benefits/problems to be largely determined by modellers (i.e., software users).
B	Cyclists	
B.i.	Road position and overtaking	Allows for lateral movement of vehicles and bicycles, allowing for good representation of overtaking and road position behaviours. Attention must be paid to the calibration of parameters – particularly for bicycles, as detailed consideration of bicycles remains a relatively new application of the model.

Ref	Key consideration	Comments & assessment
B.ii.	Classification of speed and acceleration	Parameters have been identified and an initial study has provided values for guidance (see COWI, 2013); these could be built on with further local research/testing.
B.iii.	Dealing with obstructions	Features such as narrowing of bicycle routes and bus stops (including consideration of bus position and pedestrians) have been assessed, leading to initial suggestions for modelling (see COWI, 2013).
B.iv.	Behaviour at traffic signals	Combination of lateral movement, advanced stop lines, signal timings, red-light violations and encroachment on pedestrian crossings tested in past work and can form the basis for good representation of a range of traffic signal behaviours. Further local calibration/validation studies may be required.
C	Pedestrians	
C.i.	Route choice flexibility	Allows for easy implementation of navigational routes, and 'partial routes' to allow for secondary goals. Local navigation of obstacles and other agents is handled by the Social Force Model.
C.ii.	Realistic pedestrian model	Helbing's Social Force model well used within the industry and shown to produce credible results. 'Dynamic potential' feature a potentially useful extension but, as with the basic model parameters, needs skilled implementation and testing.
C.iii.	Conflict areas	Good ability to define conflict areas between different agents. Allowance made for range of priority and signal options. Good development of non-signalised junctions and gap acceptance behaviour.
C.iv.	Crossing behaviour	Pedestrians have a range of sight and can react to vehicles within that range, judging their crossing based on gap acceptance. A degree of sophistication is available – for instance, allowing cars to give way to pedestrians which are taking longer to cross because of congestion.
C.v.	Response to traffic signals	Pedestrians (and vehicles) can be made to obey traffic signals using class-dependent or probability rules.

4.3 Commuter / InfraWorks 360 Traffic [Autodesk]

4.3.1 Overview

Commuter was originally released to market by Azalient Ltd (UK-based) in Australia in 2008. Subsequently, the *Commuter* software has been acquired by Autodesk; announced on 4 December 2013. It is currently part of a project to integrate it into Autodesk's product '*InfraWorks*' under the title *Project Commuter for InfraWorks*. This is

InfraWorks is a product designed to assist with preliminary work and option testing for infrastructure projects – *Project Commuter* is designed to add simulation and visualisation of people movement to the software's capabilities.

Commuter is described as a "nanosimulation modelling software which analyses door-to-door trips made by people". The concept is that all segments of a person's trip may be modelled, as described by Autodesk:

- walking segments: for example, from home to station, or parking to office;
- self-driven segments: for example, from driveway to city-centre parking; and
- public transport segments: for example, suburban station to city-centre.

This approach allows for dynamic route *and mode* choices. Furthermore, the inclusion of motor vehicles, public transport (trains, buses, taxis), bicycles and pedestrians creates in principle a very strong integrated tool for examining streetscapes and junction / road crossing design (e.g., Figure 21).

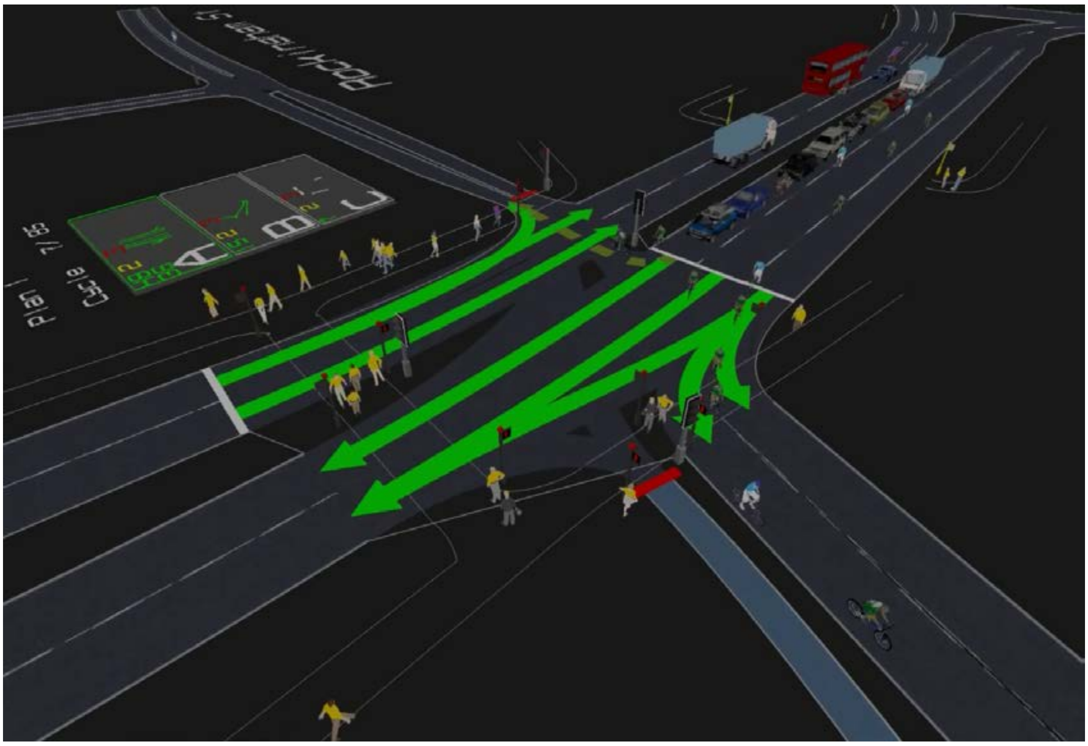

Figure 21: Example of vehicle, bicycle and pedestrian interaction modelled in Commuter (prior to acquisition by Autodesk): 'Cycle Super Highways' at Elephant and Castle, London, UK. Source: Azalient Ltd (https://www.youtube.com/watch?v=aByT-Kgdh5k, accessed 30.11.2014).

4.3.2 Theory

Motor vehicles

One of the potential strengths of *Commuter* is the ability to select the car-following model to be used within a specific model – or even on different links within a model. *Commuter* allows the modeller to select from the three major car-following models (see Section 2.2.2): Wiedemann (the basis for *Vissim*), Gipps (the basis for *Aimsun*) and Fritzsche (the basis for Paramics).

Bicycles

Bicycles (and motor vehicles) are modelled with lateral movement, as demonstrated by the video which accompanies the Elephant and Castle example given in Figure 21 (see https://www.youtube.com/watch?v=aByT-Kgdh5k) and the explanation given for lane sharing between cars and motorbikes (see Figure 22). Further examples are available at http://project-commuter.info/gallery/. Road lanes are modelled as spaces for vehicles; if there is sufficient width, more than one vehicle may use the lane – including narrow agents such as bicycles and motorbikes. This principle used from the start of the model development, together with available examples, suggest that this will be a strength of the model, when commercially available.

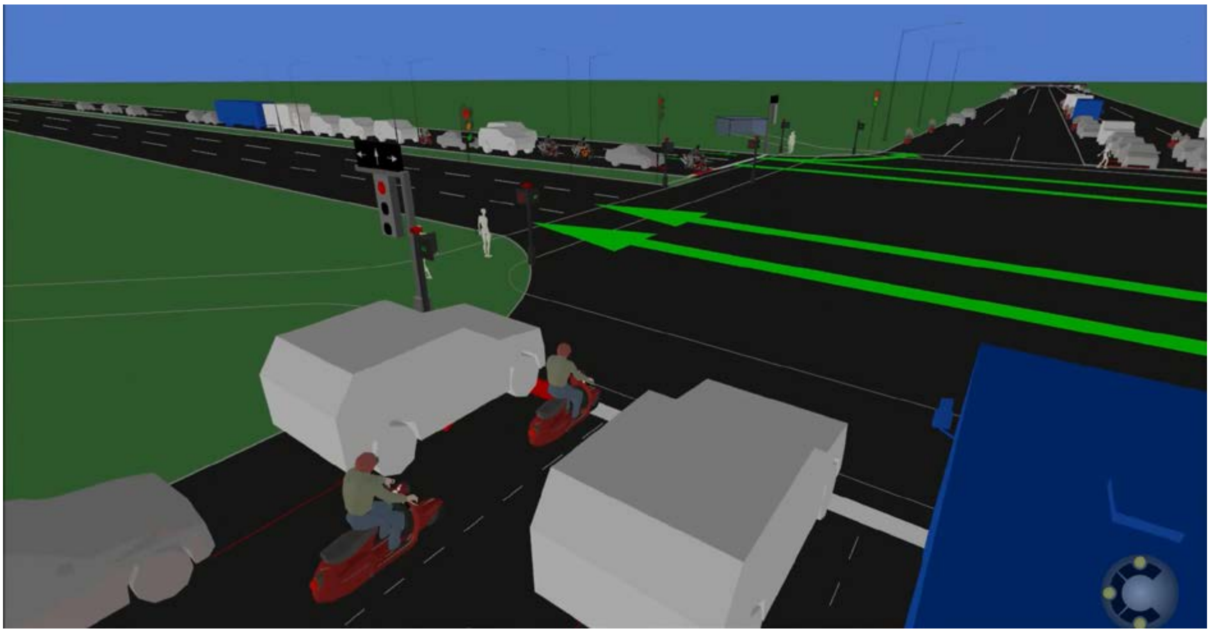

Figure 22: Example of lane sharing based on lanes being defined in Commuter as spaces available for vehicles, allowing for width-based judgements. Source: Azalient Ltd (https://www.youtube.com/watch?v=SgbIKeKoNFA&index=12&list=PL5l-5Lg_rwm2fUeljrfuB7GAhSxe39uDl, accessed 30.11.2014).

Pedestrians

Details of the algorithmic/theoretical basis for the pedestrian model are not yet available. However, we understand the approach to be a vector force-based model, similar in broad principles to the implementations in *Viswalk* and *Legion*.

Some key concepts are (see http://project-commuter.info/peopleWalking.php):

- agents are defined by a position, forward vector (heading towards a target) and angle of climb;
- agents occupy a physical circular or elliptical space;
- agents have a larger personal space, which defines the preferred minimum distance to other agents;
- agents are free to move in any direction on a surface;
- in normal motion, agents move in the direction of the forward vector;
- agents advance along their current path; and
- agents avoid fixed obstacles and other agents, with reference to the defined personal space.

On this basis: "each person, at each time-step, calculates a speed and direction for itself based on the path-advance vector and any avoidance vectors. In this way, it takes account of physical constraints and social forces" (http://project-commuter.info/peopleWalking.php).

Vehicle/bicycle/pedestrian conflicts

The modelling of both road lanes and pedestrian space as areas should lend itself to good representation of conflicts between motor vehicles, bicycles and pedestrians. The limited information currently available gives an indication of the potential power of the model, such as in control of signalised crossings (e.g., Figure 23) and 'shared space' situations (e.g., Figure 24).

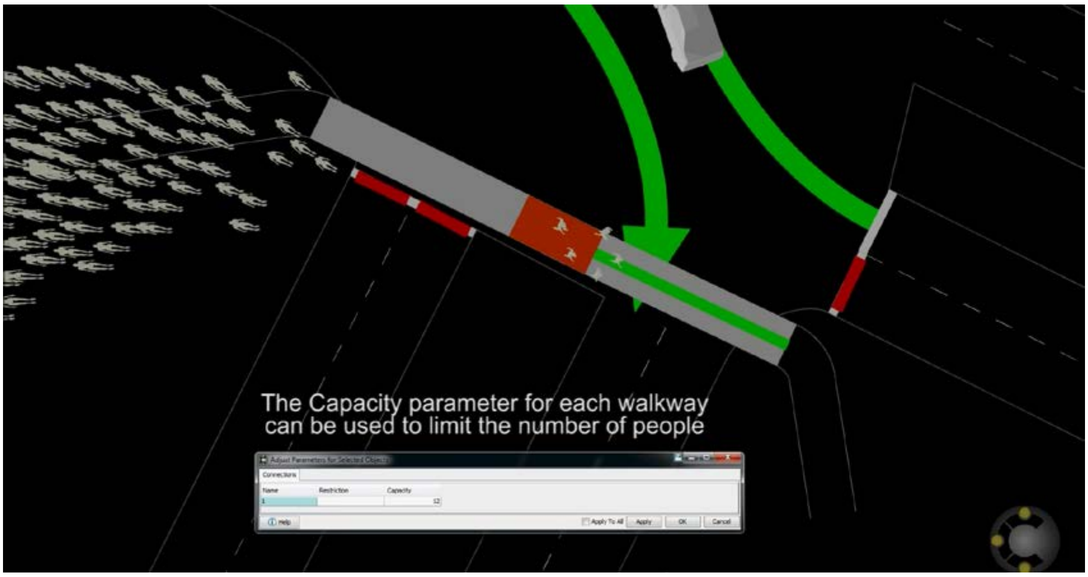

Figure 23: Example of control over pedestrian crossings in Commuter – modelling a crossing with central island and controlling. Source: Azalient Ltd (https://www.youtube.com/watch?v=TLFFWAQCWOA&list=PL5l-5Lg_rwm2fUeljrfuB7GAhSxe39uDl&index=7, accessed 30.11.2014).

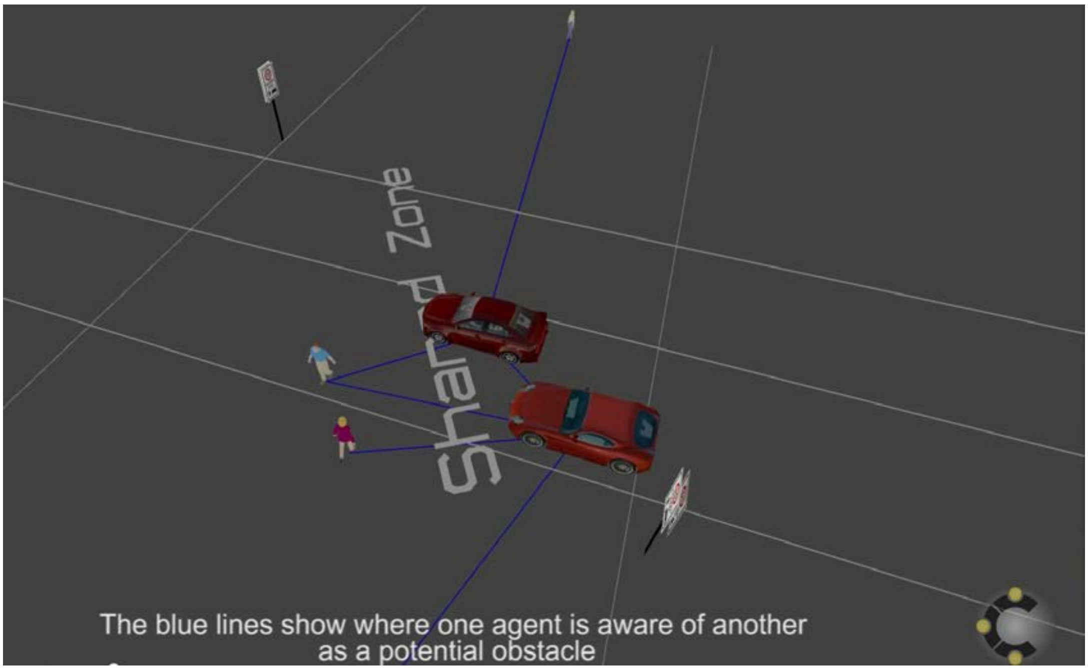

Figure 24: Example of awareness between vehicles and pedestrians in road space with no crossing in Commuter. Source: Azalient Ltd (https://www.youtube.com/watch?v=y6qJF0dHwVA&list=PL5l-5Lg_rwm2fUeljrfuB7GAhSxe39uDl, accessed 30.11.2014).

4.3.3 Approach and interface

The software is currently in beta testing, and commercial confidentiality prohibits the sharing of details. That said, the native 3D environment and strong links to CAD through Autodesk – and Building Information Modelling (BIM) more generally – suggests that the approach taken is likely to be well supported and a strength of the model.

Graphical animations are clearly a key output of the model. Information on the potential for other metrics and mapped outputs is not yet available.

4.3.4 Licensing and training

As the software is currently in beta testing, licence and training information is not yet available. It is, however, possible to join Autodesk's beta programme (see https://beta.autodesk.com/callout/?callid=D23E3D96B32A41EAA1AE9E8F1E319977).

4.3.5 Assessment against key considerations

Table 4: Key considerations: Commuter / InfraWorks 360 Traffic.

Ref	Key consideration	Comments & assessment
A	General	
A.i.	Model validation	Details not yet available, but sound basis on combination/choice of the three predominant car-following models (Wiedemann, Gipps and Fritzsche). Pedestrian model details not yet available, but will be vector force-based model similar in broad principles to Viswalk and Legion.
A.ii.	Fully integrated interactions between modes	Yes – a potential strength of the model as it has been designed with this in mind from the start. In fact the focus on 'person trips' and ability to make dynamic mode choice decisions could set the model apart from others.
A.iii.	Integration with signal timing software	Not confirmed.
A.iv.	Quality and clarity of outputs	Available examples include native 3D animated outputs and more sophisticated 3D renderings. Details to be confirmed.
A.v.	Cost	Licence costs not yet available. New software may mean increased learning curve for modellers. However, expected single interface and good integration with Autodesk products and BIM could provide savings.
B	Cyclists	
B.i.	Road position and overtaking	Well accounted for by the modelling of lanes as spaces for vehicles, taking account of widths and allowing for lateral movement.
B.ii.	Classification of speed and acceleration	Details not yet available.
B.iii.	Dealing with obstructions	Details not yet available, though lateral movement should make possible.
B.iv.	Behaviour at traffic signals	Details not yet available, but indicative videos demonstrate cyclists' responses to signals.
C	Pedestrians	
C.i.	Route choice flexibility	Details not yet available, but model is intended to offer mode, as well as route, choice.
C.ii.	Realistic pedestrian model	Details not yet available, but expected to be similar to Social Force Model.
C.iii.	Conflict areas	Available information suggests very good provision for modelling conflict areas, including formal junctions and 'shared space' areas.
C.iv.	Crossing behaviour	Available information demonstrates awareness between vehicles and pedestrians, with apparent speed adjustments and gap acceptance.
C.v.	Response to traffic signals	Ability to link pedestrians to traffic signals and control numbers permitted to cross to central reservations. Details to be confirmed.

5 Conclusions and recommendations

5.1 Overall conclusions

5.1.1 Model capabilities

In recent years, the development of micro-simulation tools has been rapid and complex multi-model environments have been modelled. Specific high-profile projects such as Oxford Circus in London, together with in-depth studies such as the Copenhagen bicycle modelling study, have shown that it is feasible to assess complicated junction design for all road users.

That said, because these developments are new – and on-going – there remain challenges in refining some model features and behaviours (notably for bicycles), and not all software developers are at the same stage of development, despite moving towards similar goals.

The recommendations given below are therefore presented in the context of our best understanding of both the current and future position of the software market. We anticipate that these timings could have a bearing on the most appropriate software choice, depending on the precise requirements and timescales of forthcoming projects.

5.1.2 Indicative costs

Licence and training costs do vary and there may also be scope for negotiation with the software companies on detailed pricing. However, those material costs should be weighed against other concerns, such as:

- The specific strengths and weaknesses of particular software tools in relation to the project(s) in question.
- The existing modelling skills in particular software tools, either or Statens vegvesen or their consultants.
- Existing models (in particular software) which may form the basis for (near-) future studies.

In relation to the practical cost of developing models in the different tools, we do not anticipate a material difference between the main tools recommended. Their interfaces are well matured and refined (except for models in progress like COMMUTER). In practice, the aptitude and experience of modellers is likely to make a bigger difference than either usability or licence cost. Going to the market for quotations remains the best means of determining the cost of proposed modelling, particularly given that overall market conditions may have a bearing on prices at a particular time. Conversely, if work is to be done in-house, an assessment of staff skills and experience, and existing models, would need to inform the decision.

5.2 Recommendations: software tool selection

Based on our understanding of the requirement, trends in junction design for pedestrians and cyclists, and the review of simulation tools presented in this report, we recommend the possible use of three software tools. They are presented here in priority order based on *current functionality at the time of writing*. Note that the relative merits of these software tools may change substantially within the next 12 months, given our understanding of the development priorities and broad timescales of the software developers.

1. **Vissim/Viswalk (PTV)**
   - Excellent integration of vehicles, bicycles and pedestrians. Allows testing of features such as bicycle lanes/paths; signal timings, including 'green scramble' and 'green waves'; forward stop zones, including feeder bicycle lanes; narrowing lanes; and a range of priority and gap acceptance behaviour for vehicles, bicycles and pedestrians.
   - Most developed bicycle model, incorporating lateral movement and including recent developmental experience in Copenhagen.

2. **Aimsun/Legion (TSS)**
   - Currently almost as capable as Vissim/Viswalk, but lacking lateral movement for bicycle modelling. Also slightly more complex integration between vehicles and pedestrians because of separate companies' collaboration.
   - Within approximately the next year, likely to have developed lateral movement (based on a specific, major, funded project) and become a relatively even competitor for Vissim/Viswalk.
   - Potential efficiencies given existing use of *Aimsun* by Statens Vegvesen and City of Oslo.

3. **Commuter/InfraWorks (Autodesk)**
   - Not currently commercially available.
   - However, is multi-modal from conception and would offer (arguably) the greatest flexibility of the three recommended tools.
   - Early indications suggest that conflict between vehicles, bicycles and pedestrians may be the better implemented of the tools (though note the more limited information freely available).
   - Potentially well integrated with Autocad CAD and BIM tools.
   - Proven in a range of past projects, though currently unavailable during integration with InfraWorks.

5.3 Additional considerations / next steps

- It is likely to be of benefit, perhaps required, to collect new data for calibration and validation. This may be Norway-specific or even city-specific. A study similar to that conducted in Copenhagen may be a suitable next step. The support of software suppliers may also be valuable in facilitating and making a success of this process.
- Modern survey techniques, including mobile phone counting and video analytics, may provide a cost-effective way of gathering new data, subject to data protection laws.
- In combination with collecting new data, specific software tests/comparisons may be made (beyond the simple review using trial licences for this study). In the first instance, this should be done using PTV software – though it may be appropriate to wait for Aimsun development of lateral movement (instead or in addition to PTV), or even release of Commuter, depending on other timescales / project pressures.
- Simulation tests may be compared with real-world data where possible. An example of this is the on-going testing by TRL in the UK for 'Dutch-style' roundabouts; a similar initiative could be done in Norway.
- The assessment of modelling techniques in this report has not dealt with accessibility issues; models are typically poor means of assessment of provision. However, from the project examples examined, we note that it may be of benefit to put together an 'inclusive design panel' as part of junction design projects, to help safeguard those provisions with the advice of key stakeholders.
- We note that compliance with Building Information Modelling (BIM) may be of increasing importance in future, particularly for projects involving complex infrastructure that may be subject to BIM standards. In principle, BIM should enable more efficient workflows and provide potentially useful inputs for simulation modelling.

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7 Contacts

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