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MODELING ROAD TRAFFIC ON AIRPORT PREMISES

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ABSTRACT

This paper describes the development of a traffic-modeling tool as an Arena template and two applications of it: one to evaluate alternative designs for the road network on the premises of Amsterdam Airport Schiphol and one to assess the effects of traffic signaling on a junction. The tool uses discrete event simulation, very suited for modeling traffic in areas where there are a lot of interactions other than car-following. Generation of the O/D matrix was done automatically by a custom-made application.

1 INTRODUCTION

1.1 Context

Amsterdam Airport Schiphol is one of the larger airports in Europe, facilitating approximately 400,000 flight movements per year, of which a major part are transfer flights. To handle the baggage and supplies (fuel, catering, waste disposal, etc.) the airport's operation is dependent on its road network between and around the piers, the so-called 'Randwegen' (Service roads, see Figure 1).

Because of the ongoing growth of flight movements and the increase of aircraft size, the traffic demand has risen considerably in the past decades. Furthermore, the airport is subject to continuous reconstruction. The development of the road network has not kept up with those developments, causing congestion and delays. The delays encountered by road traffic can cause disturbances of the flight schedule, which is considered a negative effect.

Because the airport premises are densely built, modifications in the road network are costly; often the road is part of a structure, so changing the road would mean a complete renovation of the structure.

To evaluate the possibilities of a road network redesign within the constraints of relatively low investments, Amsterdam Airport Schiphol commissioned Incontrol Business Engineers to develop a traffic-modeling tool. The tool and two applications of it are described in this paper.

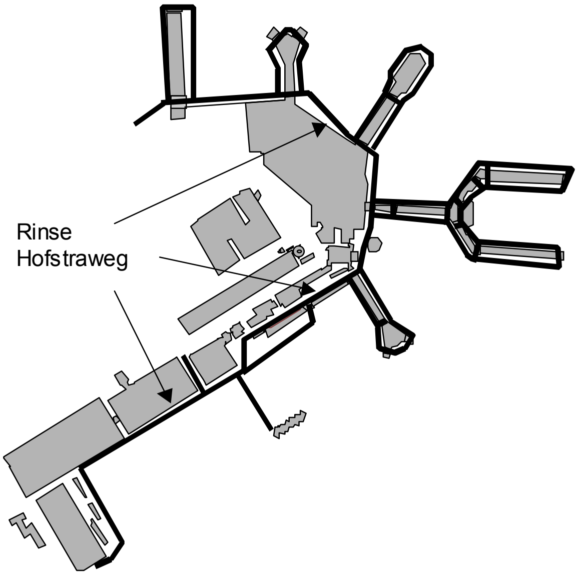


Figure 1: Structure of the Amsterdam Airport Schiphol Premises Randwegen (Service roads) with its Main Service Road Called 'Rinse Hofstraweg'

Before elaborating on the Arena template, we want to point out the difference between a discrete event simulation approach and, in the area of traffic and transportation, the more traditional continuous modeling approach. This will also explain the advantages of a discrete event approach to a transportation problem like the one on Schiphol airport.

1.2 Development of Traffic Modeling

Traffic modeling has developed strongly in the 1980's as computing power became cheaper and easily available (Ortúzar and Willumsen 1990). The bases of the different approaches to traffic modeling however date back to the 1950's (Reuschel 1950 and Pipes 1953). In those early days, traffic modeling was but an academic art and skill with – at that time – little relevance to decision makers in the area of traffic and transportation.

Only when the knowledge of numerical analysis, combined with the rise of the smaller, faster computers, was sufficient to comprise larger models, the art of traffic modeling was discovered by decision makers as a tool for decision support. Now, it is hardly imaginable that the planning process for e.g. the construction of a bypass isn't supported by quantitative results from a modeling effort.

1.3 Types of Traffic Models

There are generally three distinct types of traffic modeling:

- Static models;
- Dynamic, macroscopic models;
- Dynamic, microscopic models.

A *static* model is based on econometric theories. It tries to balance supply and demand of transportation resources based on different characteristics of an area, e.g. the number of residents, the amount of car ownership, the number and total area of retail stores, etc. (Ortúzar and Willumsen 1990). Using one or several characteristics of the transportation network, shortest paths are established on which the traffic then is assigned.

The traffic volumes on different roads can be used as a basis for urban planning and rudimentary analysis of congestion.

However basic in its approach, this method has proven to be very powerful when applied carefully. Because of the limited need for data, a lot of basic problems can be assessed early in the planning process.

There are, however several drawbacks. For instance, time is not an explicit element of the model, which makes it hard to assess the way that congestion builds up or breaks down during peak/off peak periods.

A *dynamic, macroscopic* model is comparable to a static model, however it incorporates the passing of time and can make the distinction between peak and off-peak traffic. The need for data for this type of modeling is much higher – the influence of traffic flow on the actual driving speed must be known for every road segment, which is not compulsory for a simple static model. Moreover, the spread of traffic demand over time must be known and implemented in a type of 'dynamic origin/destination matrix' (Williams 1997).

A *dynamic, microscopic* model does not analyze flows of traffic, but models individual vehicles, which interact on the basis of a car following model and conflicts. The car following models that are developed until now are mainly based on, and validated for situations where traffic can flow quite freely and disturbances are moderate (Gabard 1987). Very often, the used dynamic models do not hold well in situations where traffic is frequently interrupted and where most congestion and delays are induced by the handling of conflicts on junctions.

1.4 Which Delays are Relevant?

When we limit ourselves to traffic models that assess the delays that are encountered by traffic (caused by e.g. congestion or traffic lights) we would normally be interested in selecting an alternative where delays are minimal. Pending on the specific situation, those delays are mainly induced by longitudinal interactions, like shock waves, or by lateral interactions, like yield situations or traffic lights at intersections.

As said before, the continuous modeling of traffic in areas where it can only move relatively slow and is interrupted frequently by conflicts (e.g. junctions, yield situations and traffic lights) is not always possible or even needed to sufficiently analyze the traffic situation. If we describe the lateral interactions by the following summation:

$$T_{LAT,total} = \sum T_{LAT,i} + \sum \varepsilon_{LAT,i}$$

in which $T_{LAT,total}$ is the total delay time encountered by a vehicle by lateral interactions, built up from individual delays $T_{LAT,i}$ with an estimation error $\varepsilon_{LAT,i}$, and if the longitudinal interactions are described similarly:

$$T_{LON,total} = \sum T_{LON,i} + \sum \varepsilon_{LON,i}$$

It can be argued that delays encountered by lateral interactions are much greater than delays encountered by longitudinal vehicle interactions – even the error of the conflict delay alone is very likely much greater than the possible longitudinal interaction delay. The accuracy of the latter is then less relevant:

$$T_{Total} = T_{LON,total} + T_{LAT,total} \approx T_{LAT,total}$$

In that case, the problem under analysis breaks down to a problem where driving time and waiting time determine the performance of a traffic situation.

2 VEHICLE INTERACTIONS AND DISCRETE EVENT SIMULATION

2.1 Lateral Interactions

Most interactions that cause delay for vehicles that are not directly dependent on the interactions with the predecessor are caused by conflicts. For traffic situations, these conflicts are in fact quite limited in typology.

The first type of delay is encountered by *the solving of conflicts*. These occur at intersections where there is no signaling or where signaling allows for conflicting directions to drive at the same time. Depending on the layout of the intersection and the traffic regulations, vehicles can pass the intersection by priority (e.g. traffic from the right first).

The second type of delay is encountered *by waiting for traffic control signals*. This includes waiting for a red traffic light.

The third type of delay is encountered by *queuing*. This happens when more than one vehicle approach an intersection, and the first vehicle has to wait. All other vehicles have to queue behind it.

2.2 Longitudinal Interactions

Platooning causes the fourth type of delay. It happens when one vehicle drives slower than the others, so the others have to adjust their speed to the first one. Because the following vehicles can not reach their desired speeds, the trip will take more time (see Figure 2).

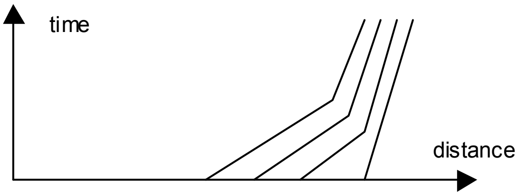


Figure 2: Trajectories of Vehicles Forming a Platoon

This does not account for the type of longitudinal interactions that are usually modeled in continuous models. They incorporate speed adjustments based on the gaps between vehicles and/or speed differences. The speed adjustments are applied with lag times (which represent the normal reaction speed of a driver), which amplify acceleration and deceleration of following vehicles, causing *shock waves* that can add to the delays. In the type of traffic situation like on the Schiphol Airport premises or in a city center, however, these delays can be assumed to be of little importance (see Figure 3).

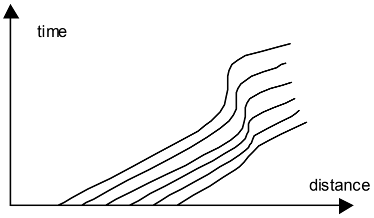


Figure 3: Longitudinal Vehicle Interaction Caused by a Small Disturbance in a Continuous Model

2.3 Translation to a Discrete Event Simulation Approach

As described earlier, the traffic situations to be studied with a discrete event simulation approach are characterized by a large number of intersections and short road segments where longitudinal interactions can occur. The four types of interaction mentioned will then fully determine the performance of the traffic situation.

The road segments as well as the intersections can then be seen as a server, with a process time depending on the length of the segment and the driving speed of the vehicle, and a capacity depending on the length of vehicles on it, including the gaps between them. The same goes for junctions; the central area of the junction can be seen as a server with several queues; the decision which queue to pick is dependent of the strategy adopted at that point (yield situations, traffic lights, etc.). Process time is dependent on the time the vehicle needs to clear the area.

3 IMPLEMENTATION OF A DISCRETE EVENT SIMULATION APPROACH

3.1 Introduction

Amsterdam Airport Schiphol consists of several piers, where airplanes are handled during boarding time. Fuelling, loading the baggage, supplying catering and disposing of garbage have to take place in a short period of time. Most of the equipment and supplies are brought to the airplanes over the road network connecting the piers – the so-called ‘Randwegen’ (service roads). In addition, passengers are moved over the same network by bus.

The increasing size of airplanes and the increasing number of flights to be handled are responsible for a growth in traffic flows on the road network. Because of that, and partly because of the variety of vehicle types being used for handling a flight (e.g. baggage trains have a low acceleration rate and a low driving speed), congestion and conflicts happen frequently, leading to delays. Those delays can cause departing flights to be late, with the effect that the flight schedule is disturbed. Because of the efficient land use on the airport premises, it is hardly possible to substantively expand the road network.

In order to improve the traffic situation, Schiphol Airport initiated several studies to analyze the occurrence and generation of delays for the road traffic. To do so, Incontrol Business Engineers developed an Arena template which can model a traffic situation based on the principles described in this paper.

3.2 Template Overview

The ‘Incontrol Traffic Template’ consists of a limited set of building blocks needed for modeling a traffic network.

First of all, there is a block defining general model settings. Secondly, there are points that generate vehicles and attract vehicles. Thirdly, the road segments take care of routing and delays. The fourth type of building block is a conflict point, defining the priorities of different directions on an intersection. The fifth type consists of traffic lights and the controls thereof.

The building blocks, as they appear in the template panel, are depicted in Figure 4.

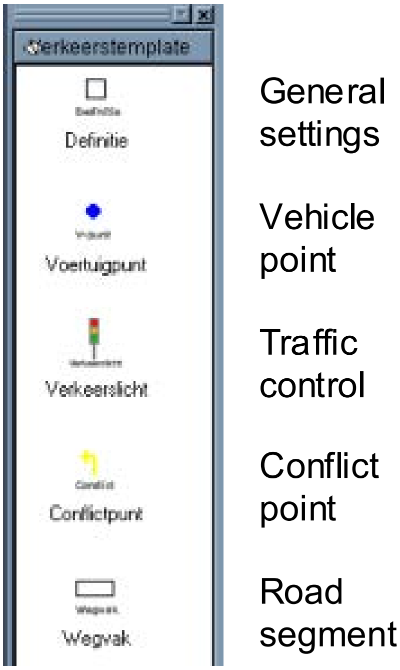


Figure 4: Building Blocks of the Traffic Template

3.2.1 General Settings

The general settings within the template are used to define different types of vehicles, their behavior and their appearance. Also, the dynamic origin/destination table can be selected here. Furthermore, the general settings define run length and numbers of replications. We will elaborate on the vehicle behavior.

Depending on its type, a vehicle will have a maximum driving speed that can be deterministic or uniformly distributed. Furthermore, its acceleration characteristics are defined. This is necessary to realistically model vehicles driving away from a stand-still – an important delay factor for heavy vehicles, like baggage trains. The acceleration characteristics are defined as points on a curve; given acceleration from e.g. 5 to 10 km/h, the distance traveled and the time needed are defined. An acceleration profile like that can be used by multiple vehicle types. The headway is defined similarly; desired headway is dependent on vehicle speed.

3.2.2 Vehicle Points

A vehicle point generates and attracts vehicles. The naming of the vehicle points corresponds to the origins and destinations in the origin/destination table.

As an extra functionality, airplane locations can be defined. An airplane location has an animation function; when an airplane arrives, it is animated to be located alongside the pier.

The overall delays that are encountered by vehicles can be registered in a vehicle point where a trip ends. These delays are derived from a comparison between the 'nominal driving time' and the 'realized driving time'. The nominal driving time is the time it would take to make the trip at the desired vehicle speed, while the realized driving time incorporates all delays accounted for in the template.

3.2.3 Road Segment

A road segment is used to let vehicles drive along it. It has a length and, depending on the vehicle entering it, a nominal driving time. Furthermore, routing is controlled at the road segment; depending on the destination of the vehicle, it is decided which next road segment to take. Finally, a conflict point or traffic control unit is defined if the road segment connects to an intersection.

A vehicle will enter the road segment and – according to its desired speed and the vehicle length– drive along the segment in a certain time. If another, slower vehicle is already on the segment, a check is performed to prevent a 'collision'; if needed, the driving time is adjusted for the following vehicle, according to the trajectories shown in th lower part of Figure 5. This correction will lead to a somewhat different platooning effect than is described in Section 2.2 and shown in the upper part of Figure 5.

Though both methods differ, an equal driving time along the road segment is established.

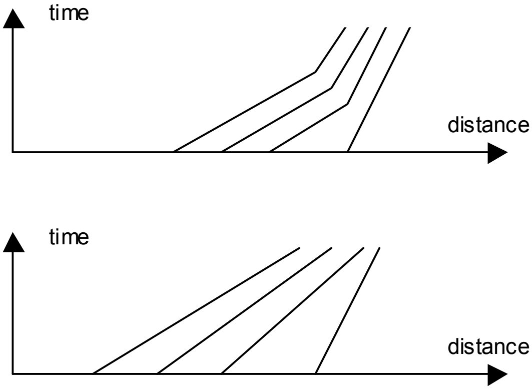
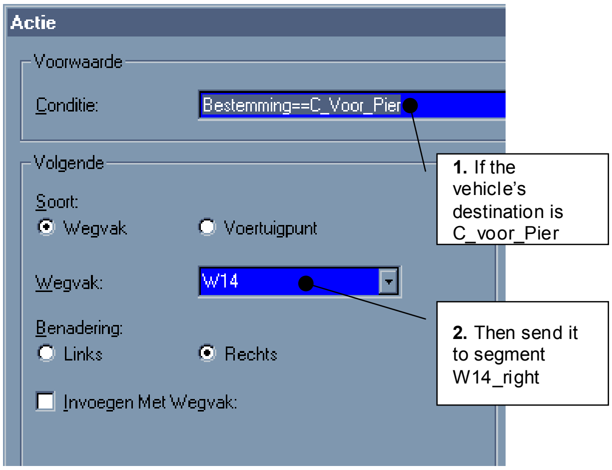


Figure 5: Normal Platooning Trajectories (upper) and Modelled Platooning Trajectories (lower)

A vehicle leaving the road segment will be directed to a next road segment. This can be achieved by using logical operators (see Figure 6). Routing can thus be established: according to the destination of the vehicle, several turns can be enforced.


Actie

Voorwaarde

Conditie: Bestemming==C_Voor_Pier

Volgende

Soort: ● Wegvak ○ Voertuigpunt

Wegvak: W14

Benadering: ○ Links ● Rechts

☐ Invoegen Met Wegvak:

1. If the vehicle's destination is C_voor_Pier

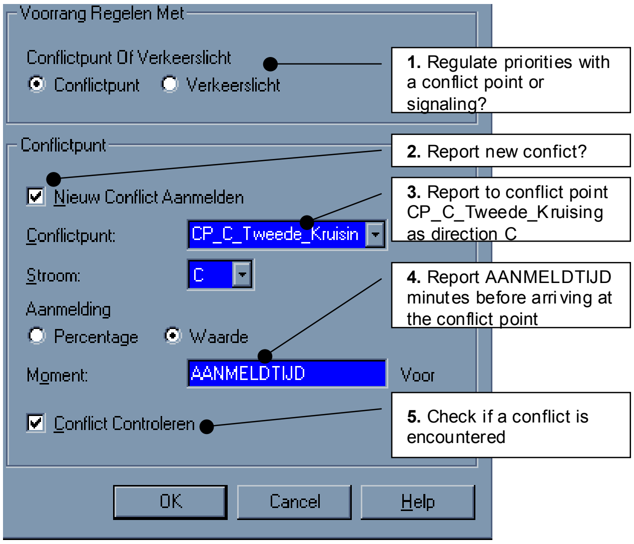
2. Then send it to segment W14_right

Figure 6: Routing Logic

It is also possible to extend the logic; a turn can be made according to a vehicle's destination and e.g. the length of queues on the different possible routes. A useful application is to route vehicles according to their type. That way, special purpose lanes can be modeled (e.g. bus lanes).

Finally, the routing logic can be used to let vehicles take over one another; if the preceding vehicle is slower than the one entering, the left lane is chosen.

When leaving a road segment at an intersection, the vehicle has to report itself to a conflict point or traffic control regulating the priorities.


Voorrang Regelen Met

Conflictpunt Of Verkeerslicht

● Conflictpunt ○ Verkeerslicht

Conflictpunt

☑ Nieuw Conflict Aanmelden

Conflictpunt: CP_C_Tweede_Kruisin

Stroom: C

Aanmelding

○ Percentage ● Waarde

Moment: AANMELDTIJD Voor

☑ Conflict Controleren

1. Regulate priorities with a conflict point or signaling?

2. Report new conflict?

3. Report to conflict point CP_C_Tweede_Kruising as direction C

4. Report AANMELDTIJD minutes before arriving at the conflict point

5. Check if a conflict is encountered

Figure 7: Defining How a Vehicle Exits a Segment

The conflict point to which the vehicle has to report is assigned within the road segment. The reporting to conflict points is dependent on the same logic as the routing is – this way, every different turn can be assigned its own direction.

3.2.4 Conflict Point

At a conflict point, the priority of every connecting direction (road segment) over every other connecting direction is defined. This way, all kinds of yield situations can be modeled.

As said before, the conflict point is referred to from logical conditions in every connecting road segment. All these connecting road segments have a unique identification within the conflict point.

In the case of the unsignalized intersection shown in Figure 8, the priorities would be A over E; B over E; C over B; D over B; E over C; F over C.

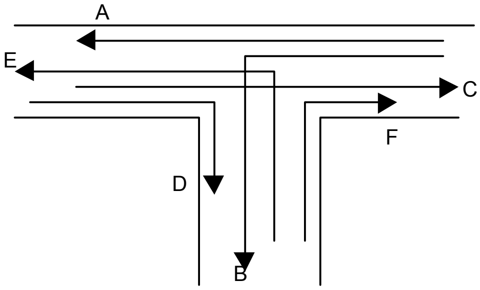


Figure 8: Directions at a Conflict Point

3.2.5 Traffic Control

Traffic control operates similar to a conflict point. The big difference is, that every direction is given a time slice in which vehicles can pass freely (green light). At this moment, control is only rigid; the cycle, in which directions are given red and green times, is fixed.

3.3 Additional Functionality

With the described functionality, the template will – in most cases – work properly. However, the probability of deadlocks occurring is very real. For the model to behave realistically, the deadlocks have to be solved. For that purpose, several options are available to deal with possible deadlocks.

A first possibility to prevent deadlocks is to let vehicles check if they can drive further on *before* blocking an intersection. That way, the intersections are kept clear of traffic.

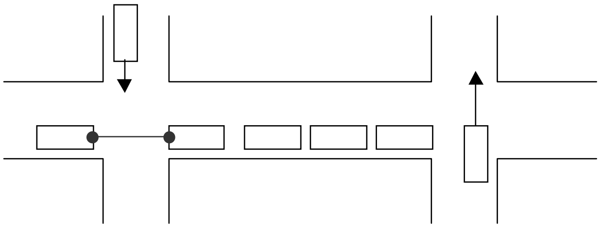


Figure 9: Keeping Clear of Intersections

One type of specific deadlock can occur when vehicles turning left are blocked by a queue going straight through in the other direction. When the vehicles in the queue are standing still, the left-turning vehicles normally would use a small gap to cross the queue (see Figure 10). This deadlock is solved accordingly in the template. For Figure 10, cars 5 through 8 can profit from the fact that vehicles 1 through 4 are standing still.

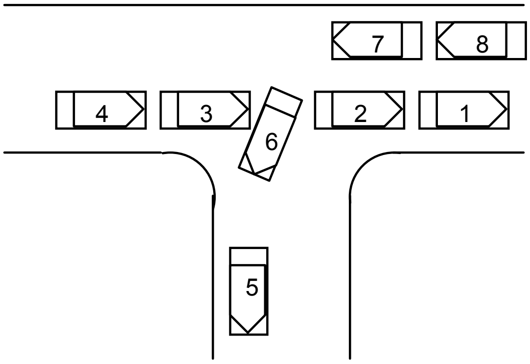


Figure 10: Breaking a Deadlock Created by a Queue

Other types of deadlocks can occur when all conflicting directions are occupied at the same time (everyone has to yield for everyone). In that case, there is an obvious solution available: one direction can be assigned to ‘break’ the deadlock by driving through. This moment of driving through can be delayed by a user-defined parameter.

3.4 Building the Schiphol Model

With the use of the template, models of the different alternatives were built. To be able to properly compare the alternatives, the traffic assignment had to stay the same.

To generate traffic, a real flight schedule was used from which the number of handling vehicles (primary traffic) needed at certain times and places was derived. This was done with a separate application, in which a complete and unique rule-base was implemented. Additional, secondary traffic then was generated proportionally (Figure 11). To account for future traffic demand, a simple growth factor was applied (Bouwman, Joustra and Teunisse 1998a,b as well as Bouwman and Joustra 1999a,b,c).

Routing was assigned to the road segments attached to intersections. Depending on the destination of a vehicle and possibly other state variables in the model (e.g. downstream queue lengths on different possible routes), the vehicles are directed towards the proper next segment. Also the underlying logic for decisions to take over slower vehicles were implemented in multilane road segments.

Conflict points and/or traffic control were used to regulate the intersections. For each pair of directions on an intersection the priority order was defined.

Certain data collection points were assigned, which, controlled by logic, gathered information from vehicles passing it during the simulation. These were chosen carefully. This way, enough information could be gathered without overflowing the analyst with information.

4 RESULTS

The results of two of conducted studies will be described here.

4.1 First Studies: Selecting Alternatives

To improve traffic flow on the service roads, Amsterdam Airport Schiphol has devised several alternatives. These alternatives vary on intersection lay-out, numbers of lanes on certain road segments, and most importantly, the lay-out of bus infrastructure.

The latter is of importance, because the buses are used for the transportation of passengers to and from the airplanes. Delays for the buses are annoying for the passengers, influencing their perception of Schiphol’s performance. To improve traffic for this type of vehicle, the construction of special bus lanes is considered.

Using the template, different layouts for the bus lanes were compared (to each other and to an autonomous growth scenario). The first layout, using a separated buslane and a signalized crossover for the ‘Rinse Hofstraweg’ is shown in Figure 11. The second alternative, also with a separated bus lane but without a crossover, is depicted in Figure 13. The third alternative is shown in Figure 14. In this latter alternative, the bus station is relocated forcing passengers to walk further to the terminal.

Based on the established delays for all types of traffic, a variant was chosen in which buses can access the bus station by a signalized crossing (Bouwman and Joustra 1999).

Concurrently, the layout of several road segments was improved; separation of queues at the junctions and increased possibilities for taking over slow traffic were introduced and assessed with the template. The effects were positive, as was to be expected.

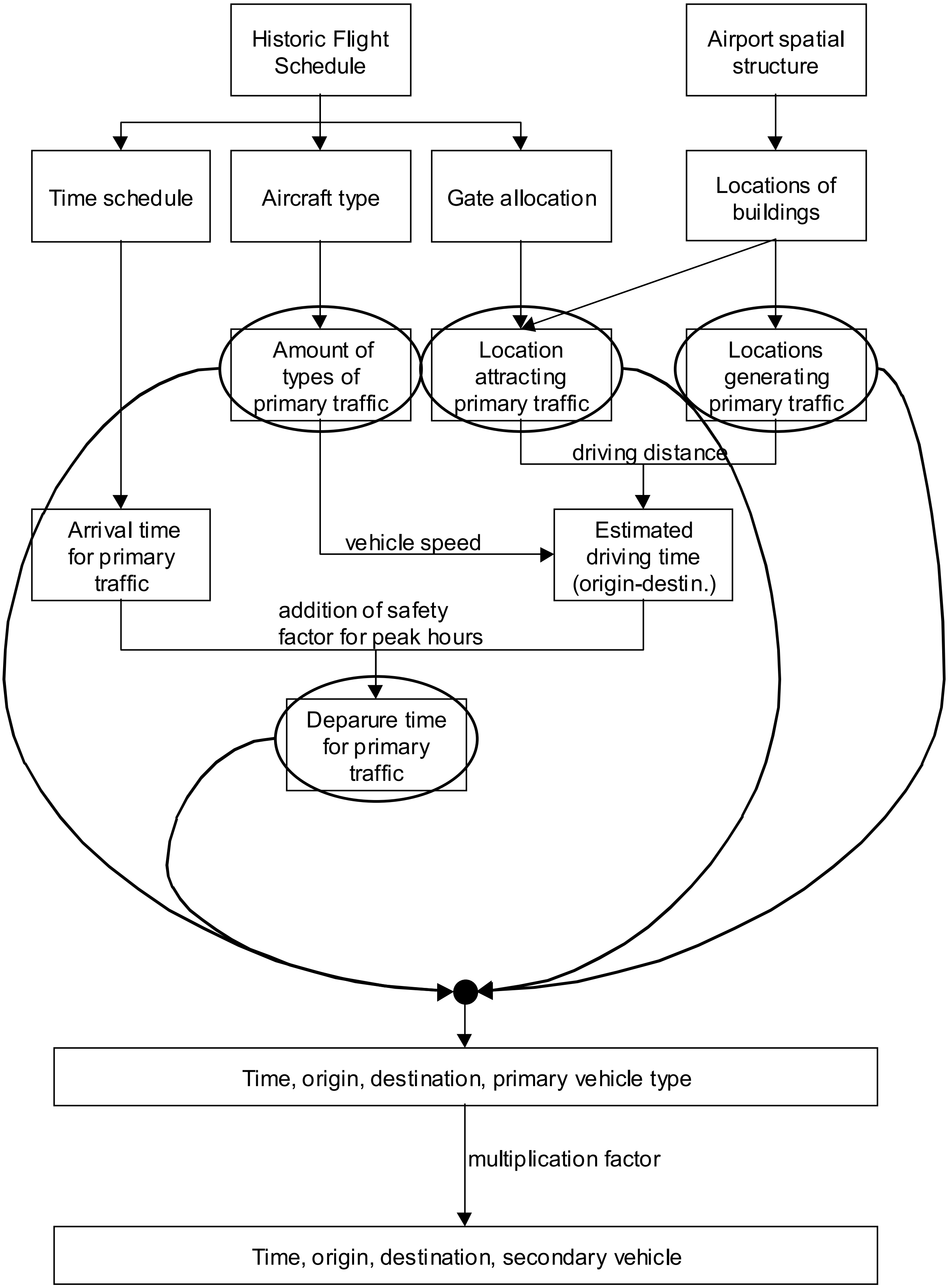


Figure 11: Generation of Traffic Based on Historic Flight Data from Schiphol Airport

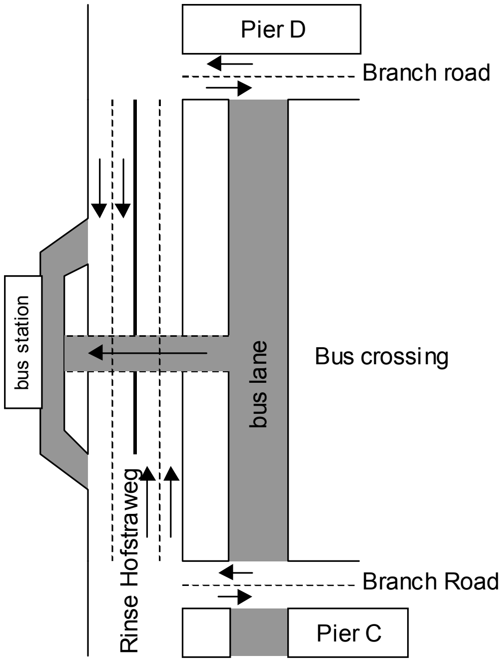


Figure 12: First Alternative Showing a Separated Bus Lane and a Crossover

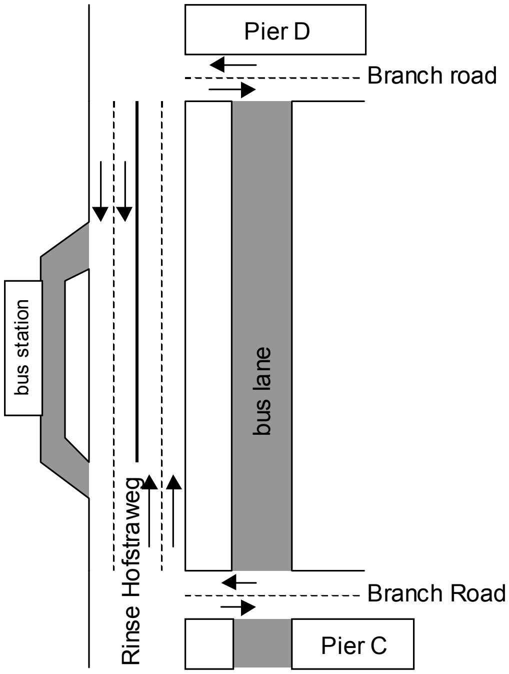


Figure 13: Second Alternative Showing a Separated Bus Lane Without a Crossover

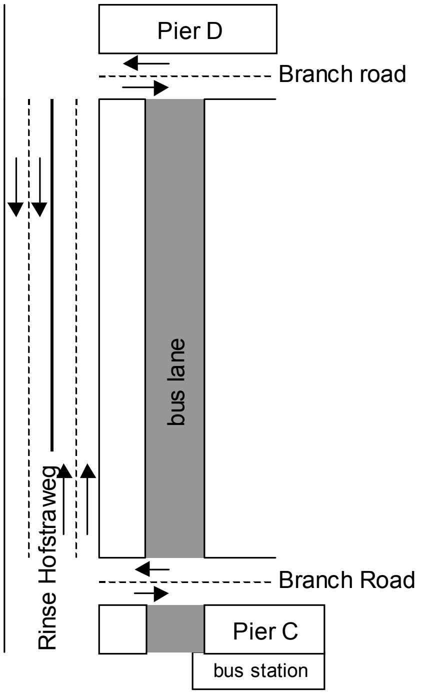


Figure 14: Third Alternative Showing a Separated Bus Lane and a Relocation of the Bus Station

4.2 Second Studies: Signalized Intersection

During the first studies, it became clear that traffic on the ‘Rinse Hofstraweg’ would get too dense in the near future. This would prevent traffic from branch roads enter the main road. To create some time to let those vehicles cross the street, a traffic light was proposed at the intersection of the ‘Rinse Hofstraweg’ and the D-pier branch road (see Figures 12 through 15).

To assess the effects of the traffic light, a peak hour was picked in which the signal control was assumed to be fully used. That way the modeling effort could be limited to a rigid traffic light control in a fixed cycle (Bouwman and van Burgsteden 2000).

Using different control strategies, it turned out that every intervention with traffic lights had such negative effects – waiting times could amount up to 15 minutes on a stretch of road 200 m long – that it was strongly discouraged to proceed with that option (van Burgsteden 2000).

5 SUMMARY

Although being more course in its approach, the use of discrete event simulation has – in this particular case – its advantages over the continuous simulation approach that is so common in traffic and transportation studies. Especially in cases where traffic is slower than ‘normal’ urban or highway road traffic, and conflicts are more common, the

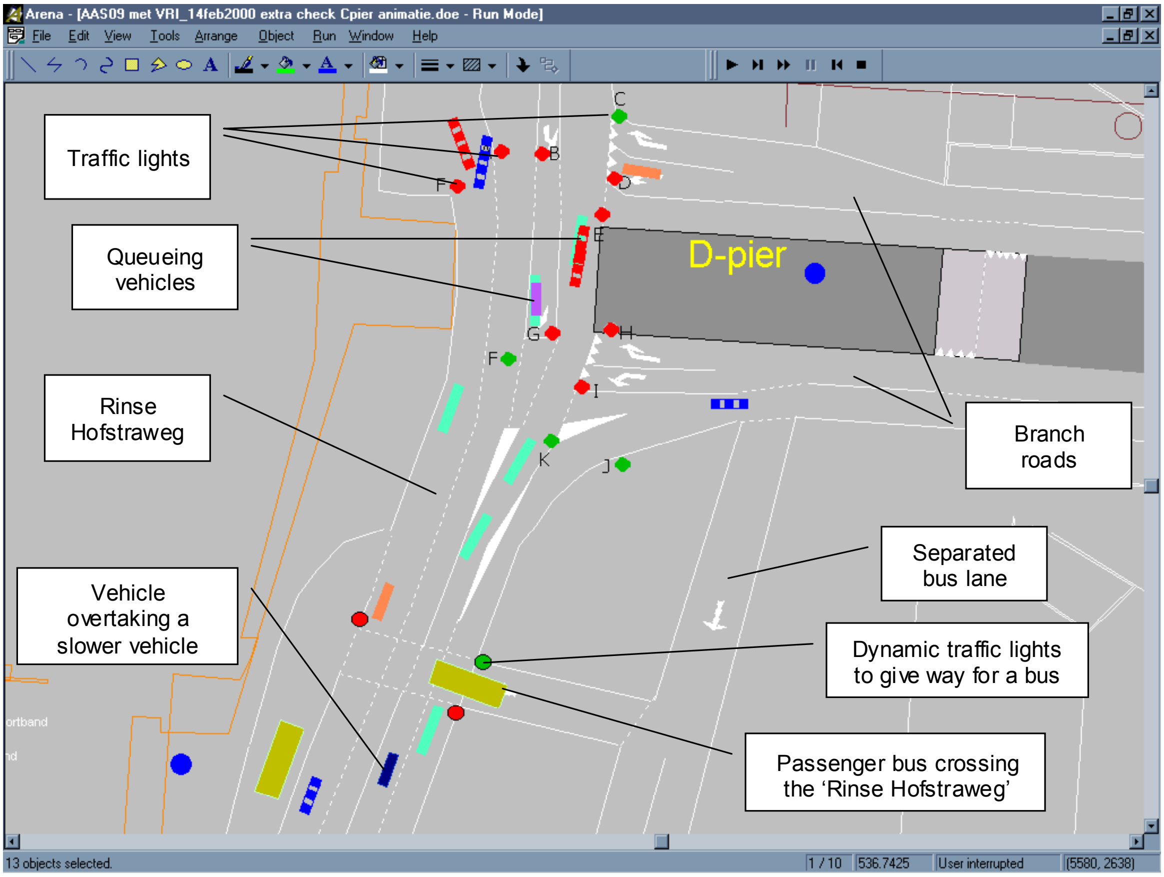


Figure 15: Animation View of the Signalized Intersection

applied approach is more straightforward, making it easier to interpret and communicate the simulation results.

The use of the Traffic Template has had its benefits for Schiphol Airport; decision-makers now have a clear view on the effects of service traffic growth on airport operations. They now also have a better understanding of how different measures affect the flow of traffic, ultimately influencing the long- and short-term effectiveness and efficiency of the airport as a whole.

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MICHIEL BOUWMAN is a senior business engineer working at Incontrol Business Engineers since November 1995. He received his M.Sc. for Computer Science at Delft University of Technology. During his career at Incontrol Business Engineers he has conducted a wide variety of studies on the area of logistics simulation for several clients, including banks, airports, factories and railway operators. Michiel is one of the developers of the original template discussed in this paper. He can be reached by e-mail at `<Michiel.Bouwman@incontrol.nl>`.

MARK HULLEGIE is employed at Amsterdam Airport Schiphol charged with the maintenance and development of airside capacity, including service road infrastructure. He studied Aeronautical Engineering at the 'Hogeschool Haarlem' College, from which he received his B.Sc. The Amsterdam Airport Schiphol website is `<http://www.schiphol.nl>`.