Behavioral Road Traffic Simulation with ARCHISIM

Alexis Champion [1,2,3], Stéphane Éspié [2] and Jean-Michel Auberlet [2]

[1] **SRILOG**
6 rue des Frères Caudron
F-78140 Vélizy-Villacoublay
champion.srilog@c-s.fr

[2] **INRETS**
2 avenue G^al Malleret Joinville
F-94110 Arcueil
{espie ; auberlet}@inrets.fr

[3] **LAMIH (UMR CNRS)**
Université de Valenciennes
F-59313 Valenciennes Cedex 9

Keywords
multi-agent systems, driving simulator

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Road Traffic Simulation

Simulation modeling is an increasingly popular and effective tool for analyzing a wide variety of dynamical problems. Road traffic is an example of such problems.

Road traffic constitutes a dynamic problem associated with complex processes. These processes are characterized by the interaction of the elements of the system: road users, infrastructures and operators. Traffic can be considered as a supply and demand problem whose difficulty relies on two opposite postulates. The offer responds to a collective use: the road network is dimensioned to allow a certain flow. The demand is individual: each driver wishes to travel under its conditions. Therefore the “traffic system” characteristics imply strong constraints for the modeling.

Different types of traffic simulation models exist [Lieberman and Rathi 1997]. According to its granularity, a simulation model can be macroscopic or microscopic. A macroscopic model describes the traffic stream, which is represented in some aggregate manner by scalar values of flow rate, density and speed. A microscopic model considers all the vehicles as individuals and the fundamental interactions take the form of mathematical formulas. All these traffic simulation models describe traffic in statistical formats.

ARCHISIM: A Behavioral Traffic Simulation Model

In addition to these models, the INRETS (French National Institute for Research in Transportation and Safety) has done some research on road traffic simulation based on the real driver behavior for more than ten years. The INRETS’ ARCHISIM simulation tool makes use of a behavioral sub-model for driver decisions. The driver model results from in-depth studies carried out in driving psychology for actual situations [Saad 1999]. Thus, the behaviors are not normative. In ARCHISIM, traffic phenomena come from individual actions and interactions of the various actors of the road situation [Espié 1999].

ARCHISIM is a behavioral simulation model and its implementation follows the multi-agent principles. Within ARCHISIM, agents are simulated drivers in virtual vehicles and consist of three subsystems: perception, “interpretation – decision-making” and action. We focus on the “interpretation – decision-making” part. Each agent has a model of its environment and interacts with the other agents (cars, trucks, trams…), the infrastructure (traffic lights) and the road. Each agent has goals and skills.

In opposition to works done in robotics [Reece and Shafer 1993], the agents’ behavior is not normative. Each agent has its own attitude. The objective is not to build a robot able to drive automatically but to study the driver’s behavior and the way in which the traffic phenomena occur. Within ARCHISIM, agents are autonomous and can potentially react to any situations. The “traffic system” can then show a greater aptitude to organize and to coordinate itself.

The advantage of multi-agent models is that it offers a more open and interactive system than classic models do [Champion et al. 1999]. Thus, it is possible to dynamically modify simulation conditions (virtual drivers’ preferences, traffic lights control algorithms...). Indeed, ARCHISIM permits a better understanding of the effects of such modifications on the traffic and an enhancement of the traffic model.

At INRETS, our ambition aims at making ARCHISIM an open tool for the study of the “traffic system”. The modularity of the simulation architecture offers the opportunity to integrate various actors such as a scenario module, a 3D-imaging module, a data recorder module, etc. Moreover, ARCHISIM has been developed such that the traffic model can host a driving simulator. In this case, the human subject in the driving simulator interacts with the traffic within the simulation model (Figure 1). This step appears significant to us because it makes it possible to confront the new concepts with the final users while following an iterative process (Figure 2).

ARCHISIM is a flexible tool for which a set of applications has been found: new road design, test scenarios (automatic incident detection, adaptive cruise control), etc. In fact, any study relating to a modification of the “traffic system” and requiring the use of simulated traffic situations.

Figure 1. Examples of traffic situations simulated with ARCHISIM

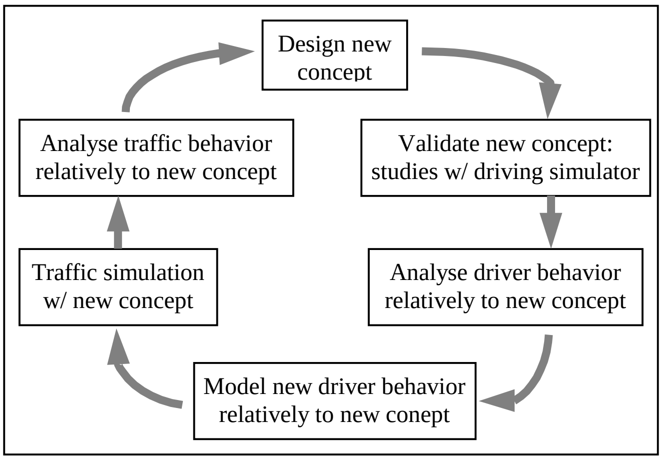

Figure 2. Study and simulation process

The ARCHISIM traffic model has been validated for some highway situations [El Hadouaj 2000] and works are in progress to validate it for critical and urban situations.

In this paper, we present four traffic simulation projects carried out with ARCHISIM in partnership with private companies or civic institutes. The first project deals with new infrastructure concept testing. The next two projects relate to the evaluation of ATT (advanced transport telematics) systems. Finally, we present our new project, which deals with the evaluation of control strategies on high density networks.

EXAMPLES OF TRAFFIC SIMULATION PROJECTS

The first project we present has used together both the traffic simulation model and the driving simulator. In this case, the driving simulator is used for identifying drivers' behavior relating to a new concept. The two other projects have used ARCHISIM as a stand-alone traffic simulation model and the assumptions related to the drivers' behavior have been previously set. In all cases, simulation is used to quantify traffic performance at both safety and capacity levels.

New Concept Evaluation

The investigation power of a driving simulator comes from its ability to let the various elements of the driver-vehicle-road environment interact. This tool is particularly interesting for studying risky situations and situations involving elements that do not exist yet. From a virtual model, driving simulation makes it possible to study new road concepts by the means of their perception and their acceptability by the road users. The project we now shortly describe involves new types of traffic lights for ramp metering (further information can be found in [Nouvier 2001]).

Ramp metering uses signal control of the on-ramp of a highway intersection to limit the entry rate and timing of vehicles to the main flow. The benefits of ramp metering are a reduction in the occurrence and severity of flow breakdown. The metering of flow on the ramp smoothes entry patterns to the main carriageway at critical times. This marginally increases delay to vehicles on the ramp but should improve the total network performance.

Ramp metering in a well-known technique, particularly in the United States. In Europe, a few interesting experiments have been conducted. Several countries are now launching significant programs to spread this concept. In France, two different methods are used: platoon insertion or insertion of a single vehicle at a time, this method being called the "drop by drop" method. This latter type of regulation being new in France, it has been necessary to study its implementation by means of traffic simulation associated with a driving simulator.

The virtual road database includes an urban highway section and an interchange with entry and exit lanes. Six different scenarios have been developed. These scenarios relate to the four types of traffic lights (usual two and three color traffic lights red/yellow/green or modified, green being replaced by blinking yellow) with short cycle (5 seconds) and two conditions of insertion (leader vehicle or follower vehicle). A hundred of subjects were involved in the experiment. After an adaptation to simulator driving, each of them had to make three journeys on an entry lane in different scenarios. An investigator wrote down the behavior (hesitation, incomprehension…) and the spontaneous commentaries of each driver while driving. Moreover, after each journey, the investigator interviewed the drivers about safety and their acceptance of the concept.

The first qualitative results show that the understanding of the regulation system is not immediate, particularly during the initialization phase or when the subject is leading. Some traffic lights are sometimes misinterpreted (red/blinking yellow). This experiment with driving simulation allowed to make an assessment of the envisioned solutions and to draw up an experiment in real conditions.

Vehicle Based ATT System Evaluation

The second project is a study carried out to assess large-scale ATT effects inducted by vehicle based autonomous systems [Aron 1999]. Such systems are developed to enhance the sensory performance of the driver. They operate using control and/or advice and operate independently purely within the vehicle. This section provides a description of the modeling approach used, objectives of the investigation and the key findings for the ATT system under consideration, which is an Adaptive Cruise Control (ACC) system.

In an ACC system the control is based upon a sensor (usually a microwave radar) which measures the distance to the preceding vehicle. The system attempts to maintain a desired speed (controlled by the driver) by managing the gas pedal while observing a predefined headway between the vehicles. The ACC system studied is fully independent (no communication) and assume that the driver has control of the steering at all times. The first stages of deployment of ACC are likely to target drivers seeking improved comfort and perceived safety from the system. The system will only operate in high speed highway driving conditions. It has been suggested that ACC will improve road capacity, reduce journey times and improve safety. The objectives of the ACC study are to identify those parameters within both the ACC algorithm and within the traffic stream.

There are conditions that must apply before a vehicle enters the ACC following control. It is assumed that if the ACC system can be used, it is used. The maximum deceleration of the ACC equipped vehicle when under distance control mode is limited to $-1.5 m/s^2$. The maximum acceleration under ACC is $1 m/s^2$. Experiments have been limited to target head-ways of 1.5s and 1.2s. These values have been determined by examining the upper and lower ends of a number of typical following headways.

The study examined the effects of different penetration of ACC to traffic efficiency and stability on a simple 3-lane stretch of road. For a target headway of 1.5s, there is no notable effect on average journey time whereas the travel time for a target headway of 1.2s is reduced with up to 20% equipped and then the effect stabilises (Figure 4). The modal headway for ARCHISIM is between 1.2 s and 1.4 s. The headway distribution is therefore not significantly altered when a target headway of 1.5 s is employed for ACC. However, a target headway of 1.2 s shifts the headway distribution to the lower end (Figure 5).

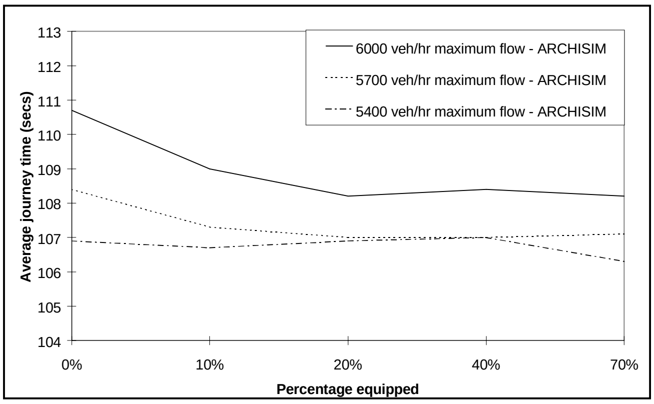

Figure 4: Effect of ACC on average journey time for target headway 1.2s

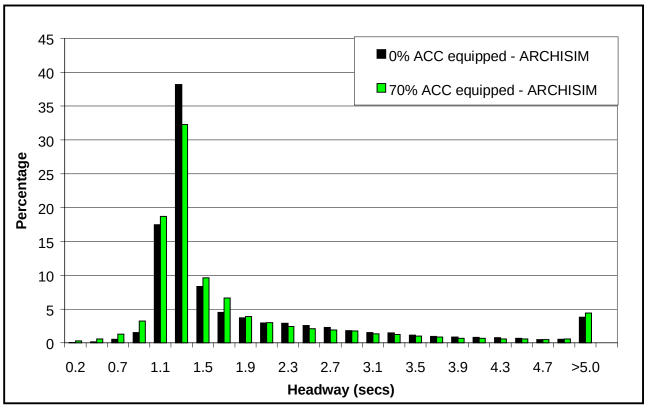

Figure 5: Time headway distribution for peak flow 2000 veh/hr/lane 0% and 70% equipped - target headway 1.2 s

The impact of ACC within ARCHISIM is an increase in short operating headways with a corresponding increase in larger gaps. This provides greater lane changing opportunity and reduces delay for vehicles stuck behind slower vehicles in lanes one and two, reducing delay and increasing average journey time. The results of the ACC modeling have been shown to be highly dependent on the baseline time headway distributions within the model. If it can be shown that the benefits of ACC are highly dependent on the baseline headway distribution then the impact of ATT technologies and the variations in headway distributions on existing networks will be important impact areas to decision makers.

Early indications are that the frequency of very short headways can be reduced with ACC. Low total time to collision can also be reduced. These findings may lead to a safety gain although the factors that cause accidents are not yet sufficiently well known to make this link definite. Currently the understanding of how drivers will use ACC systems and how non-ACC equipped drivers will interact with the systems is undefined. Finally, it is important to state that the benefits that have been shown from the ACC simulations to date are primarily comfort based. This is a direct result of studying systems that are first to the market. In the long term, once the technology is proven, it will be possible to operate with higher desired speeds, shorter headways, externally controlled headways and algorithms with a greater control range.

Infrastructure Based ATT System Evaluation

The third project is a study carried out to assess large-scale ATT effects inducted by infrastructure based systems. Such systems act to affect the behavior of different groups of drivers by the provision of information and/or application of control at specific points on the road network. The ATT system under consideration in this section is an Automatic Incident Detection (AID) system

AID systems monitor traffic conditions on a highway and attempt to identify abnormal road conditions that pertain to accidents or congestion. The action that the system then takes can vary significantly between systems. In all cases, the system is used to inform network monitors who can visually confirm the incident and inform the emergency services. In some systems, the information concerning the queues and local changes in recommended speed is communicated via variable message signs. The principal benefits of AID are a reduction in duration of the incident and an increase in awareness of drivers approaching the incident that should reduce secondary conflicts.

The simplest AID system has been modeled. The objective of the modeling exercise was to determine the reduction in congestion and queue lengths that would be achieved by a 5-minute earlier clearing of an incident over a range of demand levels. While any reduction in congestion length implies a reduction in the opportunities for secondary conflicts, no direct attempt was made to model the modification of driver behavior to information regarding the incident. Driver behavior adaptations are not sufficiently well understood for any such modeling to be valid. Modeling was performed using ARCHISIM on a 3-lane and 4-lane road without on-ramps. Two constant demand flow levels were applied for a one-hour simulation (low demand 1200 veh/hour/lane and high demand 1250 veh/hr/lane).

Figure 6 below shows the average speed in the section before that containing the lane drop. The lane drop causes a flow breakdown with flows of 3600 and 3750 vehicles per hour having to pass through a two-lane section. The reduction in duration of the speed drop with the reduced clearing time produced by the AID system is clearly visible. Similar effects were found for the 4-lane scenario. However, because there are three lanes that are not blocked, there are more opportunities for vehicles to change lane and avoid queuing near the incident. The effects are therefore not as severe as for the 3-lane scenario with any given flow level per lane. It is important to note that while the reduction in average travel time through the introduction of AID in the low flow scenario is small (5%), the improvements afforded at the high flow scenario are significantly larger (17%).

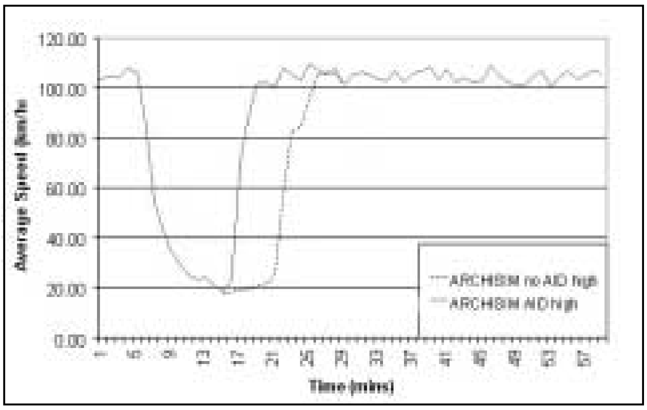

Figure 6: Average speed against time for high demand scenario (Cologne 3-lane site 665 to 100m before lane drop)

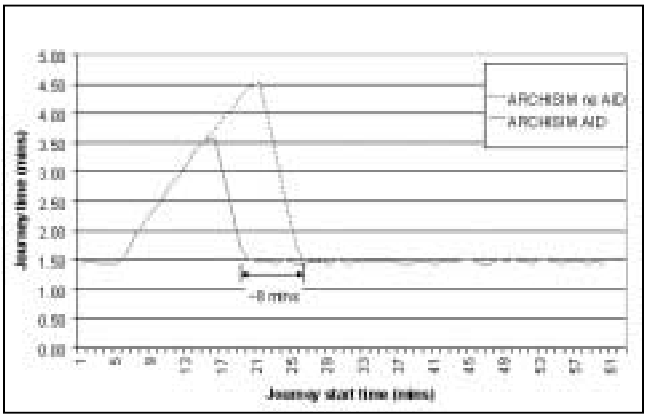

Figure 7: Average journey time against start time for journey – high flow 3-lane

Comparing the patterns of average journey times of vehicles over the low and high flow scenarios (Figure 7) again highlights the increased benefits of AID. The reduction in the duration of the flow breakdown, where average journey times are elevated, is only slightly (approximately one minute) above the 5 minute gain in early detection for the low flow scenario. The reduction in congestion is three to seven minutes longer than the 5 minute gain in the high flow scenario. The presence of the incident produced large numbers of short inter-vehicular distances and low Time to Collision values. Incidents also increase lane changing to avoid the queue. The reduction in the duration of the incident and associated queuing reduced the occurrence of these low headway and time to collision values. No behavioral shift is implied in this but it is a benefit of early detection.

As presented, ARCHISIM –like mathematical models– can be used for various traffic studies. But, unlike these models, ARCHISIM gives the possibility to dynamically modify some simulation conditions and can host a driving simulator. However, a behavioral model does not only show advantages and some limitations exist. The first limitation is that the development of a tool such as ARCHISIM is extremely costly because the driver behavior is not completely modeled yet and its implementation is not trivial. The second limitation is that behavioral simulation needs more computing than mathematical simulation because the system is distributed and simulated vehicles are fully autonomous. Therefore, until now, the experiments and studies led with ARCHISIM have been mostly done for low-density road networks. Indeed, the number of simulated vehicles could not exceed one thousand while classic models can manage several dozens thousand vehicles. To mitigate this gap, some current works conducted by INRETS and SRILOG –a company specialized in traffic studies– aim at using ARCHISIM for traffic studies requiring high density networks.

TOWARDS HIGH-DENSITY NETWORKS PROJECTS

We wish to conduct traffic study projects for high density networks for two reasons. First, at SRILOG, we intend to conduct traffic studies with ARCHISIM because we have measured the potential of a behavioral simulation tool and think that it would be more interesting, in some cases, to go for such a tool rather than a mathematical model based tool. Secondly, at INRETS, our will to validate ARCHISIM for most situations urges us to work on innovative projects.

Hence, the project we present now is a test project, on which we are currently working to validate ARCHISIM for traffic studies requiring the simulation of a high-density highway network. This traffic study conducted by means of the behavioral model ARCHISIM is the simulation of a real experiment conducted in 1999. This experiment consisted in measuring and studying the impact of ramp metering on a 16km 3-lane section of the highway 6 to Paris. On this site, place of frequent disturbances during the morning rush hours, four over five ramps are equipped with a regulation device including a detection system for flow breakdown on the local area network. The experiment, which concerned an evaluation of regulation devices (regulation by fixed traffic lights cycle and adaptive regulation), showed that the adaptive regulation gives best results and that route time decreases of 15% with regard to the reference situation (without regulation).

The project stages for the simulation of this experiment are: 1) simulate the traffic on the network without regulation and validate it with regard to the reference situation; 2) simulate the traffic with regulation by fixed traffic lights cycle; 3) simulate the traffic with adaptive regulation.

The work to be made for this project is:

1) Create the virtual roads network (the highway 6 section). Create the traffic demand corresponding to the rush hours (from 6 am to 9.30 am). Verify the traffic validity by comparing the simulation data to the real data collected during the experiment. In this project, up to vehicles 10,000 are to be considered at the same time and this is our main obstacle. To overcome it, at least two solutions are to be investigated. The first idea is that it is not necessary, for a traffic study, to use real time simulation. The second idea is that it is possible to save computation time by optimizing the algorithms related to the perception and the interpretation of the simulated situation. Indeed the traffic almost immobility, bound to its high density, allows limiting the useful environment of each simulated road user.

2) Set up regulation strategies. This part does not really show any difficulty because ARCHISIM is conceived to manage this type of systems.

3) Compare the data obtained from the simulations to the real experiment results.

This project should allow us to validate ARCHISIM for traffic studies involving high-density highway networks. Design, studies and coding are in progress and the first results are encouraging. We hope to get the work done by the end of July and are looking forward for new projects.

CONCLUSION AND PERSPECTIVES

The results obtained with the behavioral road traffic simulation tool ARCHISIM allow showing the capacity of this type of non-mathematical model to answer various projects. In this frame, ARCHISIM is validated and has been used for several years for simulations of highway networks requiring a high precision, flexibility or interactivity. Behavioral simulation allows henceforth being able to propose a large field of application for traffic studies.

After these first successes, we now try to meet a new challenge: conduct traffic studies related to high-density networks with a behavioral simulation tool. If the test study reproducing a real experiment is decisive, we shall have then the possibility of proposing ARCHISIM on a market today held by mathematics-based simulation tools.

Ultimately, our intention is to be able to conduct specific traffic studies requiring an important opening of the simulation tool and a high level of detail, whatever the network and the traffic density are. The perspectives of application are encouraging and, even if the work is still important and that of numerous unknowns persist, we intend to make ARCHISIM a commercial product before the end of next year.

ACKNOWLEDGMENT

The authors would like to thank Mr. Aron of INRETS, Mrs. Lancelin and Torjemane of SRILOG and Profs. Kolski and Mandiau of the LAMIH Lab at the University of Valenciennes for their support.

This work was partly sponsored by ANRT through a research grant CIFRE.

REFERENCES

Aron M. and Espié S. 1999, "DIATS Deployment of Interurban ATT Test Scenarios." Technical Report RO-96-SC.301. INRETS, Arcueil, France.

Champion, A., Mandiau R., Kolski C., Heidet A. and Kemeny A. 1999. "Traffic generation with the SCANeR II simulator: towards a multi-agent architecture." *In Proceedings of the Driving Simulation Conference '99* (Paris, France, Jul. 7-8). Renault, Guyancourt, France, 311-324.

El Hadouaj S., Espié S. and Drogoul A. 2000. "To combine reactivity and anticipation: the case of conflicts resolution in a simulated road traffic." *In Proceedings of the MABS 2000 at ICMAS 2000* (Boston, USA, Jul. 10-14). Springer Verlag LNAI series.

Espié S. 1999, "Vehicle-driven simulator versus traffic-driven simulator : the INRETS approach." *In Proceedings of the Driving Simulation Conference '99* (Paris, France, Jul. 7-8). Renault, Guyancourt, France, 367-376.

Lieberman E. and Rathi A.K. 1997, "Traffic simulation." in Traffic flow theory, Gartner and Messer, eds, Oak Ridge National Laboratory. http://www-cta.ornl.gov/cta/research/trb/tft.html

Reece D. A. et Shafer S. A. 1993, "A computational model of driving for autonomous vehicles." Transpn. Res.-1. Vol 27A, No. 1, Pergamon Press Ltd, 23-50.

Nouvier J., Duraz M. and Aillerie I. 2001, "Evaluation on driving simulator of new solutions for the regulation of access to urban highways." *In Proceedings of the Driving Simulation Conference 2001* (Sophia-Antipolis, France, Spt. 5-7). Renault, Guyancourt, France, Forthcoming.

Saad F. 1999, "Analyses of drivers' activity in real driving conditions: theoretical and methodological issues*" In Proceedings of the First Internationnal DRiiVE workshop* (Espoo, Finland, Jul. 21-23).

BIOGRAPHIES

Alexis Champion is project leader for SRILOG, a company specialized in road traffic management and simulation, and works in partnership with the INRETS (French National Institute for Research in Transportation and Safety). Mr. Champion holds B.S. and M.S. degrees in Computer Science from the University of Valenciennes and is currently pursuing a PhD in Artificial Intelligence. His research interests includes multi-agent coordination and behavioral road traffic simulation.

Stéphane Éspié is Senior Scientist and co-leader of the Traffic Simulation and Driving Simulator Department at the INRETS. He has been working at INRETS since 1982, first on new sensors for traffic (video, laser beam...), then on traffic simulation. Mr. Espié is also involved in the INRETS ITS works and was part of European Union 4th framework program DIATS (Deployment of Interurban ATT Test Scenarios). His research interests includes design of hardware and software architecture for both traffic simulation and driving simulator, Distributed Artificial Intelligence and co-operative systems.

Jean-Michel Auberlet is Research Scientist at the INRETS and is a member of the Traffic Simulation and Driving Simulator Department. He holds B.S. and M.S. degrees in Mathematics and a PhD in Biomathematics from the University of Angers. Dr Auberlet's research interests includes viability analysis and model design for simulation.