

Spatial Analysis and modelling based on activities

Dr. Dirk Conradie

1 Introduction

This chapter describes the development of an agent based Computational Building Simulation (CBS) tool, termed KRONOS that is being used to support advanced research questions such as traffic safety assessment and user behaviour in buildings. The intention is to provide better support for dynamic space-time related research as well as investigations into static built environment modelling and simulations such as people motion studies. The authors (CSIR researchers) view CBS as a technical specialization of Building Product Models (BPM) also known as Building Information Models (BIM). The research findings, supported by a traffic safety case study and other precedent research, indicate that traffic safety assessment can not be predicted through vehicular traffic micro simulation models alone. It must be understood as a contextual product of both vehicles, drivers, pedestrians, animals and the environment. To study traffic safety requires simulators with both advanced static and dynamic capabilities. The research team created a modelling and simulation environment based on an experimental BPM. Within this environment agents and props were placed to dynamically simulate and predict emergent behaviour. Emergence is the way complex systems and patterns arise out of a large number of simple agent interactions. The data from this case study and other precedent case studies used in KRONOS indicated that the agent based micro modelling approach is feasible.

South Africa has the highest number of people killed in road accidents per 100 000 people. South African cities have a road fatality rate that is significantly higher than cities in other parts of the world. Compared to European cities, the fatality rate is between five and eight times higher (Vanderschuren, 2008). The Moloto Road, north of Pretoria (Route 573) is notorious for the large number of serious road collisions and casualties that occur here frequently. An analysis of accident data (Department of Roads and Transport, 2008) for the period January to December 2007 for the most hazardous sections that include Zakheni, Kwamahlanga, Phola Park and Vezubuhle indicates that the two most common types of accidents are Pedestrian (32.47%) and Head/ Rear (28.57%). U-Turn, Side Swipe and Rolled combined contribute equally to 35.06% of accidents. 53.25% of accidents within said area fall within the serious category (Figure 1).

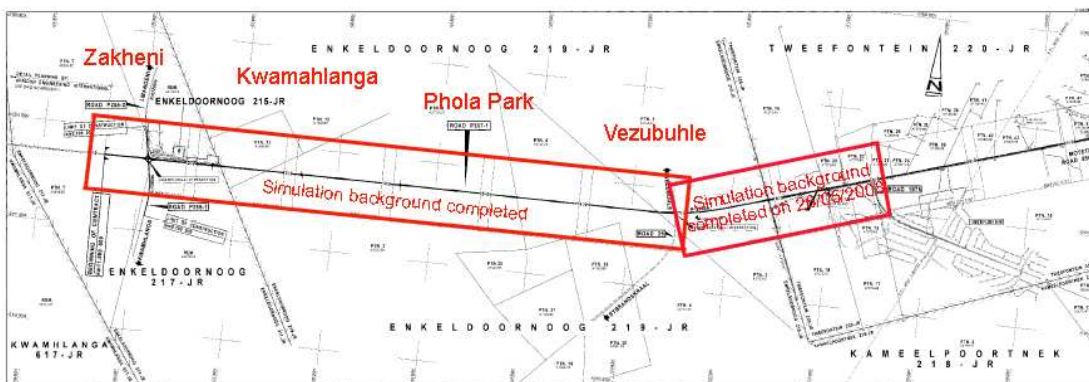


Figure 1: KRONOS modelling of Moloto Road

The road serves as a commuter route for a large number of workers to Gauteng (especially Tshwane) from many widely spread low density residential communities living across the provincial border in Mpumalanga Province.

It was decided to study the area marked in red (Figure 1) intensively for the purposes of the simulation case study and to build an agent based simulation. The section of approximately 8.5 km starts at 25°24' 12.25" S and 28°42' 04.54" E and ends at 25°23' 50.17" S and 28°47' 27.76" E.

2 Agent based simulation

In the late 1950s Allen Newell and Herbert Simon proved that computers could do more than calculate. Marvin Minsky, head of the Massachusetts Institute of Technology (MIT) Artificial Intelligence (AI) project at the time, announced with confidence that within a generation the problem of creating Artificial Intelligence would be substantially solved. Then suddenly the field of AI ran into unexpected difficulties. The trouble started with a failure of attempts to program an understanding of children's stories. The program lacked the common sense of a four year old and so no one knew how to give the program the background knowledge necessary for understanding even the simplest stories. An old rationalist dream was at the heart of the problem. At the time AI was based on the Cartesian idea that all understanding consists in forming and using appropriate symbolic representations. For Descartes, these representations were complex descriptions built up out of primitive ideas or elements. Bellman (1978:144) came to the conclusion that the human brain remains far superior to anything that can be mechanised.

Against abovementioned background simulation programs could not produce reliable analysis until the beginning of the 1990's. Even if the algorithms behind these programs were based on proven analytical methods, hardware capabilities were severely limiting the researchers.

Post-Modern Artificial Intelligence (AI) brought new more realistic opportunities in the simulation field. According to Riesbeck (1996:374) AI is the search for answers to the eternal question: Why are computers so stupid? Riesbeck (1996:377) indicates that the problem of AI is to describe and build components that reduce the stupidity of the systems in which they function. The goal should be the improvement of how systems function through the development of intelligent components to those systems. One does not want a micro simulation system that attempts to equal the formidable capabilities of the human brain. One wants a simulation system that can within the closed world of traffic simulation support and reasonably predicts likely outcomes for a given scenario. In Post-Modern AI, AI becomes a more realistic and invisible part of the overall system.

At the moment two fundamentally different types of approaches are used with regards microscopic traffic simulation, i.e. cellular automata and agent based approaches. A cellular automaton consists of a regular grid of cells, each in one of a finite number of states. The grid can have any finite number of dimensions. Time is also discrete and the state of a particular cell at time t is a function of the states of a finite number of cells (called its neighbourhood) at time $t - 1$. These neighbours are a selection of cells relative to the specified cell, and do not change (though the cell itself may be in its neighbourhood, it is not usually considered a neighbour). Every cell has the same rule for updating, based on the values in its neighbourhood. Each time the rules are applied to the whole grid a new generation is created. This approach makes it very difficult to simulate the real world realistically, e.g. where pedestrians and animals interact with vehicles within a particular environment.

In contrast the KRONOS approach is agent based. Wooldridge (1997) defines an agent to be:

- An autonomous system, making decisions based on its internal state,
- Situated in an environment and being able to perceive it in order to react to the changes,
- Able to take the initiative and exhibit goal-directed behaviour,
- Able to interact with other agents and to cooperate.

Russel *et al.* (2003) defines four types of agents. The *simple reflex agent* determines its actions solely through reactions based on *condition action* rules. If a particular condition becomes true, it becomes active. This type of agent is simple, but is inadequate for complex problems requiring more than one action and foreseeing forthcoming states of the environment. The *model-based agent* maintains a state of the world updated by its sensory inputs and by functions describing changes over time including the effects of own actions. This softens the requirements of fully observable environment required by the first type. The reasoning is based on the representation of the environment in the agent's internal state. *Goal-based agents* comprise goals. As their goals can change or addressed in different ways, goal-based agents are more flexible when used in applications. The choice of action is determined by the environment, the agent's internal state and

by a set of goals. Planning and search is used if there are goals that cannot be achieved by a single action or procedure. Many successful agent architectures are based on the belief-desire-intention model (BDI) of agency that is essentially an extension of the *goal-based* agent. This architecture is based on a model of human-like traits and mental attitudes (Bratman, 1987). In this model, each agent carries beliefs; its internal representation of what is sensed (informational attitudes). The agent also has desires or plans to achieve its goals (motivational attitudes). Finally the agent outputs an intention, that what the agent strives to achieve in the environment (deliberative attitudes) (Pokahr, 2005). The BDI model does not cover emotional and other 'higher' human attitudes.

KRONOS is a generic Computational Building Simulation (CBS) tool that was developed over the past three years to work on advanced architectural and built environment research questions such as user behaviour in buildings. The intention was to provide better support for dynamic space-time related research as well as investigations into static building modelling and simulations such as energy performance. Two precedent empirical case studies (Conradie *et al.*, 2007) indicated that building performance can not be predicted through the development of building and environmental models alone. It must be understood as a product of both an environment and its users. To study or predict building environment performance requires both advanced static and dynamic capabilities.

One of the innovations in KRONOS is the inclusion of a dynamics engine to facilitate more realistic accident simulation and the analysis of forces and vehicle performance during an accident. The particular dynamics engine used is Open Dynamics Engine (ODE). It is an open source, high performance software library for simulating rigid body dynamics. It is fully featured, stable, mature and platform independent with an easy to use C/C++ Application Program Interface (API). It has advanced joint types and integrated collision detection with friction. ODE is particularly useful for simulating vehicles, objects in virtual reality environments and virtual entities such as pedestrians. It is currently used in many computer games, 3D authoring tools and simulation tools. The latter is of particular interest to the research team and is directly applicable to the current project.

It was realised that the particular requirements of traffic safety assessment on the Moloto Road ((Route 573) could be met with the unique agent based approach of KRONOS if it is refined further. An agent is seen as any entity that can move, such as vehicles, pedestrians and animals. KRONOS also uses entities called props or pads. Props are normally static and are placed in the simulation environments. Props can be "observed" or "sensed" by the agents and include entities such as traffic lights, road furniture, trees and buildings. It is the opinion of the research team that agent based simulations will yield better results than for example cellular automata for a number of reasons.

- Accuracy: Traffic flows consist of a large number of complex emergent behaviours. It is the result of the individual decisions of drivers, pedestrians, traffic controllers and other individuals. Agent technology helps building micro simulation models with detailed, rich behaviours for individual entities. The architecture for individual agents promote modularising internal behaviour and decision making capabilities of an agent and changing behaviour from its interactions with other agents. This is particularly important for driver and pedestrian behaviour that changes with locality as well as time.
- Computational performance: Agent technology is inherently distributed. In future it would be possible to deploy KRONOS on a network of computers.
- Study of scenarios: Scenarios can be configured in KRONOS. These scenarios are then run in almost real time. Due to the interaction of a large number of parameters or characteristics emergent behaviours develop such as traffic congestions and accidents. The parameters for individual agents and props can be adjusted to test hypotheses or to determine the benefits that might be derived with changed conditions.

Agent based simulations require reliable datasets to facilitate the simulation and to provide context. In the Moloto Road project the first step was to acquire data in three main categories:

- Agent related data: This is data that relate to the number and type of vehicles. It also includes the pedestrian behaviour as well as the presence of free roaming animals.
- Prop related data: This category relates to the position of existing significant entities such as bus stops, road furniture, trees, bridges, retail areas and houses to make the simulation context realistic.
- Environment related data: This type of data relate to characteristics of the environment such as visibility and the position of the sun.

The last requirement is a detailed vector based map of the road section being studied that will act as a “virtual stage” on which the agents and props will be placed.

3 Research method

It is generally recognised that the reasons for the exceptionally high accident rate in the area under consideration, especially over weekends, is due to many complex and interacting factors. The simulation team assumed that some of the factors could never be quantified such as driver and pedestrian attitudes and perceptions. Similarly the roadworthiness of vehicles on this road is not known. For this reason it was decided to concentrate on the reasonably scientifically knowable. The simulation team specifically avoided jumping to conclusions without thorough investigation. In order to progress with the KRONOS simulations, the following five basic fundamental hypotheses were made and configured on the simulation platform:

- The accidents are mainly caused by reckless and aggressive driving.
- The accidents are mainly alcohol related, causing slow reaction times leading to accidents.
- The accidents are mainly caused by cognitive/ sensory factors such as bad visibility in all its various manifestations such as direct sunlight, lack of street lighting and cognitive overload.
- The accidents are caused by inconsistent road markings and signs or a generally badly designed road.
- Accidents are mainly caused by unexpected driver behaviour such as taxis suddenly stopping without warning.

It is recognised that the actual causes of accidents are probably a combination of the abovementioned factors. Two additional base line scenarios were configured, i.e. *Real World* and *Ideal World* scenarios. The base line scenarios helped to calibrate the relative contributions of the causes of accidents given in the other five hypotheses mentioned above.

4 Simulation case study

A preliminary visit was paid to Moloto Road on 4 December 2007 to get a sense of the state of road safety in the area. On 13 December 2007, the research team set out on a more extensive site inspection of the road. The trip was made onboard a vehicle equipped with video surveillance and GPS equipment. The electronic equipment would enable the research team to re-run the whole trip from the office and collect relevant data for the project.

To configure the KRONOS simulation it was decided that the following data would be essential, although other data like conventional road safety audits were also obtained.

- 1) The availability of exact traffic volumes according to headways, vehicle categories and speeds.
- 2) Detailed CAD design drawings of the study area especially the complex Kwamahlanga four way stop intersection. This is essential for KRONOS because it essentially provides the simulation environment for the agent based simulations.
- 3) Identification of hazardous road sections to narrow down the area for intensive study. From accident reports it was apparent that it was the area indicated in red on Figure 1.
- 4) Road accident data. This exercise proved very successful and the Accident Report (AR) forms for 2007 (except for October 2007) were retrieved from different police stations. These accident reports informed abovementioned statistics for the study area accurately.

- 5) A land-use survey was conducted on 10 April 2008 covering the study area. This is the most hazardous section of the Moloto road, about 8.5 km in length. Four aerial (satellite) photos, covering the entire area, of the Moloto road were obtained from the CSIR Satellite Applications Centre (SAC). The images are from the French SPOT IMAGE 5 satellite and the image used was recorded on 5 January 2007 at 11h32. The images are recorded in five electromagnetic spectrum bands, panchromatic, green, red, near-infra-red and short-wave infrared. The raw image has false colours and had to be adjusted to get natural colour and reduced in size to make it useable in the simulation environment. (Figure 2)
- 6) Vehicle specifications. To ensure accurate vehicular simulations detailed specifications were obtained for busses and minibus taxis. The road vehicle performance simulations in KRONOS are based on the algorithms as described by Mannering *et al.* (2005). The following factors were requested from vehicle manufacturers:
 - Total Vehicle mass in kg (Without Passengers)
 - Weight of vehicle on front axle in kg. (With and without passengers)
 - Weight of vehicle on rear axle in kg (With and without passengers)
 - Vehicle dimensions in mm (width, length and height)
 - Frontal area, i.e. total area of vehicle meeting the rush of air whilst travelling in m². This is a value required to determine the aerodynamic resistance of the vehicle.
 - Number of passengers (including driver)
 - Maximum torque in Nm
 - Maximum power in kW
 - Vehicle Name and model.
 - Is the vehicle front wheel or rear wheel drive.
 - Length of wheelbase in m.
 - Height of centre of gravity above road surface in m.
 - Distance from the front axle to the centre of gravity in m.
 - Distance from the rear axle to the center of gravity in m.

The research team also wanted to know if the particular vehicle is fitted with devices such as ABS or other braking, traction or stability improvement devices. It is important because different formulas are used in these cases.

From this data the team built an extensive simulation model containing a combination of vehicular and pedestrian agents. A portion of the model is illustrated in Figure 3. It contains a raster layer with colour coded land use reference points and a vector layer assembled from simplified CAD road design geometric drawings. A total of 393 simulations were run and the emergent behaviours of the combination of agents were observed and studied. In the simulations 1 137 agents were typically used, of which 194 were concurrent at any point in time. Each agent took approximately 100 decisions per second, which translated to 19 400 decisions per second during complex simulations. The most complex simulations were run continuously and automatically over a period of three days. In future it would be possible to study various interventions such as the placement of barriers to create order, subways and bridges.



Figure 2: Preparation of SPOT IMAGE 5 satellite image. (Raw left, processed right)



Figure 3: Section of 2D simulation drawing with a vector and raster layer

3 Conclusion

The case study indicated that the agent based approach, although still experimental, shows much promise although it took a significant amount of effort to obtain relevant data and to process it in a form suitable for simulation. A sun calculator that has also been developed as part of the simulation platform has identified hazardous months of the year where visibility on the road near sunrise and sunset would be severely impaired, possibly contributing to accidents. One of the advantages of a visual based simulation is that non-technical role players can visualise problems and it enables them to work with professional, scientific and technical designers. The vector graphic part of the simulation environment can be conveniently built by means of standard CAD programs such as *AutoCAD*, *AutoDesk Revit*, *3D Studio Max* or *MicroGDS*.

Although the development of autonomous agent based micro simulation programs is far more complex than is the case with cellular automata, the research indicates that this approach has more potential to create realistic and predictive simulations. It is for example possible to mix pure Newtonian based vehicle performance agents with pedestrians following an AI based BDI approach within one environment. The project also indicated that the sophistication of current hardware and software technology is able to meet the challenging demands posed by autonomous agent based modelling exercises within the South African context.

References

Bellman, R. 1978. *An introduction to artificial intelligence: can computers think?* Boyd & Fraser publishing Company, San Francisco, California.

Bratman, M. 1987. *Intention, Plans and practical Reason*. Harvard University press, Cambridge.

Conradie, D.C.U., Gibberd, J., Mentz, F. And Ras, H. 2007. Towards a Continuum of Computational Building Simulation Tools to Support the Design and Evaluation of Complex Built Environments. In proceedings of *CIB World Building Congress, Construction for Development*, Cape Town 14-17 May 2007.

Mannering, F.L., Kilareski, W.P. and Washburn, S.S. 2005. *Principles of Highway Engineering and Traffic Analysis. Third Edition*. John Wiley & Sons, USA.

Pokahr, A., Brauback, L. and lamersdorf, w. 2005. *Jadex: A BDI agent System combining middleware and Reasoning*. Birkhuser Book.

Riesbeck, C.K. 1996. *Case-based Reasoning* edited by D.B. leake. AAAI Press, Menlo park, California.

Russell, S.J. and norvig, P. 2003. *Artificial Intelligence: A Modern Approach (2nd Edition)*. Prentice Hall.

Vanderschuren, M. 2008. Safety improvements through Intelligent Transport systems: A South African case study based on microscopic simulation modelling. *Accident Analysis & Prevention*, 40 (2008) 807-817.