THE USE OF AGENT BASED SIMULATION FOR TRAFFIC SAFETY ASSESSMENT

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ABSTRACT

This paper describes the development of an agent based Computational Building Simulation (CBS) tool, termed KRONOS that is being used to work on 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). 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 both advanced static and dynamic capabilities. The research team created a modelling and simulation environment based on a BPM. Within this environment agents and props were placed to dynamically simulate and predict emergent behaviour. The data from this case study and other precedent case studies used in KRONOS indicated that the agent based micro modelling approach is feasible.

Keywords: Traffic Safety Assessment, User Behaviour, Agent Based Modelling

1. INTRODUCTION

1.1 Background

According to the Road Traffic Management Corporation (RTMC) the number of fatalities increased from 12 778 in 2004 to 15 393 in 2006. According to the World Road statistics (IRF, 2006), 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 (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 hazourdous sections that include Zakheni, KwaMahlanga, Phola Park and Vesakihle 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).

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.

Road casualties by road user type along the section of Moloto Road in Mpumalanga Province, covering the period April 2006 to March 2007 show that 36 persons were killed and another 147 were injured during a period of one year. In addition, casualty statistics for April 2007 show that 20 casualties (7 fatal and 13 injuries) were recorded on the route, indicating that the situation is worsening. The casualty statistics for the same route for the period April 2006 to March 2007 indicated that the afternoon period (12h00 – 18h00) and the evening period (18h00 – 12h00) were more prone to casualties. Each represented respectively about 29% and 56% of all the road casualties along the route.

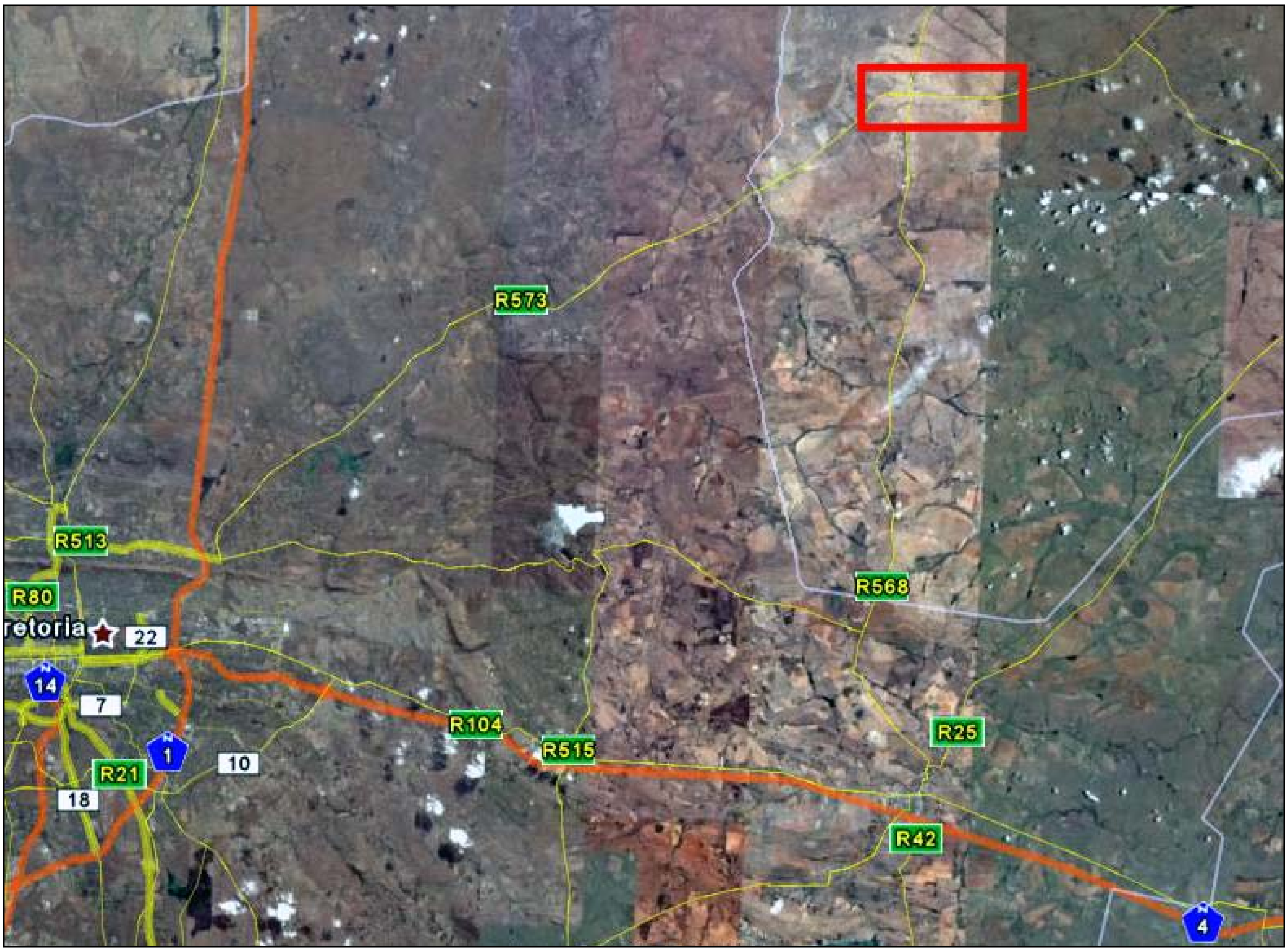

Figure 1 The study area of the most hazardous section of the Moloto Road study (red rectangle)

It was decided to study the area marked in red (Figure 1) intensively for the purposes of the 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.

1.2 Problem statement

In the light of the high accident rate in the area indicated in Figure 1 and the large number of factors that influence traffic safety it was decided to use novel methods. The research question is firstly if a combination of human and traffic flow information can be simulated and modelled by advanced simulation systems to discover possible unforeseen lacunae in the current configuration. Secondly do specific solutions of road configurations or other improvements exist within the evidently chaotic situation (Figure 2 and 3) that will significantly improve the traffic safety? The CSIR researchers are of the opinion that agent based micro simulations provide an opportunity to analyse the existing situation and to predict what the likely outcome of possible interventions such as lighting, fences, walls, bridges and sub ways might be.

Figure 2 Large number of pedestrians

Figure 3 Businesses in street reserve

1.3 Aim of paper

The aim of the paper is to introduce current research in the field of agent based simulation as applied to traffic safety assessment within the context of the Moloto Road Feasibility Study.

1.4 Scope of paper

The scope of the paper is to briefly discuss two recent precedents and the enhancements that have been made to KRONOS to support traffic safety assessment. The specific data that was acquired and analysed is discussed and the likely outcomes, because it is still work in progress.

2. SIMULATION PLATFORM

Building Product Models (BPM) were originally intended to facilitate collaboration between different architectural and engineering design systems such as Computer Aided Design (CAD). According to Eastman (1999) a BPM is a digital information structure of the objects making up a building, capturing the form, behaviour and relations of the parts and assemblies within the building.

The current commercially available BPM’s place much emphasis on the form and relationships of the parts, but very little on user behaviour. The International Alliance for Interoperability Industry Foundation Classes standard (IFC) is at this stage the most advanced and simultaneously complex general purpose BPM available. The conceptual current IFC architecture (IFC 2x2) consists of four basic layers, i.e. Resource Layer, Core Layer, Interoperability Layer and Domain Layer. BPM’s have not previously been used for dynamic simulation in the built environment.

Due to resource constraints the CSIR team decided to use a much simpler model that contains the essence without making too many compromises. The closest existing model to fulfil this requirement was a XML based model offered by the Cambridge based Informatix company.

Two precedent case studies informed the requirements of autonomous agent based user simulations more precisely. The first study simulated people and vehicular movement for the new Moreleta Dutch Reformed 7 500 seat mega church in Pretoria. This property experienced severe traffic problems due to inadequate vehicular exits (Conradie *et al*., 2007). The other case study was different from the first one because there was no real perceived problem. The opportunity was used to observe first hand the behaviour of members of the public at the Stellenbosch Traffic Department (Figure 4) which is a public service centre with many service counters. The two case studies highlighted many deficiencies, such as inadequate support for complex queues, in the KRONOS simulation software. The Moloto Road project provided the opportunity to add support for traffic safety assessment simulation.

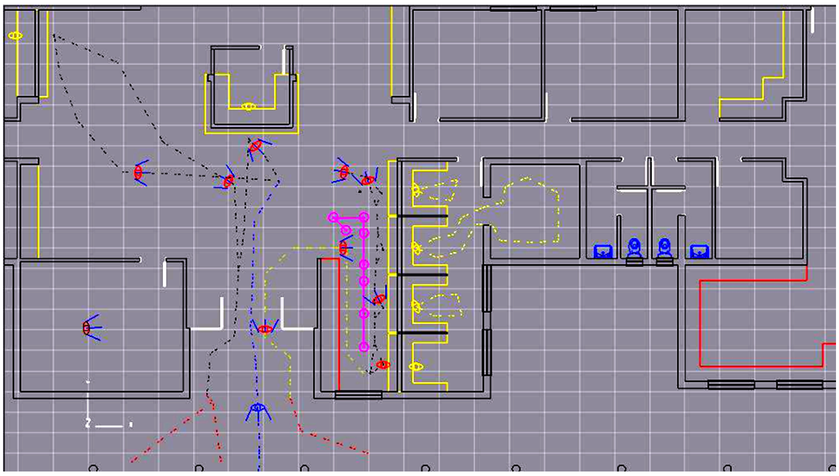

Figure 4 A typical 2D simulation of people queues in the Stellenbosch Traffic Department

2.1 Reasons for project

The built environment and especially traffic safety assessment is very complex, requiring both static and dynamic simulations. At the moment many static type of simulations are widely used in academia and industry such as energy evaluation, daylight calculation and structural design. At the moment advanced micro traffic simulation systems exist that place more emphasis on the vehicular traffic than the interaction with pedestrians.

It was realized that the technical improvement of a BPM could offer the possibility to create a generic modelling and simulation platform which is not only almost photorealistic, when required, but also scientifically correct. The intention was that that many different types of experiments and built environment related evaluations could be undertaken on the basis of this generic technical platform. Recently an increased emphasis has being placed on the simulation of multiple physics. This is necessary so that complex built environment designs and infrastructure can be better explored and validated.

In the light of abovementioned it was decided to first concentrate on the behaviour of people who will use and occupy the built environment. Some good commercial software products are available for this type of simulation; however the social relationships are often ignored. According to Yan (2004) at least five different methods have been used to evaluate environmental design-related human spatial behaviour:

1) Norms and regulations
2) Case studies and precedents
3) Post-occupancy evaluation
4) Direct experience behaviour simulation
5) Indirect experience behaviour simulation

2.2 Computer simulation of user behaviour

According to Yan (2004) existing spatial behaviour simulations are mostly limited at well-defined areas of human activities where there has been considerable empirical research to support the development of cognitive models. Some of the areas of research are the behaviour of pedestrians (Feurtey, 2000), evacuations from a church (Oldengarn, 2003), egress analysis from a hotel (Kuligowski, 2005) and crowd dynamics (Still, 2000). Other researchers modelled pedestrian road crossing behaviour in traffic (Yang *et al*., 2006). Extensive research has also been undertaken into differences of drivers' reaction times according to age and mental workload (Makishita et al., 2007).

3. 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 the common understanding 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. AI at the time 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 above 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.

At this stage 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. 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 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.
- Integration with control systems: KRONOS can be used to visualise data that comes from sources such as thee Sensor Web (NyendaWeb). In this mode data gives instructions to KRONOS. KRONOS makes the various instructions visible to enable traffic engineers and researchers to study the traffic patterns. Alternatively, scenarios can be configured in KRONOS. These scenarios are then run in 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 requires 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.
- Environment related data: This type of data relate to characteristics of the environment such as wind, temperature, visibility, fog, and even 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.

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 CSIR 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 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 OR 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. (Figure 5)
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:

- 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 m^2. This is a value required to determine the aerodynamic resitance 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 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 that case. If the operator/ manufacturer had empirical (lookup-table information) for braking distances available for the different models it would be helpful to check against the theoretical values.

From this data the team is inthe process of building an extensive simulation model containing a combination of vehicular and pedestrian agents. At this stage a portion of the model is illustrated in Figure 6. It contains a raster layer with colour coded land use reference points and a vector layer assembed from simplified road design geometric drawings. In the near future and when traffic profiles become available simulations will be run. It is predicted that the emergent behaviours of the combination of agent swill be observed. As a second phase of simulation various interventions will be made such as the placement of barriers to create order, subways and bridges. The efficacy of these measures will be studied.

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

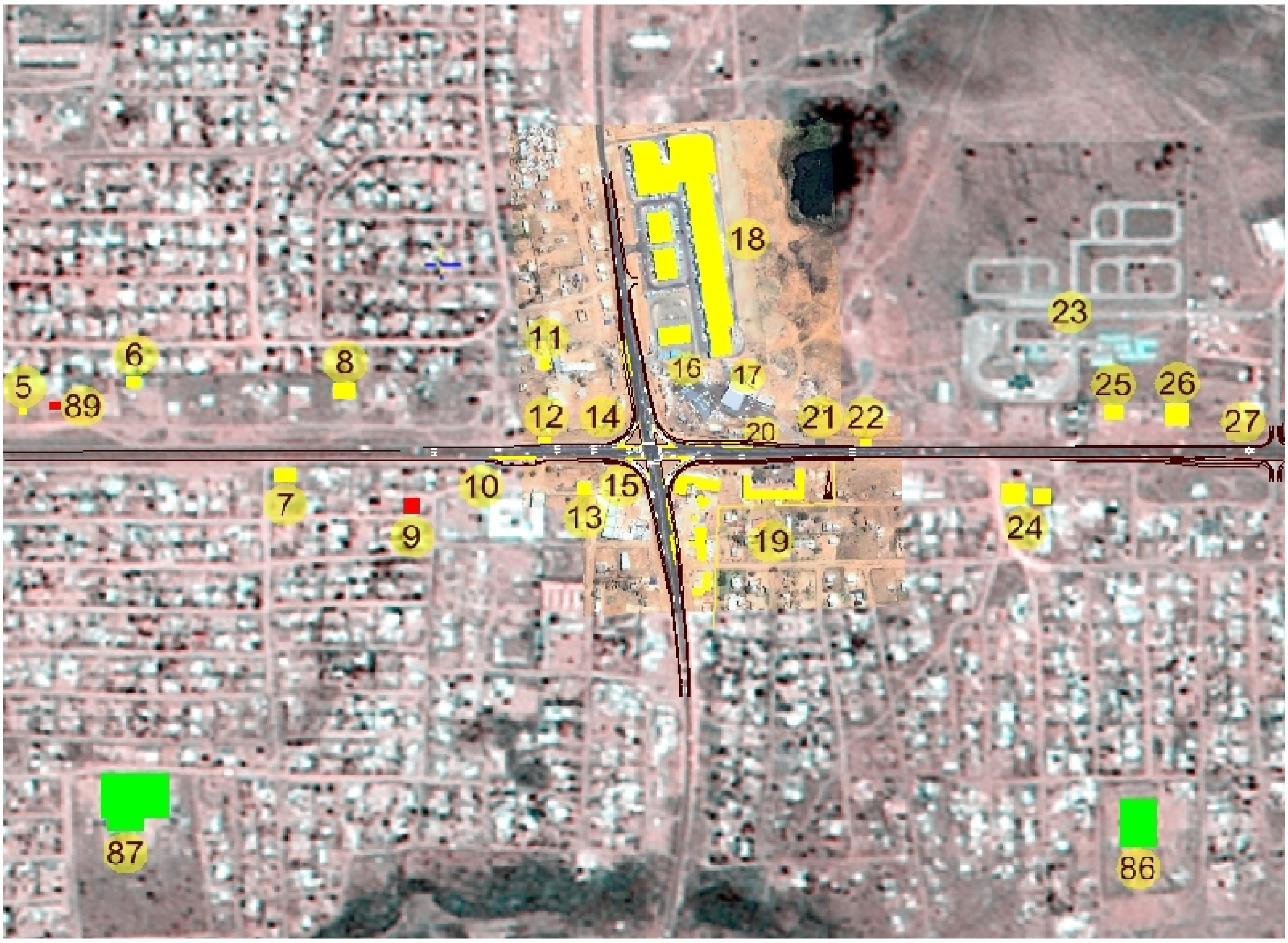

Figure 6 Section of 2D simulation drawing with a vector and raster layer

5. CONCLUSION

Early tests of this approach show much promise although it took significant effort to obtain relevant data and to process it in a form suitable for simulation. The sun calculator in KRONOS has already 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 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 part of the simulation environment can be conveniently built by means of standard CAD programs such as AutoCAD, 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 route has more potential to create more 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 shows the increasing sophistication of current hardware and software technology which is now able to meet the challenging demands posed by autonomous agent based modelling exercises within the South African context.

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