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Application of Virtual Reality for Risk Assessment and Training in the Minerals Industry

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Abstract

The minerals industry often requires people to work in hazardous environments, these environments are constantly increasing in size and complexity as organisations look for new more cost-effective ways of extracting resources. Not only does this size and complexity bring with it additional safety concerns, the introduction of new legislation has placed the responsibility of employee safety with the organisation. Safety has become an important consideration, where once it might have been viewed as costly and counter-productive, organisations are now seeking to gain competitive advantage in this area. Two key areas of a successful safety management programme are risk assessment and training. These are important in designing systems and environments that are as safe as possible and in educating and training personnel to operate safely within those environments.

Virtual Reality (VR) technology is one tool that has been applied successfully to the training requirements across a wide range of industries. In the past two years there is evidence to show that VR technology is becoming more widely used, partly due to the reduced cost and a reduction in the perceived technological complexity. As the cost of computing falls and the fidelity of the virtual worlds increases, VR is considered a viable option for a number of applications.

Two prototype VR systems were designed and built. The first, a risk visualisation system, enhances a virtual environment with a risk-based overlay. The relationships between dangerous areas and equipment can be visualised in 3D. It also provides a framework for evaluating the risk programmatically at an arbitrary location. The second is a surface mine simulator that uses a hazard identification system as a tool to aid the training of haul truck operators in surface mine. This system includes a world construction tool that allows users to import and prepare the terrain, construct the virtual world, and specify any hazards. The training system can evaluate the performance of a trainee in the virtual world using a simple scoring algorithm.

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Table of Contents

List of Figures

List of Tables

List of Equations

1 Introduction

1.1 Introduction

Virtual Reality (VR) is a computer based, interactive, immersive technology. With the rapidly increasing power of computing available, it is now possible to recreate highly realistic, high-resolution environments at relatively low-cost. Developments in both hardware and software have reduced the cost of developing and deploying VR systems, this has allowed applications once ruled out because of cost to be considered as viable propositions.

VR is already being used for a variety of applications including training and visualisation. It provides the ability to model and experience worlds as though the user was within the world itself. These worlds do not necessarily have to exist in the real world, they may be modelled based upon past, present or future plans. As such VR provides a way of evaluating an environment without constructing it in the real world.

VR has long been used in the training world, with flight simulators being one of the best known applications. It provides a means to train subjects without ever putting them in any real danger and since it is a controlled environment subjects can be exposed to a wide variety of hazards in a relatively short space of time. When the cost of training is high it is possible to make substantial cost savings by training in a simulator (RTI, 1997).

The minerals industry will often require personnel to operate in hazardous environments, as such safety is an important consideration. The increase in size and complexity of operations brings with it additional safety concerns. These have typically been countered by more regulations aimed at maintaining a safe and healthy working environment. Improvements in safety have traditionally been viewed as conflicting with organisations that are essentially financially driven, however, there is now significant evidence that this is not the case. Akass (1994) believes that attitudes towards industrial safety have advanced significantly in recent years, with the introduction of new legislation the emphasis has changed from prescriptive to new management systems. Safety management has become a standard term in many companies

Staley (1994) believes that the key to improving safety in the minerals industry is prevention, and that this prevention comes in two forms:

1. Designing out of accidents.
2. Education and training.

This work uses two examples of VR technology to demonstrate its applicability in both these areas. A tool has been developed to aid in the assessment of risk within a work environment. A second system has been developed to demonstrate the potential of a VR system to aid in the training and assessment of haul truck operators in a surface mine.

1.2 Research Aims and Scope of Work

This work addresses two components of safety, risk assessment and training. The author believes that both of these components could benefit through the application of VR technology.

An important component of risk assessment is visualisation. It is necessary for the assessor to understand the environment before a meaningful assessment can be made. Prior to beginning this work, the AIMS Research Unit had already undertaken some preliminary work on building a virtual environment and enhancing it with a risk based overlay (McClarnon et al., 1995 and Denby et al., 1995). Part of the work undertaken was to further develop the approach, refine the algorithms used, and identify further uses for this technology.

VR has also been used successfully in a number of industries as a training medium as it is able to provide an interactive, controlled and safe environment. There are a number of situations within the minerals industry where VR might be used as part of an existing training programme. The operation of a haul truck in a surface mine was identified as an area that could benefit from a VR based simulator. Working conditions in these environments are hazardous and training will often require interaction with expensive equipment and unavailable equipment. A VR training system was constructed with the aim of demonstrating and investigating the potential of such systems.

The scope of this work is restricted to identifying and investigating the viability of producing VR systems that might be used within industry. It is not intended to fully evaluate the effectiveness of such systems rather to demonstrate the applicability of VR technology. The aims of the work could be summarised as follows:

- Further develop the concept of 'Risk Regions' and identify further applications for this technology.
- Design and implement a low-cost prototype VR training system to investigate and demonstrate the potential for VR as a training medium within industry.
- Identify the important components of a low-cost VR system.
- Evaluate the viability of using low-cost VR systems in an industrial environment.

1.3 Research Methodology

A literature review was undertaken to provide an overview of current trends and issues in VR and industrial safety. This includes a general consideration of the current problems with regards to risk analysis and training. An operational overview of both underground and surface mines was also undertaken.

For the risk visualisation system, a review of the current work and systems was undertaken. A new methodology was developed and implemented in a new application. Two case studies were undertaken to evaluate the effectiveness of the new approach.

As a result of the literature review and the work on the risk visualisation system, a haulage training and assessment system was investigated. Further literature reviews were conducted with respect to training to help identify the requirements for such a simulator. A training and assessment simulator was developed to look at the potential for such systems within the industry. Provision has been made to examine potential improvements to all developed systems.

1.4 Thesis Overview

Chapter 1 **Introduction**

Presentation of the research aims, scope of work, and structure of this thesis is provided.

Chapter 2 **Literature Review – VR and Industrial Safety**

A definition of VR is discussed before the typical components and architecture of a VR system is described. Common applications of VR systems are also presented. The importance of a safe work environment is stressed with reference to legislative changes and the cost of accidents. The concepts of risk assessment and training are introduced and discussed. The safety record within the UK mining industry is briefly considered.

Chapter 3 **An Overview of Mining Operations**

Typical mining operations and terms are described with reference to both underground and surface mining. Common configurations of mines and typical methods of extraction are described.

Chapter 4 **Using VR to Aid Risk Analysis**

This chapter contains a review of the work already undertaken on the risk visualisation system. A description of the work undertaken to improve the system is given before finally describing two case studies that were performed using the newly developed system.

Chapter 5 **Proposed Haulage Training and Assessment Simulator**

This chapter describes the justification for the development of a training and assessment simulator and the proposed features. It describes the intended methodology for training in the system (hazard identification) and other technical considerations.

Chapter 6 **Development of the Haulage Training and Assessment Simulator**

Introduces the architecture of the system developed and describes the technical issues that were overcome. Also contains a description of both of the applications that were written to accomplish the tasks described in the previous chapter.

Chapter 7 **Conclusions and Recommendations**

2 Literature Review

2.1 Introduction

This chapter provides an introduction and reviews the currently available literature for both Virtual Reality (VR) and industrial safety. Given that these subject areas are very broad, attention is paid to relevant issues within the scope of the work covered, particularly the development of low-cost PC-based VR systems, and the areas of risk analysis, education and training.

2.2 Virtual Reality

2.2.1 Definition

VR has never been tightly defined, it has come to describe an enormous spectrum of work. Many authors have identified areas that they believe define the concept, however an all encompassing phrase has never been agreed upon. One good example of a definition is the following:

> "Virtual reality is the technology that allows you to step through the computer screen into a 3D artificial world. You can look around, move around, and interact within computer worlds every bit as fantastic as the wonderland Alice found down the rabbit hole." (Pimentel and Teixera, 1993)

VR systems create a synthetic 3D universe that exists inside a computer. The computer generates views of this world in real-time. This allows users to look and move around, interacting with objects held inside the computer's memory as if they were real. The key enabling technologies behind VR are real-time computer graphics, colour displays, and simulation software.

VR allows us to see worlds that are modelled inside computers and to experience things that are not normally accessible in real life or perhaps not yet created. The laws of these worlds are not physically bounded and can have as many or as few constraints as one wishes.

> "VR is more than a computer technology that places a person inside a 3-D world; it's the artificial world itself and a new kind of experience. It's also a method of communicating ideas. Inside a virtual world everything is potentially alive because the laws of the reality are up to the designer. The computer can just as easily bring to life the world of atoms as it can let you fly through space." (Pimentel and Teixera, 1993)

> "A display connector to a digital computer gives us a chance to gain familiarity with concepts not realisable in the physical world. It is a looking glass into a mathematical wonderland." (Sutherland, 1965)

These definitions are somewhat loose, many authors find it useful to look at the defining characteristics of VR to obtain a clearer definition.

2.2.1.1 Computer Based

Computers are pre-requisite in many definitions of VR,

> "VR is a way for humans to visualise, manipulate and interact with computers and extremely complex data." (Aukstakalnis and Blatner, 1992)

Computers have been the enabling technology that has facilitated the growth of VR. The improvements in computing power have allowed virtual worlds to be modelled and images of these worlds to be generated in real-time. Update rates similar to that of television and film can be maintained and graphical quality has improved tremendously in the past few years with the growth of low cost PC graphics acceleration aimed at the computer games market.

Environments are modelled mathematically on computers, and views onto this mathematical world can be presented in a number of different ways. Typically these views are visual, often through a computer monitor, however additional devices can be used to enhance the experience. These may include head-mounted displays (HMD), projection systems, or devices that provide tactile or acoustic feedback.

As new sensory devices are developed, the user's experience is expected to become richer – perhaps to the point where the difference between reality and VR is indistinguishable. This has been catalogued in many science-fiction books and films such as 'The Lawnmower Man' (Leonard, 1992).

2.2.1.2 Interactivity

There are two aspects of interactivity within a virtual world; (i) navigation, and (ii) the dynamics of the environment (Pimentel and Teixera, 1993).

Navigation describes the ability to move around freely and independently in the environment, although this may be constrained in a number of ways, for example restricting access to certain areas. Users may view the world from many different points of view, the wide variety of computer games provides testament to this. Games players may experience worlds from a first person perspective as in the computer game 'Doom' (id Software, 1993), watching from a distance as in 'Tomb Raider' (Eidos, 1996), or from some other perspective as in 'SimCity' (Maxis, 1989).

The dynamics of the environment are the rules that describe how the objects within the world exchange information.

> "Every object and its relationship to every other object (including the user) is a design element at the discretion of the developer. Among these elements are the location, colour, shape and size of the environment, the plasticity of the walls; the laws of gravity; and the capabilities and functions of the objects and actors in the environment. As a result, virtual reality is the experience of *being in another world,* a world governed by selected laws and inhabited by objects (and actors) with whatever properties the creator chooses to assign." (Pimentel and Teixera, 1993)

The geometric properties, physical laws, behaviour of objects within the world, their creation and destruction, and even time itself can be controlled. This flexibility allows anything that exists in the real world to be modelled, as well as that which does not.

> "There is no reason why the objects displayed by a computer have to follow the ordinary rules of physical reality with which we are familiar." (Sutherland, 1965)

2.2.1.3 Immersion

> "As long as you can see the screen you're not in virtual reality. When the screen disappears, and you see an imaginary scene ... then you are in virtual reality." (Offeisch, 1994)

Immersion describes the degree to which the user believes he or she is included in the environment, their sense of presence within the world. Some believe this to be the defining characteristic of VR, indeed McLellan (1994) believes that:

"the sense of presence or immersion is a critical feature in distinguishing VR from other types of computer applications".

Immersion is often aided by peripherals such as head-mounted displays, wands and datagloves, however the degree to which immersion is felt is not solely dictated by the technology available. Clarke-Willson (1998) warns that the "current excitement over creating 3D virtual environments has for the most part, overemphasised the technology and lacked the focus on quality of the actual experience". He highlights the level of immersion felt by players of computer games such as Nintendo's Mario Bros. series as an example. Vince (1995) refers to this type of immersion as 'engagement'.

The degree of involvement also seems inextricably linked to the level of interactivity, the ability of the user to manipulate the world and experience feedback from these adjustments greatly enhances their sense of presence within the world.

Many authors choose to group VR systems according to the level of immersion they offer to the user (Vince, 1995) and (Levy and Bjelland, 1995).

Desktop VR

These are also called Window on the World (WoW) systems, the primary output device is a high resolution 2D display (monitor). Typical input devices may include a joystick, mouse, keys or 3D controller. Shutter glasses may also be used to present the user with stereoscopic images. Compared to the other types of systems this is a low cost alternative, it is often used for design, training, education and, of course, entertainment.

Projection VR

An improved version of desktop VR, this can be used to increase the field of view, perhaps using stereo images and eyewear to create the illusion of full 3D. Input is generally via a joystick or 3D controller. This is a medium cost alternative and is quite often used as a training tool for groups of people, the level of immersion is normally increased due to the wider field of vision. Projection systems included many different configurations, from a standalone computer with a single screen projector to other more expensive systems such as a Silicon Graphics' Reality Centre (2000) or a CAVE system.

The University of Illinois first demonstrated the CAVE system at the SIGGRAPH 92 conference. It offers one or more people the ability to experience the sensation of being completely surrounded by high resolution, 3D stereo images and 3D positional audio. It is a room formed from three rear-projection screens (walls) and a down projection screen (floor). Inside the room users wear a pair of shutter glasses so that they can be presented with stereo images to provide a feeling of depth.

Immersion VR

The ultimate version of VR, these systems fully immerse the user in the computer-generated world often with the help of a head-mounted display. Whereas in a projection system the experience can be shared with a group of people, an immersive system is restricted to a single user.

Vince (1995) divides VR systems into three groups, immersive, non-immersive and hybrid. Immersive systems replace our view of the real world with computer generated images that react to the position and orientation of the users head. A non-immersive system leaves the user aware of the real world but allows the user to observe the virtual world through some display device such as monitor. Hybrid systems superimpose virtual images over that of the real world, often known as augmented reality systems, these are typically used in aircraft cockpit displays where features such as airports or perhaps targets (fighter aircraft) can be highlighted on head up displays or cockpit windows.

2.2.1.4 Components of A VR System

Pimentel and Teixera (1993) identify the following as essential components of a VR system.

1. Effectors, which describe both the input and output sensors or devices used.
2. Reality engine, this consists of the computer system and the external hardware that is used to supply the effectors with their required information.
3. Application, the software that specifies the way in which the simulation behaves, including the dynamics of the world, and the laws that govern the interaction between the user and the virtual world.
4. Geometry, this refers to the stored information that describes the physical attributes of the environment and the objects that inhabit it. This might include information on shape, colour and placement of each object.

In this view of a VR system the effectors and the reality engine could be considered the hardware components of a system.

Hardware

There are many possible hardware configurations, these range from the low end desktop VR systems through to more expensive fully immersive systems. At present basic desktop VR systems start at under £1000, whilst fully immersive systems such as the Cybersphere (VR Systems, 2000), which is currently under development, could cost millions.

A virtual world can be projected onto the surface of a large rotating translucent ball, termed the Cybersphere, inside which a user stands. As the person inside walks and turns, the sphere rotates on rollers. The movement is monitored by a series of tracking balls, located underneath the sphere, and the information is used by the computer to synchronise the sphere's movement with the projected images. Figure 2.1 shows the configuration of the Cybersphere.

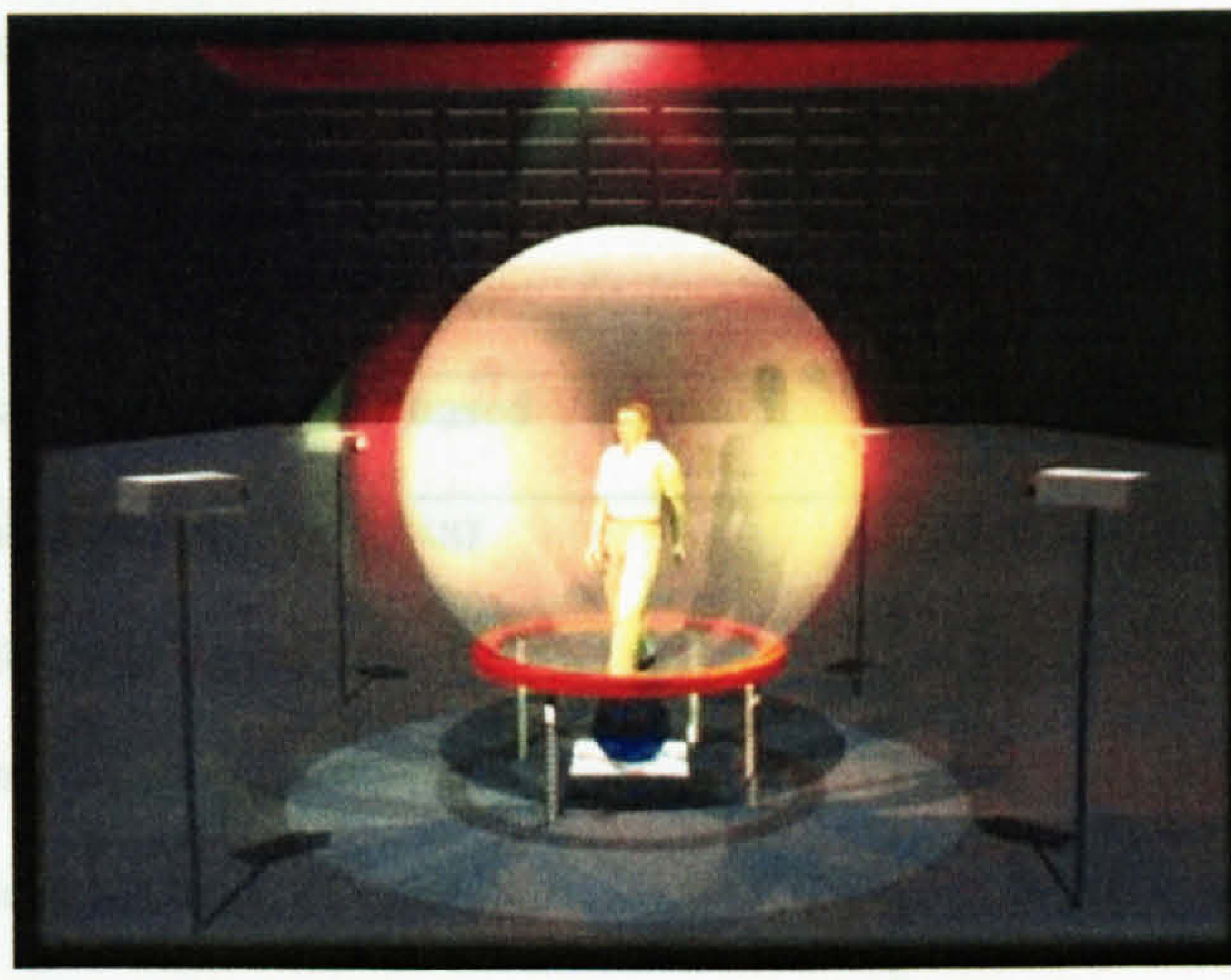

Figure 2.1 A fully immersive virtual reality system (Cybersphere)

Not surprisingly, there is an obvious trade-off between the cost of a VR system and the type of experience achieved. Although desktop-based systems are relatively cheap, it is impossible for them to provide the same level of immersive experience found inside the Cybersphere.

Vince (1995) states that one of the primary requirements of a VR system is that it is able to update images of the world at high speed, ideally this should be no slower than conventional video refresh rates which are 25Hz for PAL and 30Hz for NTSC. As the complexity of the world increases so the power of the computer must increase to be able to maintain this sort of refresh. Using more complex effectors such as datagloves and/or multiple screen high-resolution projection places an increased strain on the processing power of the computer.

With the advent of the hardware accelerated PC, it is now possible to maintain the refresh rates of conventional video, as long as certain limitations are placed on other components of the system (effectors, application and geometry).

A PC based system can be augmented with a number of additional input and output devices to enhance the experience. Some examples of these devices and their current prices are given in Table 2.1.

Input/Output device for a PC based VR system	**Current price (£)**
Liquid crystal shutter glasses (Elsa)	70
Force-feedback joystick (Microsoft)	120
Projection system (Epson)	4000
Steering wheel and pedals (Microsoft)	80
Dataglove (5DT)	350

Table 2.1 Typical input and output devices for PC based VR system

A typical desktop PC-based system, costing around £1500, might include the following:

- High speed processor with 128+mb RAM.
- 3D graphics accelerator with onboard texture memory (32+mb).
- Large monitor (21 inch).
- Joystick.
- 3D Sound card with a surround sound speaker system.
- Shutter glasses.

One of the key responsibilities of the hardware is the generation of 3D images in real-time, in a PC based system this is often achieved using some sort of graphical hardware acceleration.

Image Generation and Graphical Hardware Acceleration

The time taken to render an image is vitally important in a VR system (Vince, 1995). If the time is too great, the system will not remain in real-time and the sense of immersion will be lost. For this reason the time taken to generate each image is of critical importance. If the VR system is updating the display at a rate of 50Hz, then each image must be rendered in less than 20ms. According to Vince (1995) there are two main reasons for long rendering times:

1. The size of the geometry database. If there are millions of geometrical elements in the virtual environment then the time taken to compute which elements should be visible is large.
2. The level of realism required by the system. Photo quality image generation is still not possible in real-time. Shadow effects, fogging and reflections have helped to improve the realism of generated images, however they still fall short of photographic quality.

Until a few years ago, hardware image generation was only available on high-end workstations costing hundreds of thousands of pounds. However, helped by the popularity of 3D computer games, relatively cheap hardware accelerated graphics cards for the PC have become more widely available.

These hardware-accelerated cards reduce much of the pressure placed on the CPU in terms of image generation. They achieve this by supplying specialised hardware to aid in the computation of the image. Tasks such as calculating the depth of each pixel from the viewer, processing an object's geometry and calculating an object's correct shading in given lighting conditions might all be performed by the graphics hardware.

Application

The application defines the dynamics of the world and the laws that govern interaction between objects. It is the application that is considered the 'heart' of a VR system (Pimentel and Teixera, 1993). The application defines the number of rules and the complexity of dynamics; these vary enormously from one virtual environment to another.

The simulation of behaviours within a virtual environment requires that procedures to support this behaviour must be included. For example to represent the physical behaviour of an object falling it must be assigned the attribute of mass, the rate of acceleration must be provided, as must the equations of motion. If the object is falling through the air, it will most likely reach some terminal velocity due to friction between it and the air. On contact with the ground some of its kinetic energy may be converted into sound and it may break into a number of pieces. The rules required to simulate this are complex. Correspondingly they can make significant demands on the computational power of the hardware (Vince, 1995). The physical simulation of a system might include the use of equations of motion, kinetic and potential energy, friction, momentum, rotation and elastic or inelastic collisions.

One common issue in a VR application is that of collision detection. Given that interaction is a fundamental component of a VR system the ability to be able to detect collisions and hence objects that touch is an obvious requirement. Real-time collision detection between two arbitrary volumes is a subject area in its own right. Systems such as I-COLLIDE (Cohen et al., 1995) have been developed that perform collision detection on arbitrary 3D shapes, though the computational effort on volumes other than the most simple is considerable.

Geometry

This is often termed the virtual database (Vince, 1995), and describes the size, shape, position, colour and appearance of the environment and the objects that inhabit it.

Typically this geometrical information is built within 3D modelling packages such as 3D Studio MAX (Kinetix, 1999) or SoftImage (Avid Technology, 1999). Such packages allow a wide variety of modelling techniques, such as extrusion and sweeping, to build the geometry of the model. When building representations of real world objects, the model can be constructed from a series of technical drawings and specifications as well as photographs and possibly video footage. It is also possible to build VR models based upon CAD data, however this will often require some modification before it can be used in a virtual environment. In many applications models must be constructed to a high degree of accuracy, this must be achieved within a number of constraints. If too much detail is used the system's ability to render the image in real-time will be reduced, however, if too little detail is used the object will be unrecognisable.

The model can be coloured or textured for added realism, though this again raises important questions in terms of complexity. If the texture is too large the rendering performance of the system will diminish, too small, and the texture will be unrecognisable. Figure 2.2 shows the process of the construction of a haul truck. Note that any non-essential faces (in particular on the 'inward' facing sides of the wheels) have been removed from the model, this helps to improve rendering performance as fewer faces and vertices need to be considered.

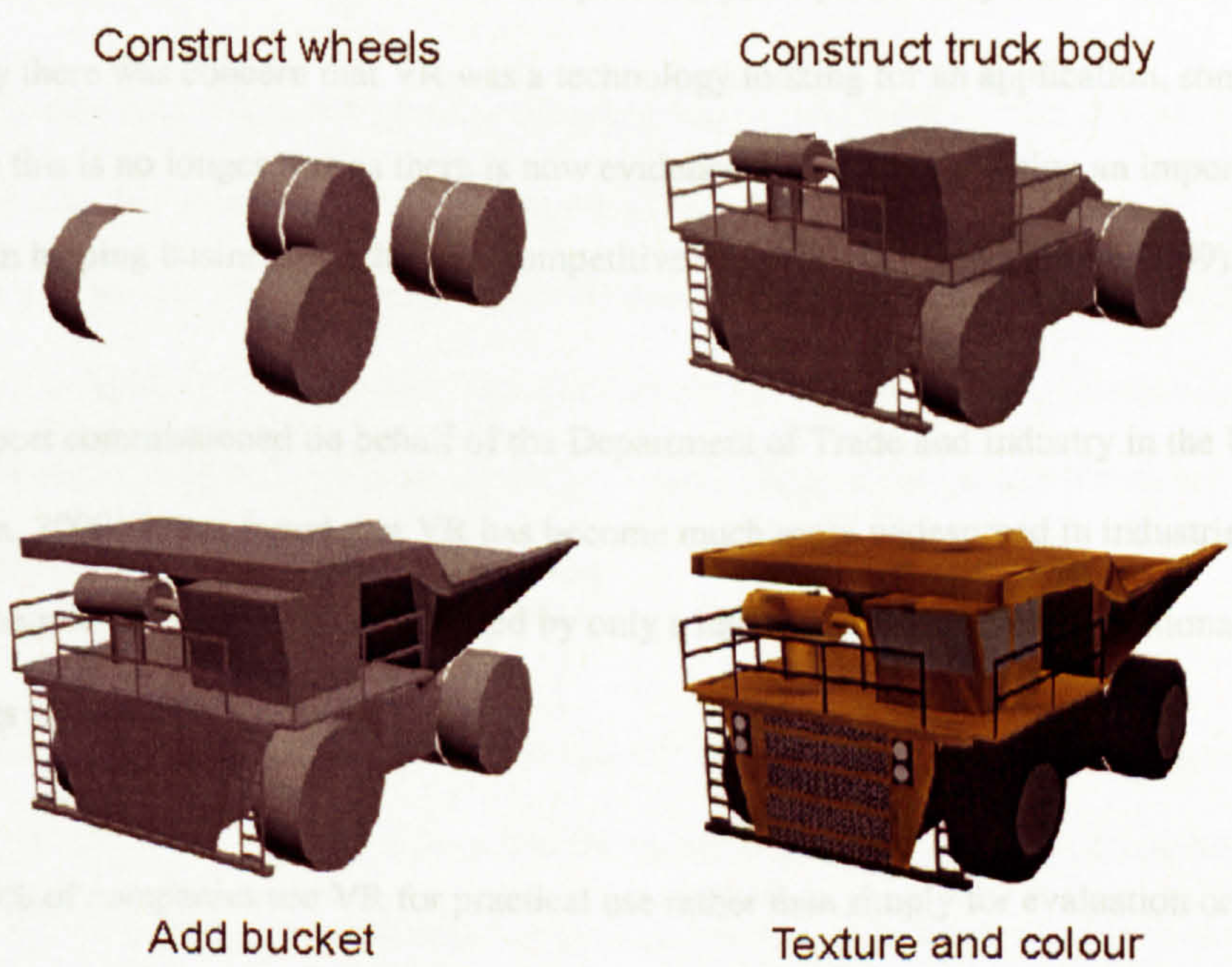

Figure 2.2 Construction of a haul truck

Once the object has been constructed within the 3D-modelling package, the object can be animated. The technique involves specifying a number of key frames that describe the object's movement. Animations might be used to show a door opening, or a bird's wings flapping. A series of frames from an animation that is used to represent a haul truck dumping is shown in Figure 2.3. This technique allows very complex animations to be modelled interactively within the 3D-modelling package.

Figure 2.3 Haul truck with an animated bucket

2.2.2 *Applications of Virtual Reality*

VR has attracted a lot of attention over the past few years particularly from the media. Initially there was concern that VR was a technology looking for an application, some believe this is no longer true as there is now evidence that VR is becoming an important factor in helping businesses achieve a competitive edge (Design Engineering, 1999).

In a report commissioned on behalf of the Department of Trade and Industry in the UK (Cydata, 2000) it was found that VR has become much more widespread in industries since the mid nineties where it was used by only a handful of companies. Additional findings included:

- 63% of companies use VR for practical use rather than simply for evaluation or pilot testing purposes.
- 88% describe their experience of VR as highly or moderately successful, with 60% or respondents able to specify benefits of using VR in their industry.
- 25% consider VR to be 'essential technology both operationally and competitively' to their company and business.
- 79% expect to make more use of VR over the next few years, spending some £30 million on over 300 projects.

- The percentage of companies citing cost and technology problems as the major shortcomings of using VR dropped significantly between 1998 and 2000.

VR is currently being used across a wide range of disciplines, some of which are highlighted in the following sections.

2.2.2.1 Engineering

Engineers use CAD and CAM techniques to design everything from manufacturing processes to end products such as shoes or chairs. Existing CAD/CAM packages have benefited from improved and interactive visualisation offered by Computer Graphics (CG) and VR.

BNFL (2000) used VR to design a new central control room for their mixed oxide plant. Traditionally this would have meant inspecting CAD drawings this often leads to problems in perception. According to BNFL there is a risk that each individual will construct a slightly different mental model of the proposed environment. These slight differences in perception can have significant impacts later in the project if they are not considered early enough in the design stages.

According to BNFL, introducing a VR model allowed the design team to understand the issues 'on their own terms'. People could immediately understand and experience the design allowing them to discuss evaluate and resolve many issues that would otherwise have been difficult. Users were able to walk through the model and examine it from every possible angle. BNFL reported that the use of VR has resulted in major benefits and has proven to be a valuable tool for plant design and operations. Figure 2.4 and Figure 2.5 show the control room in VR and in reality.

Figure 2.4 VR model of proposed control room (BNFL, 2000)

Figure 2.5 Real control room (BNFL, 2000)

2.2.2.2 Training

VR has long been used in the field of training. Training simulators have developed for all kinds of operator based tasks including the operation of planes, submarines, power plants, tanks, cars and performing surgery. Such simulators will often use a replica of the operational environment and real-time computers to simulate the environment (Vince, 1995).

Many writers have identified benefits of using VR as a training medium including Iovine

(1995) and Kozak et al. (1993), these can be summarised as follows:

- There is an opportunity to create a wide variety of scenarios including ones rarely or never previously encountered in 'real life'. These may include hazardous situations that can be experienced by the trainee without ever putting them in any real danger.
- Financially the cost of creating full-scale physical scenarios is often much greater than creating a virtual world.
- Typically VR systems are flexible and amenable to ongoing modification and customisation.
- Once constructed the training scenarios can be run repeatedly and at little extra cost.
- They allow direct monitoring and evaluation of the progress of trainees, perhaps tailoring the programme to achieve the maximum advantage.
- They can be adjusted to provide appropriate levels of trainee interaction.

RTI (1997) is a company specialising in the development of multimedia based training systems. They found that the use of a VR based training tool is particularly useful when it is difficult for trainees to practice and perfect their skills. Typically this was found when:

- Working conditions are hazardous.
- Interaction with equipment is required, but equipment is expensive, unavailable, or inaccessible.
- Down time is costly.
- Changes need to be quickly incorporated.

Training through simulation can offer significant benefits over other methods. It is possible for a trainee to experience first hand why certain procedures must be followed in the real world. When integrated with a computer based training program they can also be used to record and monitor the progress of students.

Some typical areas of VR training applications are described below.

Aircraft Simulators

One of the best known applications of VR is the flight simulator. Flight simulators such as that shown in Figure 2.6 provide highly realistic training environments where pilots can learn skill that can easily be transferred to the real world.

Figure 2.6 Boeing aircraft simulator

Flight simulators are often interfaced with mock-ups of the real aeroplane that include working instruments, force-feedback joysticks and hydraulic platforms. These types of simulators provide a virtual environment of such high realism that the pilots trained on them are often able to fly the real aircraft on the first attempt.

Driving Simulators

Although driving simulators have not been as widespread as flight simulators a wide variety have been developed. Some are developed for the purposes of research based tasks, for example the National Advanced Driving Simulator (NADS, 2000) whilst others are intended for commercial use.

Blana (1996b) identifies the major advantages and disadvantages of mainly research based driving simulators as the following:

Advantages

1. Versatility and new developments at reduced cost. The main advantage of simulators is their versatility, they can easily and economically be configured to simulate a wide variety of problems, which can subsequently be evaluated.
2. Experimental control and measurement. Simulators make it possible to control experimental conditions, this can be important in allowing back-to-back comparisons of driver performance under different conditions.
3. Safety. Simulators provide an inherently safe environment for driving. There is never any danger to the driver or other road users.

Disadvantages

1. Validity. The real world will never be replicated in all its complexity. There will always be the question of to what extent behaviour in a simulator corresponds to that in real life.
2. Cost. Driving simulators have a high initial cost.
3. Simulator sickness. This can vary widely amongst individuals that experience it and among simulators that induce it. Factors involved in inducing simulator sickness include control loop lags and delays, uneven display rate, scene detail and display distortions, and environmental factors, such as humidity inside the simulator itself.

Peck and Wachtel (1993) discuss the possibility of using a driver simulator to as part of the US driving test. They identify some of the advantages of using a simulator-based approach as the following.

1. Increased standardisation of tasks, demands and scoring.
2. Increased precision and sensitivity of scoring.
3. Inclusion of hazards and accident avoidance situations.
4. Inclusion of a wider array of tasks under different conditions, including driving on a motorway and under reduced illumination.
5. Ability to manipulate the difficulty level of the test.

Blana (1996a) reviewed a number of driving simulator studies and concluded that whatever the cost of the simulator there are differences between the real and simulated environment relating to driving speed, speed variation, steering behaviour. According to Greenberg and Park (1994), one of the main problems of assessing driving behaviour in a simulator is due to the fact that the penalty and reward structure is substantially altered. Lives are not at risk and the social and economic pressures that may lead to unsafe driving are absent.

Despite this, some commercial simulators have reported positive results in terms of safety benefits from using simulators. North American Van Lines found that drivers retrained using a simulator are 22% less likely to have an accident than those retrained without a simulator (NAVL, 1996).

Although the 'classic' configuration of a VR system, using a head-mounted display (HMD), has been used in driving simulation Olsen (1995) believes it is actually rare in driving simulators. Whilst the system offers considerable flexibility, the HMD unit itself is often cumbersome and uncomfortable, especially after long use. In addition, many HMD units still offer poor refresh rates and low resolution, which makes it hard for drivers to identify objects in the environment.

Olsen believes that the most common configuration for a driving simulator is that termed the 'cab environment VR system' by Flack (1995). These types of systems typically have a full-scale mock up of a functional cab environment. Input to the VR system will be taken from the steering wheel, pedals and other controls inside the cab. Displays of the environment outside the cab are provided to the driver so that the experience is as realistic as possible. A wide variety of such driving simulators exist, these typically range from non-motion systems starting from between US$40-80,000 up to full motion-based systems in the multi-million dollar range (Olsen, 1995). Driving simulators are often classified according to their cost (Blana, 1996b).

Low cost driving simulators

These have relatively inexpensive graphics displays often consisting of a single monitor and basic cabin environment. This will include the use of a steering wheel and pedals and often some basic cab instrumentation. In some cases some form of force-feedback has been used to improve the sensation of driving.

Medium cost driving simulators

They employ advanced imaging techniques, typically using a large projection screen and a full-sized vehicle with all the normal controls. They may be either fixed base or provide some trivial motion feelings using systems to simulate normal vibrations whilst driving.

High cost driving simulators

These provide an almost 360 degree field of view and an extensive moving base, for example the National Advanced Driving Simulator (NADS, 2000) which is currently under construction at the University of Iowa. The motion system may include 6 degrees of freedom and is similar in design to an aircraft simulator.

Some authors believe that most of the work undertaken in expensive 'high-realism' simulators can be accomplished in lower cost alternatives.

> "there is substantial applied research evidence that much of the training being conducted in expensive simulators could be accomplished in less expensive devices if the training programs used with them were properly designed and conducted." (Caro, 1973).

Similarly, Evans (1991) believes that:

> "high realism simulators appear to offer little for driver training."

Blana (1996a) states that:

> "There is not enough evidence to support the hypothesis that moving base driving simulators are better than their fixed-base counterparts."

Surgical and Medical

VR has presented the medical profession with the possibility of developing training simulators where surgeons can develop surgical skills without harming animals or human beings.

Vince (1995) describes an example of a VR training application to simulate a colonoscopy. This is the investigation of the human colon with an endoscope. A trainee colonoscopist will typically receive training on a mechanical teaching model that does not accurately reproduce the pathology of the human body. The models used are also often transparent creating an artificial learning environment. They are further limited by having only one model of the colon on which to practice.

The development of a computer based training environment can provide a more realistic alternative, provided the colon can be accurately simulated. Work by Gillies and

Williams (1987) and subsequently Poon et al (1988) have led to a kinematic model that describes the dynamics of the colon during the procedure. Based upon this model, force feedback is calculated and provided as feedback to the trainee colonoscopists. Improvements in the skill of these surgeons will reduce the risk of potential problems during the operation.

Operation Procedure

The training of operational procedures, especially for hazardous or inaccessible environments is another area for the application of virtual reality. One example of such training and assessment is provided by NORWEB Distribution (NORWEB, 2000) who is responsible for installing and maintaining regional and local power networks in the UK.

NORWEB conducted a feasibility study on using VR to train and assess engineers who are authorised to work on the electricity system. Prior to their use of VR, training consisted of a mixture of formal instruction, supervised operations, a formal interview and refresher training. The training period for an engineer was typically around two years. NORWEB estimates that a VR based training facility could reduce training times by half whilst doubling the experience gained during that period, potential cost savings for using such a system are estimated at £200,000 a year. Another important factor identified by NORWEB was to reduce the amount of time spent by an already qualified engineer on training, allowing them to spend more time on the job (NORWEB, 2000).

NORWEB used photographs, engineering drawings and sketches to create the VR models of equipment. This equipment and their environments are programmed to function the same as in real life and react correctly to actions taken by the trainees. Figure 2.7 shows some images from the virtual world.

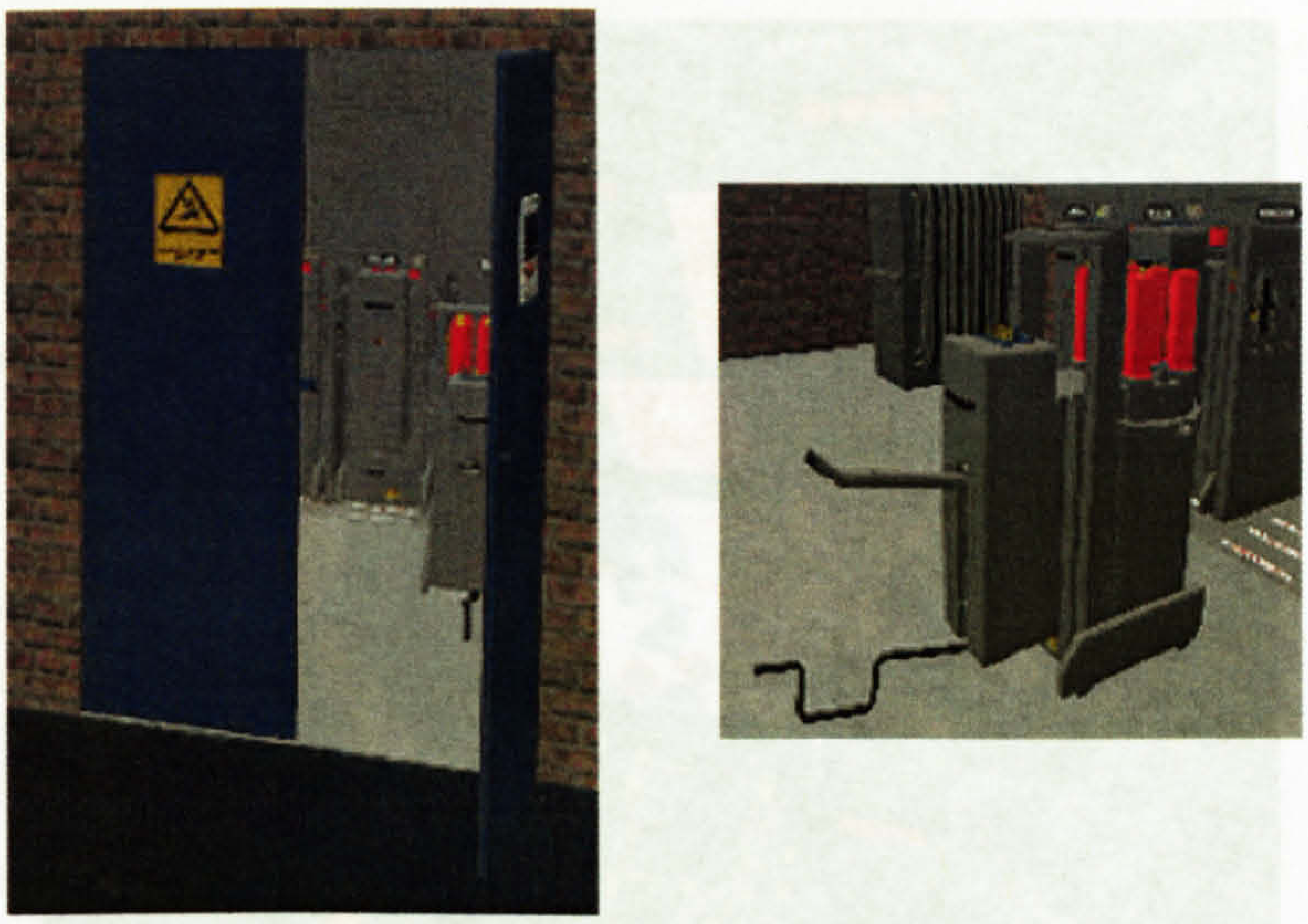

Figure 2.7 Screenshots from the NORWEB training system

Tactical and Strategic Rehearsal

Tactical and strategic training is essential to the military, the police, and the fire service. VR simulations are being developed to teach trainees to make the correct decisions in emergency situations. The alternative to VR is often to stage real scenarios that can not only be expensive but also extremely dangerous.

2.2.2.3 Entertainment

Entertainment has become a massive market for VR. 3D systems are now common in both the home with consoles such as Sony's Playstation (Sony, 1995) and Nintendo's N64 (Nintendo, 1996), and in the arcade with systems provided by companies such as Virtual World Entertainment (2000).

Virtual World Entertainment produce the Tesla Simulators which are fully enclosed, fully functional, networked cockpits. They feature functional buttons and controls, integrated voice networking, pedals, sticks, and throttles, and large display screens. A picture of the inside of the Tesla simulator is shown in Figure 2.8.

Figure 2.8 Inside the cockpit of a Tesla simulator (Virtual World Entertainment, 2000)

BattleTech is a game produced by FASA (2000), that runs within the Tesla system. It is a networked game where players take control of a robot and compete in teams or as individuals. The game allows the user to control heat management, power distribution, and weapons configuration of the controlled robot.

2.2.3 Summary

VR is a difficult concept to define, it provides a 3D computer generated real-time representation of a real or imaginary world and allows a user or users to experience, interact and feel some kind of presence within that world. VR systems are often classed according to the level of immersion they offer to the user, they must also comprise a number of essential components including effectors, reality engine, application and geometry.

In recent years low-cost VR systems have become more widely available, these have allowed 3D images to be delivered on a desktop PC for little over £1000, correspondingly authoring tools and techniques have been developed that help developers to improve the quality of their virtual environments. However, the sense of immersion felt by the user is not solely dependent upon the quality of the presented image, or feedback from the system. Simulating a real world environment requires the representation of a large number of laws and dynamics to help ensure that it is believable.

VR has been used across a wide range of disciplines, however, there are a number of common threads present in many of the examples identified. VR systems are often used to allow people to experience an environment where there might otherwise be either a financial or safety barrier to them experiencing it in the real world.

These are particularly important in high-hazard industries or when the cost of performing training in the real world is prohibitive. Additionally computer based training systems allow the standardisation of tasks and the direct monitoring and evaluation of trainees.

The diversity of existing driving simulators is as wide as available VR technology. Systems range from low-cost desktop systems to fully immersive systems costing millions of pounds. Benefits of using a driving simulator include the versatility of the system and the increased standardisation of tasks, demands and scoring. However, there are many potential disadvantages including the high initial cost and there is only limited evidence that skills learnt in a simulator transfer directly into the real world.

2.3 Industrial Safety

2.3.1 Introduction

Since WW2 the speed of technological change has altered the workplace more profoundly than at any other time since the industrial revolution. The increased size and complexity of industrial processes has created increased scope for major disasters, leading to increased public concern about industrial safety (Staley, 1994). More regulations aimed at maintaining a safe and healthy workplace environment have been introduced to counter the increased safety risk (Akass, 1994).

Attitudes towards industrial safety have advanced significantly in recent years. Traditionally safety has been viewed by industry as costly and counter-productive, concerned more about compliance with regulations and the law, than providing for the well being of those working in industry. The introduction in 1992 of new legislation in the UK changed the emphasis of industrial law from prescriptive legislation to new management systems. This in effect placed the responsibility for the safety of employees with their employers.

Many industries, including the mining industry, have reacted to this pressure and introduced modern safety philosophies (Staley, 1992). Safety Management has become a standard term in many companies and the effect of human factors on the safety of an operation has become increasingly important.

2.3.2 Cost of Accidents

Organisations are financially driven and must put economic performance first.

> "It (the organisation) can only justify its existence and its authority by the economic results it produces" (Drucker, 1955)

It would, for example, not seem reasonable that an organisation should spend all of its resources on ensuring the safety of its employees, as no profit would ever be generated.

Organisations are required to comply with regulations laid down by law, in the UK this includes the Health and Safety at Work Act (HSE, 1974) and the Management of Health and Safety at Work Regulations (Health and Safety Commission, 1992). The cost of non-compliance can be high. In 1989 an oil company was fined £500,000 for failure to implement proper health and safety systems, and manslaughter charges were brought against another company and some of its senior managers policies (King and Hirst, 1998).

The Health and Safety Executive (HSE, 1991) notes that the cost of failing to manage health and safety successfully is high:

- 30 million days are lost in a year from work-related injuries and ill health (this is nearly 10 times the number from strikes).
- Employers' liability insurance costs increased two-thirds in real terms during the period 1981 to 1991, the number of claims between 1985 and 1991 doubled.
- Uninsured losses from accidents are costing organisations anything between 6 and 27 times what they are paying out in insurance premiums.

This challenges the traditional view of health and safety as a financial burden, and indicates there may be rewards in pursuing improvements in this area. Performing a cost benefits analysis where the cost of accidents and non-compliance with regulations is balanced against the cost of preventing them illustrates the problem (see Figure 2.9).

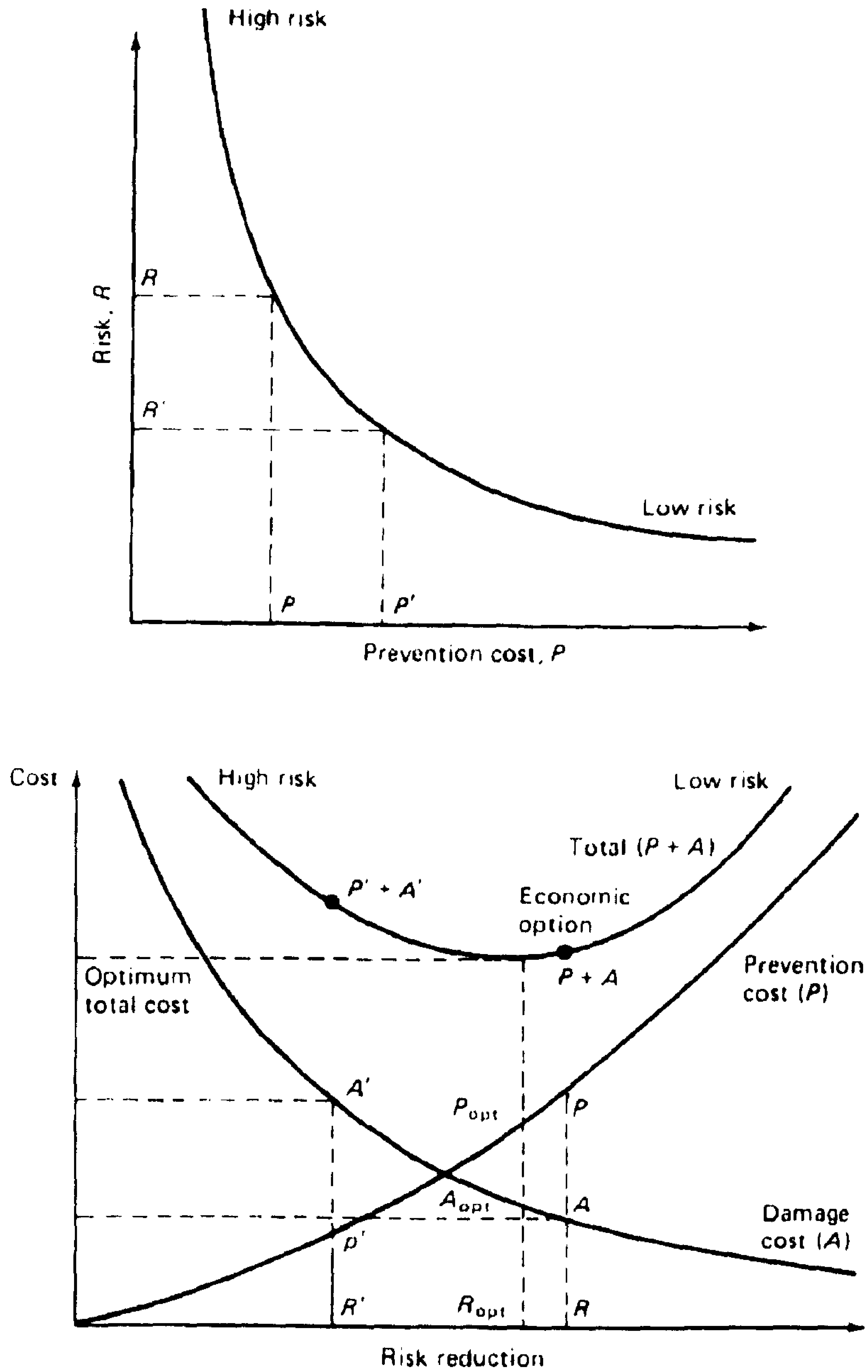

Figure 2.9 Cost benefit analysis of safety spending (King and Hirst, 1998)

In practice this sort of analysis is impossible, as it is impossible to equate the cost of a human life. Additionally, King and Hirst (1998) note that it may not simply be a case of spending more to improve safety.

Many believe that the key to improvement of safety performance lies in the successful management of health and safety (Staley, 1994). However, there is an obvious need to pursue a cost-effective implementation of the safety policy. Two key components that are often required by law are risk assessment and training.

2.3.3 Risk Assessment

Improvement in safety performance has often meant looking to reduce the number or potential for accidents. The process of risk assessment attempts to minimise or eradicate the probability and severity of an accident occurring.

Risk assessment has been used informally throughout history, whenever there is a decision to be made, or an action taken there is always an associated risk. The outcome of the decision is in the future and is therefore uncertain, different actions might mean different outcomes, some outcomes might be more desirable than others. Some assessment of the risk associated with each action is usually made before the decision is taken. Mostly this process is informal, however since the early 1930's explicit techniques have been developed and used in industry.

The wide variety of industrial activities has created a wide variety of different definitions and hence a blur between terms such as risk assessment, risk analysis and risk estimation. Jones (1992) gives one of the clearest definitions.

- Risk assessment is the quantitative evaluation of the likelihood of undesired events and the likelihood of harm or damage being caused together with value judgements made concerning the significance of the results.
- Risk analysis is an imprecise term that infers the quantified calculation of probabilities and risks without taking any judgements about their relevance. As such it is equivalent to risk estimation.

Fundamental to the discipline of risk assessment is the concept of risk.

2.3.3.1 Risk

- Risk is the likelihood of a specified undesired event occurring within a specified period or in specified circumstances. It may be either a frequency (the number of specified events occurring in unit time) or a probability (the probability of a specified event following a prior event), depending on the circumstances (Jones, 1992).
- Risk expresses the likelihood that the harm from a particular hazard is realised (HSE, 1992).

All activities involve a certain amount of risk, some involve more risk than others. When a decision is made to undertake an activity, the level of risk attributed to that activity must be accepted. Measurements of the level of risk can be made either qualitatively or quantitatively. However, in many cases it might be undesirable or indeed impossible to calculate the level of risk.

Most definitions of risk involve two aspects, which can be summarised by the following equation:

$$\text{Risk} = f\,(\text{uncertainty, consequence})$$

The first of these aspects, uncertainty, deals with probability, sometimes this can be measured, and sometimes a good estimate can be made based upon experience, however sometimes it is not possible to arrive at a mathematical conclusion. The resultant estimate of likelihood will most likely contain some element of subjectivity.

The second component of risk is the consequence. There is a wide variety of different factors, possibly including monetary and environmental (both short and long term) as well as injury to, or loss of life. There is a problem of combining these into a quantitative value such that a resultant risk value can be evaluated.

Risk can be divided into two types, perceived risk and calculated risk. Perceived risk is the risk believed by an individual or group to be associated with an activity. It may be injury to, or loss of life, but equally it might be property damage or financial loss. Calculated risk is the risk level obtained by use of a quantitative risk assessment procedure. From the definition of risk as a function of uncertainty and consequence it is often a probability combined with some assessed or defined consequence.

Dealing with perceptions and attitudes introduce a special problem. As noted by Staley (1994) people are bad at judging probability and especially bad at judging risk. Typically they are too frightened of strange situations, and too casual about familiar ones. Comparatively they under-estimate risks that they choose to take or risks which are associated with a desirable activity whilst over-estimating those which imposed on them or associated with an undesirable activity. Blockley (1992) identifies further factors that affect the perception of risk of a given situation. These include:

- The number of people involved.
- The cultural context.
- The manner of death.
- The long or short-term nature of the exposure.
- The degree to which exposure is voluntary.
- The immediacy of the consequences.

Staley (1994) notes that there is evidence that accident rates are high in groups who estimate risks as low. Constant pressure must therefore be applied to ensure that judgements of risk are realistic (ACSNI, 1992).

The difference in perception also poses problems for a safety engineer, what is perceived as safe by engineers may perceived as completely unsafe by the general public or regulatory bodies. Some standards or guidelines should be provided to ensure that the level of risk is within acceptable limits. This will inevitably involve some sort of calculated risk and is therefore less than perfect.

It is generally thought that although the problem of setting acceptable limits is a difficult one, some standard for providing guidelines as to acceptable risk would be helpful to the safety engineer. Blockley (1992) notes that in an era of increasing litigation and payouts, engineers and contractors need some standard for their protection though he warns these must be specified and used with care. One commonly used measure of risk is described below.

Fatal Accident Rate (FAR) (also known as FAFR)

This is a measure of the risk of a particular activity to an individual and is defined as the number of deaths per hour of exposure divided by the number of people at risk multiplied by 10^8. Some typical FAR values are given in Table 2.2.

Activity	FAR value
Sleeping	1
Eating	2.5
Driving a car	57
Working in the chemical industry	5
Working in the construction industry	67

Table 2.2 Typical FAR values for various activities (Blockley, 1992)

2.3.3.2 Legal Requirement for Risk Assessment

The 1992 Management of Health and Safety at Work Regulations which has since been updated in 1999 (Health and Safety Commission, 1992) introduced a specific and mandatory requirement for the use of risk assessment in general occupational health and safety. According to the HSE (1991) the assessment of risk is necessary in order to identify their relative importance and to obtain information about their extent and nature. Knowledge of both areas is necessary in order to identify where to place the major effort in prevention and control, and to make decisions on the adequacy of control measures. Every employer in the UK is required to make a "suitable and sufficient" assessment of (HSE, 1992):

- The risks to the health and safety of their employees, to which they are exposed whilst they are at work.
- The risks to the health and safety of persons not in their employment arising out of or in connection with the conduct by him of his undertaking.

The regulations also state that (HSE, 1992):

- All organisations employing more than 5 people are expected to document their risk assessments, thus risk assessments must be conducted and recorded for all current tasks and operations.
- Pre-emptive risk assessment must be carried out on all operations and processes introduced to the organisation.
- Organisations must monitor the general situation and re-assess if, "there is any reason to suspect that it [the risk assessment] is no longer valid", or there has been a significant change in the matters to which the risk assessment relates.

The report produced by the HSE (HSE, 1992) did not provide an acceptable or model approach, they merely required that the risk assessment should be 'suitable and sufficient'. The report did provide a list of the required elements of a risk analysis, and these have been subsequently revised to provide 'Five Steps' (HSE, 1998) for assessing the risks in the workplace.

1. Identify all the hazards associated with a given task, operation or system.
2. Estimate the risk associated with each hazard as a function of likelihood of exposure and the severity of consequences.
3. Evaluate the effectiveness of existing hazard control measures.
4. Define any residual risk not adequately covered by existing controls.
5. Specify and implement any additional controls where necessary to control hazards as far as is reasonably practicable.

2.3.3.3 Hazard Identification

A hazard is something with the potential to cause harm (this can include substances, machines, methods of work and other aspects of work organisation) (HSE, 1992).

Identification of hazards is often thought to be the most important step in risk analysis, perhaps because a hazard cannot be controlled until it is first identified. It can also be seen as a useful discipline in its own right. For example, identifying hazards at an early stage will often allow them to be eliminated by a modification of the design or system.

There are a number of ways to identify hazards, some of these might include:

- Workplace inspections.
- Management/worker discussions.
- Independent audits.
- Job safety analysis.
- Hazard and operability studies.

Staley (1994) believes that hazard identification depends primarily on two factors:

- Availability of information – not only on the work being performed but also on the technical equipment used, to be able to identify that a hazard could exist.

- Having a systematic method and organisational controls to ensure that knowledge is applied effectively to the task of identifying hazards and of defining safe process conditions.

Using a number of formal methods reduces the problem of ensuring that all hazards are considered in the risk assessment procedure. It is recognised that there are two categories of hazard identification techniques, these are often termed fundamental and comparative techniques.

Fundamental Methods - Hazard and Operability Studies (HAZOP)

Fundamental methods are based upon a systematic consideration of deviations from the design intent. These include such techniques as Failure Mode and Effects Analysis (FMEA), and Hazard and Operability Studies (HAZOP).

HAZOP is a technique of hazard identification that has been developed in the chemical and process industries. It usually involves a multidisciplinary team of engineers, safety advisers, production managers, designers' etc. critically examining each aspect of a process at the design stage. Remedial action can be planned at an early stage of the project with maximum effectiveness and minimum cost.

Comparative Methods

Comparative methods involve comparing the operation or design with some recognised code or standard. Additional hazards can often be identified from other sources of information such as:

- Information from suppliers.
- Health and Safety Executive guidance.

- Guidance from industry user groups.
- British Standards.
- Analysis of accident data will often help to identify low probability/high risk events.
- Observation of a task (inspections and audits).
- In many industries generic hazard groups may have been identified.

2.3.3.4 Risk Estimation Techniques

The difficulties in quantifying risk have led to the development of many frameworks to aid in the process of risk estimation. A simple form of risk estimation was described by the HSE (1991) in order to illustrate general principles, this is described briefly below.

Hazards are split into three categories according to their severity:

- Major, liable to cause death or major injury.
- Serious, as having potential for injuries where persons may be off work for more than three days.
- Slight, for other injuries.

The likelihood of harm for each hazard is rated according to probability:

- High, where it is certain or near certain that harm will occur.
- Medium, where harm will occur frequently.
- Low, where harm will seldom occur.

Risk associated with the hazard is now defined as the combination of both the severity and the probability rating:

Risk = Hazard Severity x Likelihood of Occurrence

Values can be assigned to both hazard and likelihood ratings, and a by a simple multiplication a single value for the risk of the hazard can be found. In the cases where hazards affect more than one person, the resulting value can be multiplied by the number of people to obtain a more realistic comparison. Risk values obtained from this method can be compared to currently acceptable limits based upon risk/benefit balances.

2.3.4 Training

Evidence from everyday life shows that well trained and careful workers may avoid injury on a dangerous job whilst untrained and careless workers may be injured under the safest possible conditions. Before any employee can work safely they must be shown safe procedures for completing their tasks.

Training helps people to acquire the skills, knowledge and attitudes to make them competent in the health and safety aspects of their work. It may include formal off-the-job training, instructions to individuals and groups, and on-the-job coaching and counselling. Ensuring that people are competent may demand more than formal training, for example a period of supervised experience to practice and develop new skills.

Employers training duty is set out in section two of the Health and Safety at Work Act (Health and Safety Commission, 1974) and requires,

> "the provision of such information, instruction, training, and supervision as is necessary to ensure, so far as is reasonably practicable, the health and safety at work of his employees."

In regulation eleven of the Management of Health and Safety at Work regulations (Health and Safety Commission, 1992) employers are also required to take account of the health and safety capabilities of employees when entrusting tasks to them. They should be particularly aware of training during induction, change of job responsibility, or the introduction of, or change in work equipment. It calls for repeat training, and the adoption of training to take account of changed risks to health and safety. The activities in a typical training cycle are shown in Figure 2.10.

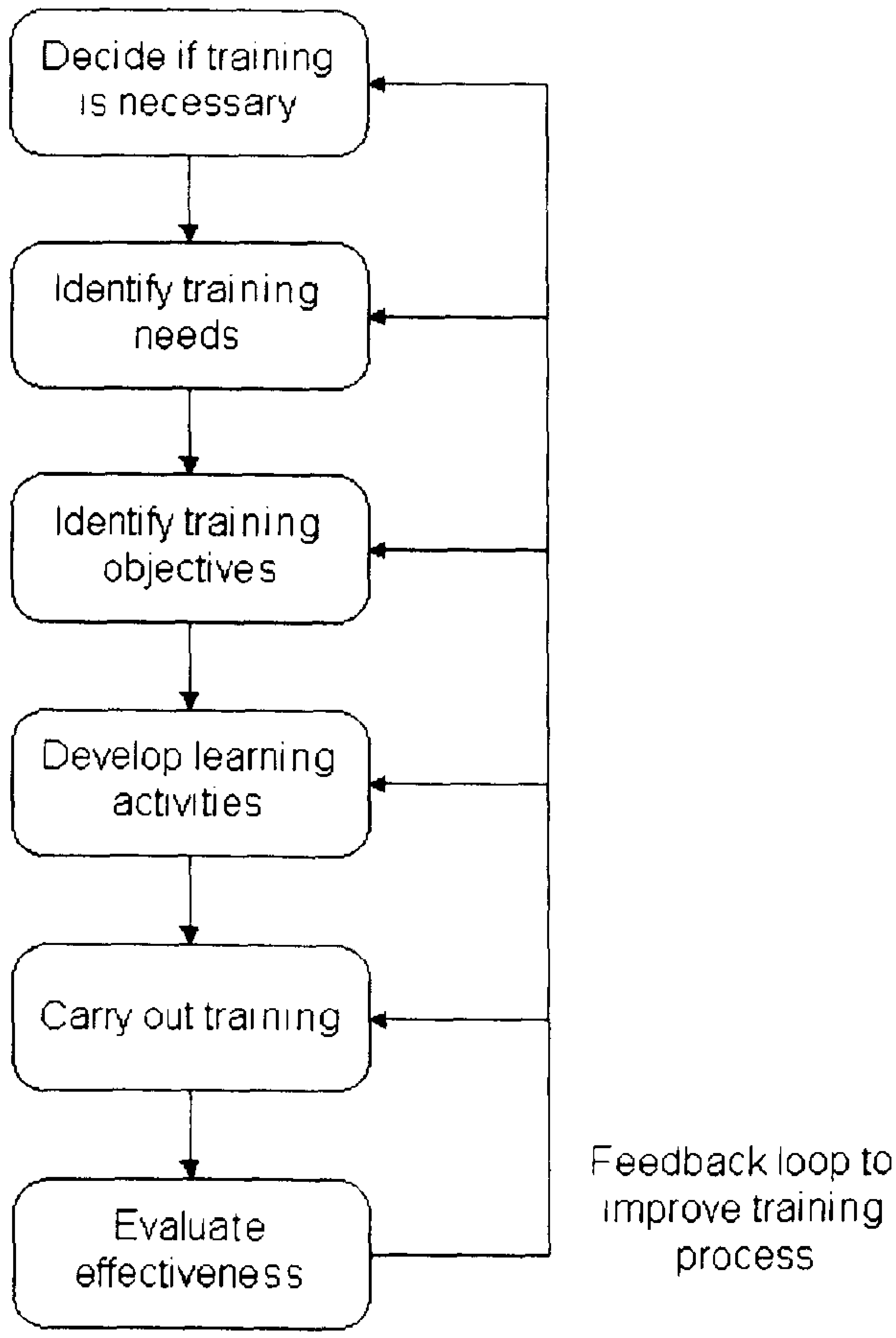

Figure 2.10 Typical training cycle (HSE, 1991)

In America the Federal Mine Safety and Health Act (Division of Mine Health and Safety, 1977) requires that each U.S. mine operator have an approved plan for miner training. This plan must include:

- 40 hours of basic health and safety training for new miners who have no underground experience, before they begin work underground.

- 24 hours of basic health and safety training for new miners who have no surface mine experience, before they begin work in at surface mine operations.
- Eight hours of refresher safety and health training for all miners, each year.
- Safety related task training for miners assigned to new jobs.

2.3.4.1 Techniques

Training comprises of both formal and informal teaching. Formal describes that which is undertaken in a workshop or classroom and is essentially off-the-job. These include induction courses for new starters, as well as those designed to update and reinforce employee's knowledge of safety techniques and practices. Informal training is essentially practical in nature and will normally take place on-the-job; an example may include an individual receiving tuition on a one-to-one basis with their supervisor.

A successful training programme must bring together both the theoretical (formal training) and the practical (informal training) aspects of the job. The methods used in both formal and informal training normally follow accepted training and educational techniques. Bird (1974) has summarised the two basic goals of job instruction as follows:

1. To make sure the employee knows the importance of doing the job correctly.
2. To be certain that the employee knows how to do it correctly.

In reality, a training programme will normally have more ambitious goals with regards to improving safety and efficiency. Typically such a training programme will use a variety of methods, some of these are listed in Table 2.3.

On-the-job training	Off-the-job training
Coaching	Lectures
Apprenticing	Films, television
	Case study approaches
	Role playing
	Simulation (gaming)

Table 2.3 On and off-the job training methods

Bird observes the following in connection with the effectiveness of different training methods (Bird, 1974):

A trainee tends to remember:

10% of what he reads.

20% of what he hears.

30% of what he sees.

50% of what he sees and hears.

70% of what he sees as he talks.

90% of what he says as he does a thing.

This is similar to the tenet, 'I hear and I forget, I see and I remember, I do and I understand' (van Ments, 1983). Ridley (1983) draws from this that involvement sessions are of most benefit. He cites a number of techniques used during training sessions.

1. Prepared notes, programmed learning (reads).
2. Lectures, talks, taped commentaries (hears).
3. Slides, posters, overhead transparencies (sees).
4. Films, slide/tapes, video presentations (sees and hears).
5. Discuss case studies, possibly with working models (sees as he talks).
6. On the job training, simulation exercises, role-playing (says as he does a thing).

Off-the-Job Training

According to Ridley (1983), there are significant benefits of active participation by the trainee. This participation can best be achieved by using training aids that suit the circumstances of the industry, the company and the trainee. Heinrich (1980) echoes this, saying that particular types of training are best suited to certain types of subject matter. An employee's training will often involve an amalgamation of the above and other techniques.

The use of role-play as an educational or training technique is part of the wider set of techniques that have collectively become known as simulation and gaming. These are techniques which aim to provide the student with either a highly simplified reproduction of a real or imaginary world (a simulation) or a structured system of competitive play that incorporates the material to be learnt (a game) (van Ments, 1983).

The idea of using a game to represent the real world is centuries old, van Ments (1983) observes that the Chinese game of Wei-Hai (now known as Go) goes back as far as 3000BC, whilst other more recent games such as chess represent the beginnings of war-gaming. Within the spectrum of all simulation games, whether it be Monopoly, the design of a house or a business game, Taylor and Walford (1972) observe some common themes:

1. Participants take on roles that are representations of roles in the real world, and then make decisions in response to their assessment of the setting in which they find themselves.
2. They experience simulated consequences that relate to their decisions and performances.
3. They monitor the results of their actions and reflect on the relationship between their own decisions and the resultant consequences.

The marriage of the gaming approach with computer simulation has allowed these games to take on an increased level of complexity (as in management or business games), as well as providing increased accuracy. It also allows 'man versus computer' situations where the computer acts as a source of material and an untiring opponent, this may help to relieve the teacher of some of the repetition needed to reinforce learning. Taylor and Walford (1972) identify three major attributes of simulation:

1. It is oriented towards activity in the classroom, and in such activity both teachers and pupils participate. It represents an informal and corporate approach to the understanding of a situation.
2. It is usually problem-based and therefore helpful in the development of inter-disciplinary approaches to learning. It also frequently involves the use of social skills that are directly relevant to the world outside the classroom.
3. It is a technique that is fundamentally dynamic. It deals with situations that change, and which demand flexibility in thinking and responsive adaptation to circumstances as they alter.

On-the-job training

Some training tools that are applied systematically include the following (King and Hirst, 1998):

- Job instruction training (JIT). After the job has been described and demonstrated to the student, the trainee is invited to carry out the operation on their own after being told where to go if they need help. The student is impressed with the phrase, 'if you are not sure – don't do it'. Using this method the supervisor checks frequently that the student is progressing adequately.
- Over-the-shoulder coaching. The supervisor remains present whilst the student undertakes the job and provides guidance as and when needed. This can be extremely effective though is time consuming and often expensive.

2.3.4.2 Training media and methods

A training programme may use several different types of media to deliver its content (King and Hirst, 1998).

Printed media

Books and notes are easily produced and whatever other methods are used to deliver the training programme a booklet or manual is usually provided for reference. The written word is quickly forgotten, and books are passive learning aids. Although the trainee may respond to the book, it cannot detect any difficulties the trainee is having.

Written exercises may require answers, however, there is little to stop the student from cheating or losing interest unless the book is used in conjunction with another delivery method. A pre-requisite for using books and notes is the literacy of the student, the student must be able to comprehend and understand what is being written.

Personal instruction

This ranges from individual coaching to lecturing to a large audience. Instructors are able to sense trainees' difficulties and alter their delivery accordingly. However, the spoken word is not a good medium as it can be easily misheard, misunderstood or forgotten. This medium can be reinforced with additional demonstrations or visual aids such as projection slides or videos, notes are also often provided for reference.

Films and video cassettes

These are a very powerful medium, as they combine moving, real-life images with the spoken word, this helps to overcome the confusion or misunderstanding of a situation. Films and videos require considerable skill, resources and planning to produce. However, there are many safety videos and films that can now be purchased from safety institutions such as the Health and Safety Executive (HSE) in the UK or the National Institute for

Occupational Safety and Health (NIOSH) in the U.S.

More recently, computer animated films have become a real possibility. Instead of shooting a film on a real set and using real equipment and people the film is generated from 3D models held inside the computer. Dangerous situations can be recreated by modelling the movement of each object inside the world. Once the viewpoint has been defined a series of 2D images are then produced, these are strung together and recorded onto video to create the animated film. This technique allows a large degree of flexibility to be incorporated into the video. Once the model has been built additional views of the incident can be generated from any location in the world at little extra cost and with no risk to personnel or equipment. There is also no lost-production for filming as the entire world is held inside a computer. A still from a minerals industry safety training video is shown in Figure 2.11.

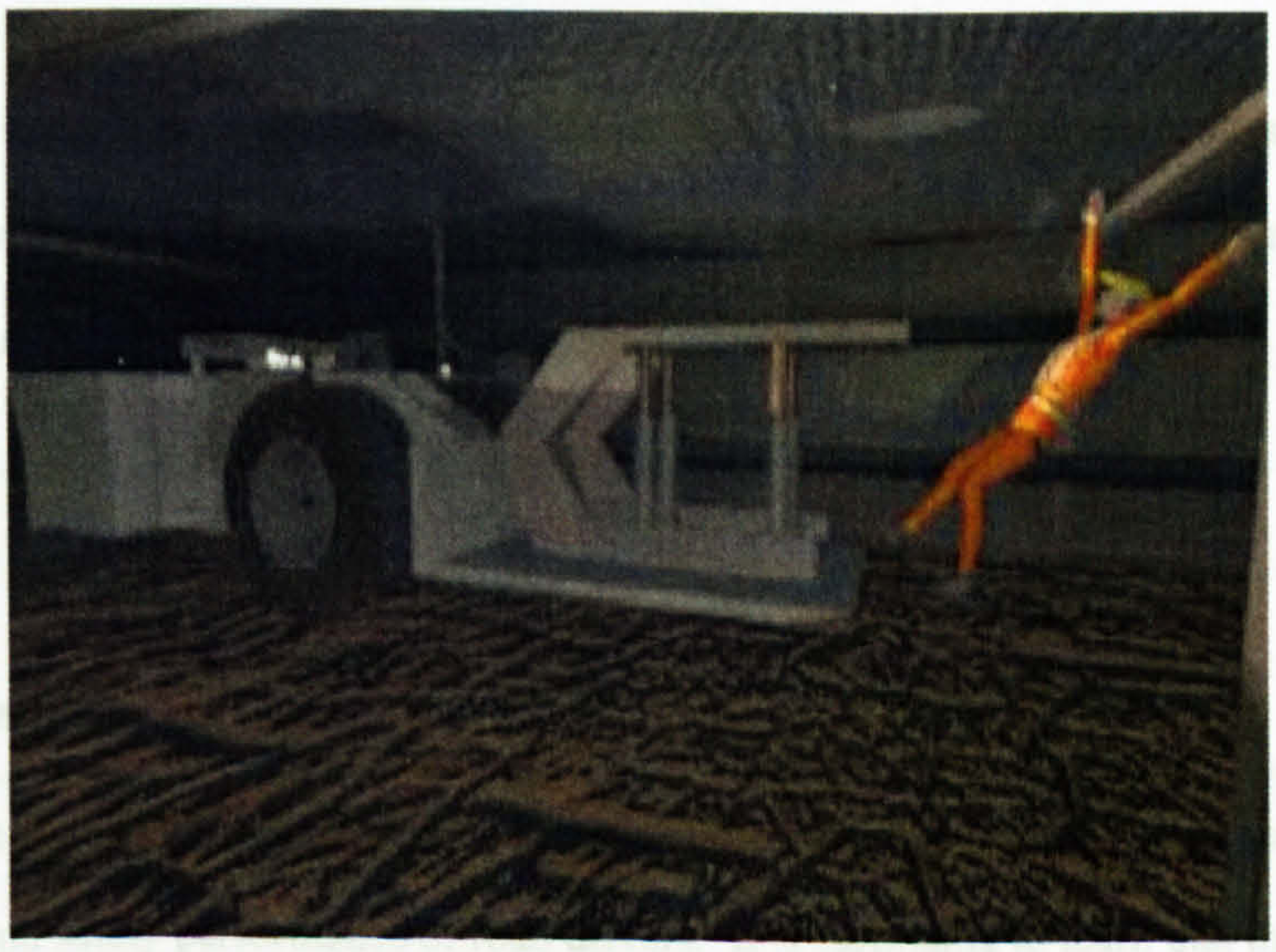

Figure 2.11 Still from a safety training video (AIMS Research Unit)

Computers

Computers were introduced as a training aid to extend the availability when teachers were in short supply. According to King and Hirst (1998) they are used in three principal ways, computer assisted learning (CAL), computer managed learning (CML) and for keeping student records.

Computer assisted learning encompasses a wide array of teaching methods, from simply reinforcing and teaching knowledge through simple question and answer (similar to class room test), to the full-scale simulation of an entire environment.

More recently developed CAL systems contain a hidden model of a real-life situation to which the trainee must respond. By providing a number of these situations the trainee can more fully understand the environment. This type of instruction can be particularly useful for situations that are complex and do not necessarily have one correct answer.

Computer managed learning and the keeping of student records deals with the general administration of student records. It might help to identify potential shortcomings in students and help to target additional training sessions to overcome these.

The use of computers in a training program will require that each person (both student and teacher) become familiar with the system used. This may place a heavy burden on the resources if the time required to achieve this is significant.

Driver Training

There have been studies into the effectiveness of current driver training programmes on the skills and safety performance of road drivers. It is surprising to learn that the value of current performance testing and driver training is to a certain extent unclear (Mills et al., 1998).

Skelly (1968) evaluated the performance of drivers in terms of number of miles driven per accident and found that the best accident records were held by drivers who had received no professional driving instruction. More recently, Lund et al. (1986) found that drivers who participated in enhanced training programmes are more likely to pass their test, but are also more likely to be involved in subsequent accidents. However, driver training programmes must be capable of developing a trainee's skills sufficiently to pass the driving test.

Mills et al. (1998) suggest that safe driving practice must involve the ability of the driver to 'read the road' (Gibson, 1969) so that potentially dangerous situations can be anticipated and corrective action can be taken in advance. An inability to foresee dangerous situations can mean that corrective action is not taken quickly enough resulting in a possible incident. Gibson (1969) identified that whilst people may learn the required operating skills to a high level, they may not identify the particular environmental cues that they need to guide their behaviour.

Mills et al. (1998) believe that teaching higher order driving skills such as hazard identification and risk perception may help the driver to identify these environmental cues, and choose which (if any) corrective action should be taken.

McPherson and Kenel (1968) and Currie (1969) performed some of the earliest work in hazard perception. They performed a study in which the driver's skill at detecting and recognising potentially dangerous situations was shown to be an important factor in driving performance. More recently Pelz and Krupat (1974) found that a group of drivers with a low accident rate reacted more swiftly to hazards than a group of drivers with a higher accident rate. McKenna and Crick (1994) found that they were able to distinguish between groups of expert police drivers and normal experienced drivers on the basis of the time taken to identify a hazard. Significantly both the work by Pelz and Krupat and McKenna and Crick was undertaken in a form of 'simulator'.

Mills et al. (1998) performed similar work but required subjects, who were all novice drivers, to undertake hazard identification tasks both in a simulator and in the real world. The simulator was based upon previous designs by Pelz and Krupat (1974) and McKenna and Crick (1994). The simulator tests involved subjects watching a specially filmed sequence of various road and traffic situations, some of which were hazardous. Subjects were asked to identify hazards as early as possible by pressing a button that was linked to a computer, this recorded the response time. Emphasis was placed upon asking the subjects what they thought would happen next, it was hoped that this would encourage them to look ahead and develop their hazard anticipation skills. In the on-road tests subjects were asked to verbally identify hazardous situations as soon as they occur. Drivers were accompanied by qualified instructors who assessed their performance and behaviour.

Mills et al. (1998) found that there was a statistically significant reduction in the average hazard perception in the simulator after training had been received either on the road or in the simulator. They established that the group who had received both on road and simulator training made the biggest improvement. They also found that drivers who saw hazards early on the road had a faster hazard perception time in the simulator and correspondingly that those drivers who saw them late had a slower hazard perception time. They found a correlation between number of hazards missed in the simulator and on the road. Their results show that their simulator was a valid test of hazard detection in the real world, and that it is possible to improve the hazard perception skills of novice drivers through training.

Indeed the Department of the Environment, Transport and the Regions (DETR, 2000) state that,

> "laboratory tests have indicated that drivers with better hazard perception scores are those who have had fewer accidents, and that hazard perception scores can be improved through training"

2.3.5 Safety in the Mining Industry

Since the mining industries inception it has been focused around hazardous environments. According to Staley (1994) their hazardous nature stems from three fundamental reasons:

- It is organic, not static, everyday the workplace changes.
- Each day large amounts of personnel work in the environment.
- Mother nature continually tries to undo the work of miners.

The principal of accident prevention is reputed to have been started by the Babylonians in 2000BC (Staley, 1994) where severe punishments were enforced for the fatality of an underground worker. Since these ancient times a large amount of people have lost their life in the pursuit of mining. McAteer (1985) claims that in the coal mining industry in total the USA alone has lost more than 122,770 men and women.

Staley (1994) claims that there can be no doubt accident rates have been reduced in the industry. Although the size of the UK industry has varied over the last 120 years the fatality rate is only 5% of the total level it was in the middle of the 19th century.

Mining in the UK still remains a dangerous occupation. Table 2.4 shows the numbers and incidence rates in the UK mining industry between the period 1995 and 1998.

Year	Number of People Employed	Actual Injuries		Rates per 100,000 Manshifts	
		Fatal Injuries	Major Injuries	Fatal Injuries	Major Injuries
1995/96	18,576	5	159	0.09	3.00
1996/97	15,061	2	160	0.05	3.66
1997/98 *(provisional)*	12,382	4	163	0.11	4.51

Table 2.4 Numbers of Injuries and Incidence rates in the UK (HSE, 1999)

2.3.6 Summary

Accidents can have a significant impact on organisations, this will include the health and safety of employees, the moral of the workforce and the public impression of the organisation. Costs associated with accidents include not only in lost production but also in employees being away from work due to ill health or injury, increased liability insurance, and uninsured losses. A successful safety program can help to reduce these costs. Risk assessment and training are two key components of a safety management programme and are often essential for compliance with the law.

The process of risk assessment involves providing some evaluation of the likelihood of undesired events and the likelihood of harm or damage being caused together with the some judgement as to the significance of the results. Risk is fundamental to the concept of risk assessment, most definitions involve two aspects, the probability of a given event occurring and some measure of the consequence of that event.

Perceptions of risk borne by an individual or group are important, accidents tend to be high in groups who estimate risk associated with an activity as low. This can also cause problems when assessing a work task, that perceived by an assessor to be low risk may be considered to be dangerous by the workforce or general public. The provision of some standard is often helpful in determining the actual level of risk.

The basic goals of training are to ensure that the employee knows the importance of doing the job and also to ensure that they know how to do it. Training will typically take place both off the job (in the classroom) and also include some on the job instruction. Many different training techniques are normally used in the delivery of a training programme. Although the type of techniques used should be designed to fit the situation many recognise that there are significant benefits of active participation by the trainee. This is often manifested in a role-playing or game type environment where participants take on representations of their role in the real world. In this case they experience the consequences of their actions and relate these to their decisions and performance. A variety of different media is often used to deliver the content of the training programme. The type chosen should reflect the subject that is being taught as each type of medium has associated advantages and disadvantages.

The benefit of current road driver training programmes is questionable, whilst they are capable of teaching drivers the required skills to pass the test it is unclear whether drivers receiving professional training are safer. Studies have been performed to investigate the potential of teaching higher order skills such as hazard identification and risk assessment. Recent studies have indicated that it is possible to teach these skills, benefiting the driver in terms of greater awareness and faster perception of hazards. Laboratory tests have indicated that drivers with better hazard perception scores are those who have had fewer accidents, and that these scores can be improved through training.

Safety in the minerals industry has been improved over recent years though mining still remains a dangerous occupation. Special conditions within the industry mean that there is a high degree of danger. In particular environments often change on a daily basis and personnel are required to work in close proximity to hazardous equipment.

3 Mining Operations

3.1 Introduction

Mining is the process of extracting useful minerals from the surface of the Earth (including the seas) (Britannica.com, 2000a). It is one of the oldest industries, perhaps the oldest known underground mine in the world was sunk more than 40,000 years ago at Bomvu Ridge in the Ngwenya Mountains, Swaziland (Britannica.com, 2000b).

This chapter is not intended as a complete review of mining operations and equipment. It is provided as a background to the operations and equipment that have been simulated. An understanding of the background is necessary before attempting to recreate these environments using VR. This chapter classifies mining according to the method of extraction and describes some common mining systems used.

3.2 Surface Mining

70% of the world's mineral production is extracted by surface mining methods (Denby, unpublished). The increasing demand for minerals has caused organisations to turn their attention to the exploitation of deposits of low grade and high stripping ratio by surface mining methods. This has resulted in larger outputs from individual mines because of the increased volumes of waste due to the need to achieve economies of scale. Surface mining machinery has shown a tendency to increase in size to enable these deposits to be mined economically at high outputs, and surface mining is tending to become a materials handling problem on a large scale (Denby, unpublished).

A number of different surface mining methods have been developed by the mining community. The suitability of each of the following methods will depend on the geology and nature of the deposit at the location that is being mined, these include:

1. Strip mining.
2. Terrace mining.
3. Open (conical) pit mining.
4. Other minor methods such as dimension stone quarrying, placer mining and auger mining.

The work that has been undertaken concentrates on the operation of open pit mining, for this reason there is little need to describe other mining methods.

3.2.1 Open Pit Mining

Open pit mining methods share some common elements with strip mining, particularly in the mode of transportation of material. Figure 3.1 and Figure 3.2 show the layout and terminology for a typical open pit.

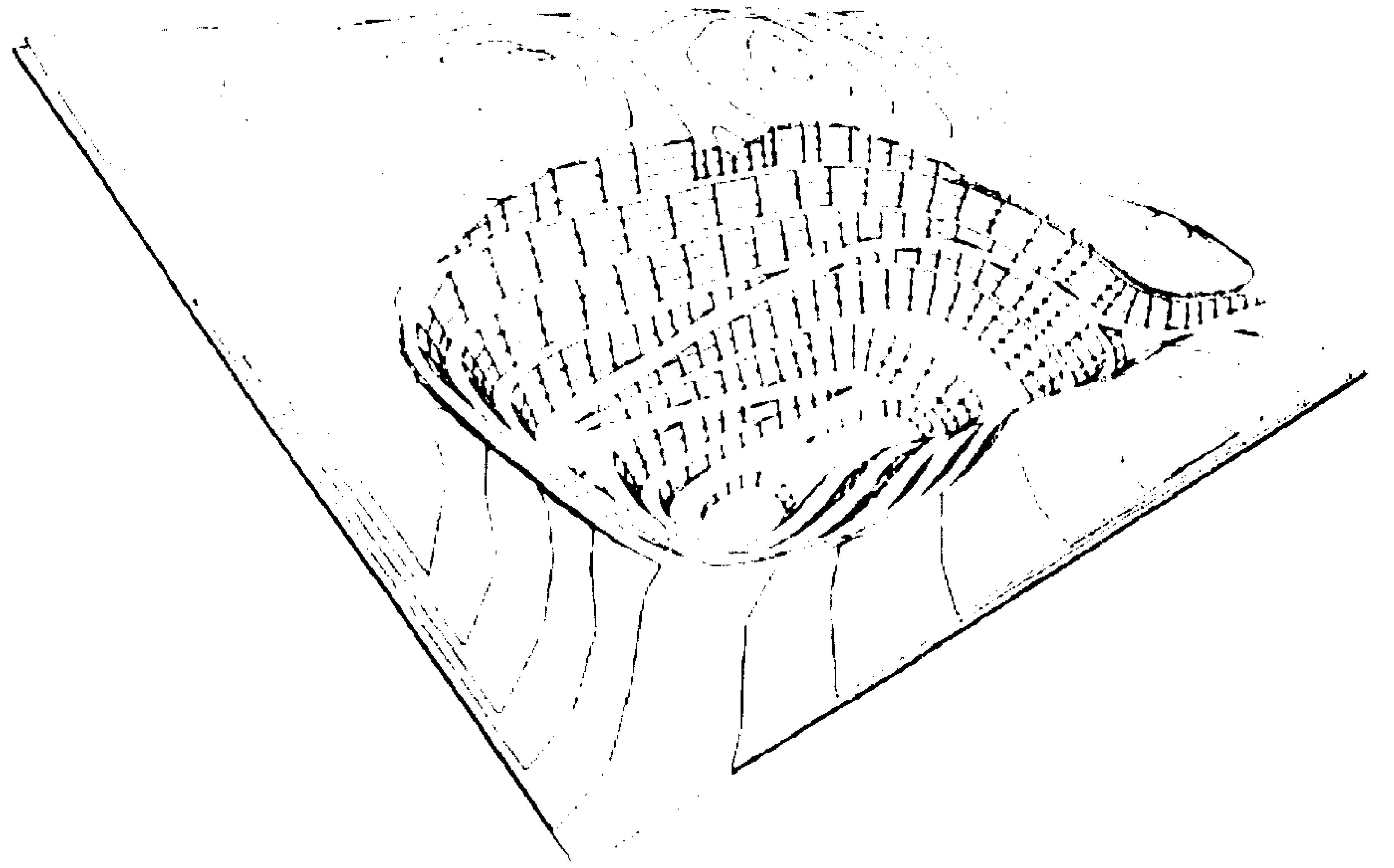

Figure 3.1 A typical open pit

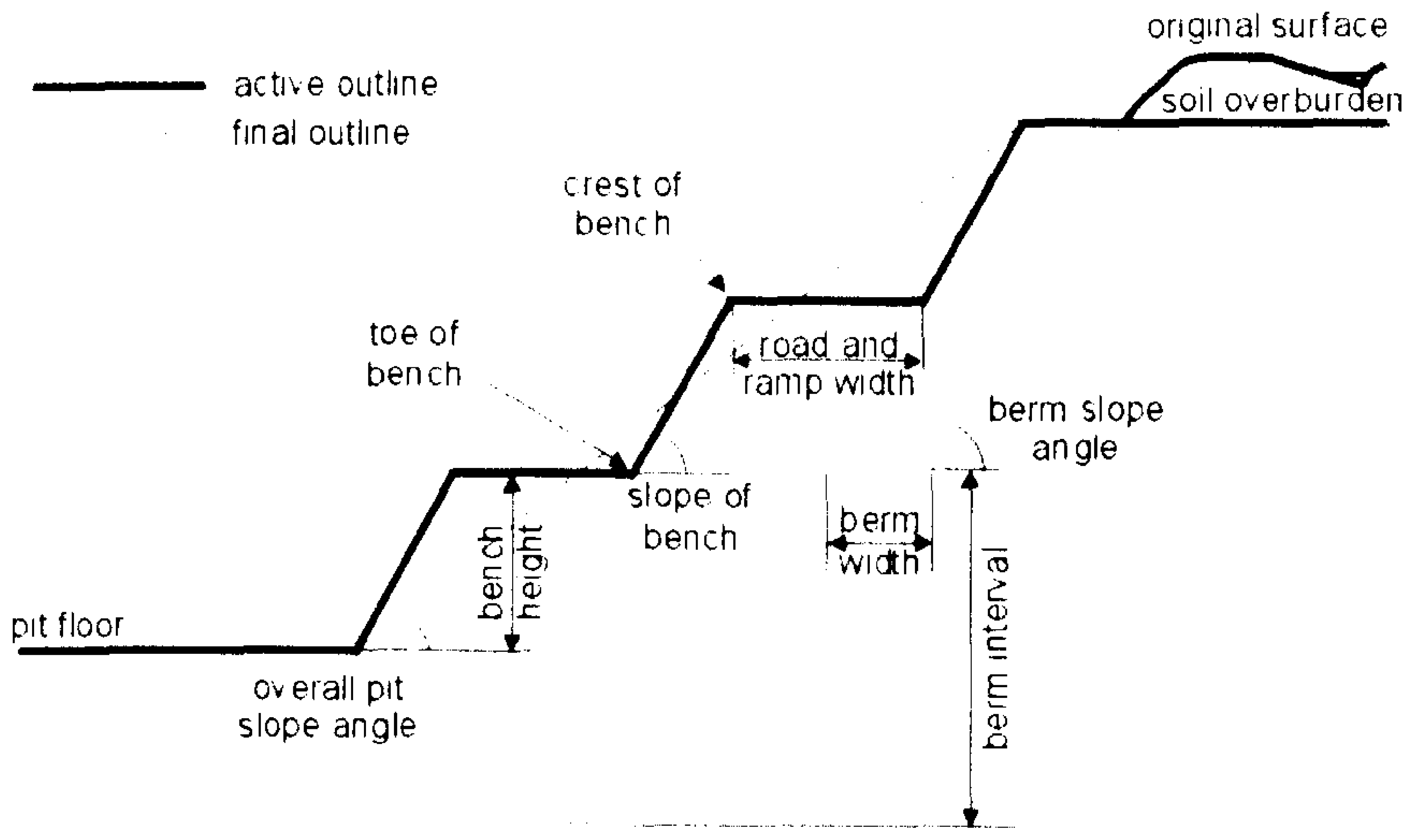

Figure 3.2 Open pit terminology

Open pit operations are typically used when mining for irregular deposits, pipes, stockworks and steeply inclined stratified deposits. The pit shape may deviate considerably from an inverted cone to accommodate irregularities due to deposit shape and mineral grade. Usually the pit is excavated by truck/shovel operations. A typical example of an open pit operation is located in Bingham Canyon (Utah, USA), it is over 4km long, 2.5km wide and 0.8km deep and has approximately 75 benches.

3.2.1.1 Transportation Systems

The function of transportation systems is to remove ore or waste from the point of excavation to the processing location or to waste dumps or stock piles. The primary method used in most open pit operations involves off-highway trucks due to the inherent flexibility that they offer. Trucks of 300+ tonne capacity are operating in some open pits. They offer high manoeuvrability in confined spaces, large capacity and the ability to handle grades of 10% when fully loaded. Other possible transportation systems include conveyor systems and rail.

There are three main types of haulage truck in use:

- Rear dump (conventional)
- Rear dump (tractor-trailer type)
- Bottom dump (tractor-trailer type)

A conventional rear dump haulage truck is shown in Figure 3.3.

Figure 3.3 A haul truck

Financially, haulage trucks are the largest cost item in the operating costs of a surface mine in some cases accounting for an estimated 50% of operating costs (Meuller, 1979). The large initial cost of these trucks also makes driver training expensive.

Truck Dispatching

In order to operate truck fleets efficiently there is a need to constantly revise the allocation of trucks to various excavators within the pit. In the past this was done in sections with haulage routes being decided on a shift by shift basis. Some mine operators have introduced computerised dispatching systems that can revise the dispatching policy within the mine on a regular basis. They work by allocating trucks to shovels on a continuous and individual basis within the context of the mining plan and conditions prevailing at the time. These systems comprise:

- Radio transmission systems that are used to constantly monitor the status and position of the shovels and trucks.
- A central dispatch computer that analyses the current status and production requirements and advises the dispatch operator.
- The dispatch operator who makes the final decision about which truck to allocate to which shovel.
- Optional radio beacons that are used to automatically locate a truck in a mine.

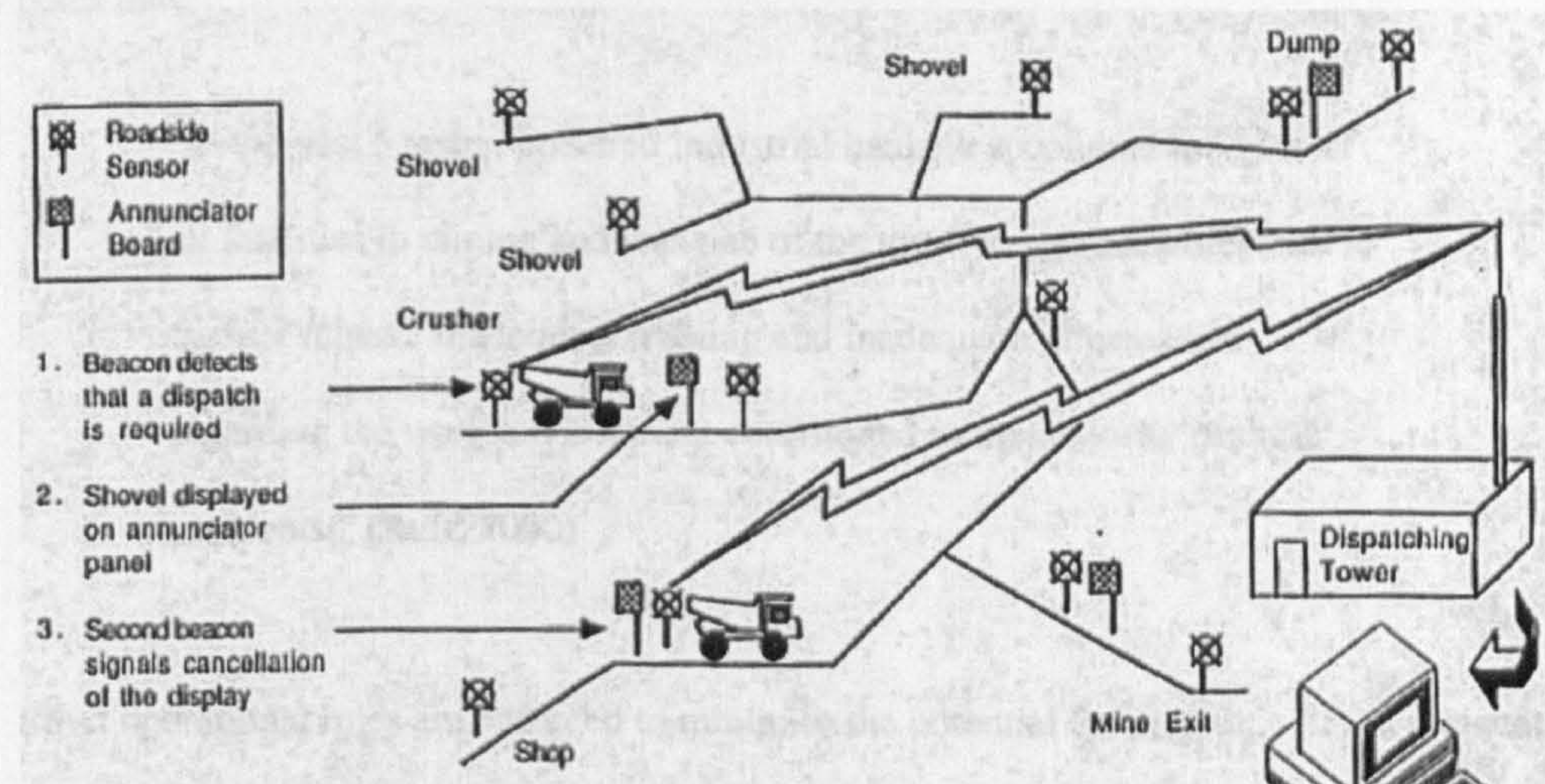

Figure 3.4 Haul truck dispatching system (Denby, unpublished)

Although these systems are expensive (costing up to $US1 million) they have been proven to reduce truck operating costs by reducing queuing and shovel wait times. They offer the following benefits:

- Increased mine production by reducing delay times on equipment.
- Greater utilisation of expensive equipment.
- Increased level of control.

- Dynamic control of ore quality.
- Reduction of delays at shift change and lunch periods.
- Accurate up to date reporting.
- Improved planning through simulation.

Haul Truck Safety

The haulage trucks huge size together with the difficult environmental conditions introduces handling and visibility problems. There is a high level of risk associated with each truck, as the consequences of an accident can be extremely severe. In the US Ruff notes that:

> "In the past 5 years, powered industrial haulage accounted for 43% of all fatalities in mining and was one of the top five sources of injuries in surface mines. Inadequate training and inadequate information regarding the work environment contributed to the majority of these accidents." (Ruff, 2000)

Strict operational rules are enforced to minimise the potential for disaster. At the moment only trained operators can drive these trucks, periodic evaluation of each truck drivers performance is also required. Competency will depend on the ability of the vehicle operator to acquire, retain, and use the knowledge, skills and abilities that are necessary.

An example of the material provided by the Mine Safety and Health Administration (MSHA) for an annual refresher training course for operators of equipment in a surface mine, is provided in Appendix 1. This example is typical of training courses currently used for haul truck drivers.

> "Accidents involving haulage trucks and other mobile surface equipment constitute a major safety problem in the mining industry.

> Between 1989 and 1993, surface and underground accidents claimed the lives of 548 American miners. Surface accidents involving haulage trucks, front-end loaders, scrapers, pickups and other mobile surface haulage equipment accounted for 95 of these deaths.
>
> Of the 95 fatalities, 72 involved trucks; the remaining 23 involved front-end loaders, scrapers and other mobile surface haulage equipment. Trucks used in the mining industry range from small pickups to mammoth haulers designed to carry loads up to 350 tons." (MSHA, 1998)
>
> "Surface accidents involving mobile haulage equipment such as trucks are a major cause of mining deaths. Most of these accidents are preventable." (MSHA, 1998)

Haulage truck safety is well documented in the US by the Mine Safety and Health Administration (MSHA). A review of the material they provide describes some common causes of accidents involving haul trucks this is briefly summarised below.

According to the MSHA (1995), the increase in size, complexity and speed of moving equipment in surface mines has led to a significant increase in the risk in the environment.

The biggest single contributing factor is the speed at which the vehicle is travelling (MSHA, 1995). The safe speed a vehicle is able to travel will depend on a number of factors. Most important are the road conditions, the current mass of the vehicle (whether it is loaded or not), and the grade on which the vehicle is travelling (slope).

Visibility in large haul trucks is particularly poor, in some haul trucks used by the Newmont Gold Company (Newmont, no date) the blind spots from the driver's cabin extend 8 feet to the left, 30 feet in front and 150-180 feet to the right of the vehicle.

Mechanical failure also contributed to accidents significantly, sometimes as a result of poor maintenance that could often have been spotted by a pre-start up check (MSHA, 1995). They also found that mechanical failure was often a result of exceeding the performance envelope of the vehicle. This is often a result of travelling too fast down a slope (often in the wrong gear) whilst carrying too heavy a mass, which leads to the brakes or retarder overheating. Equally, broken drive trains and transmissions often result from attempting to carry too heavy a load up too steep a gradient.

Notes from MSHA (1995) indicate that when working on the edge of a truck's performance envelope many drivers lost control of the vehicle either as a result of loss of traction or mechanical failure. In this case the impact the crash, or the attempt by the driver to jump clear, often resulted in loss of life. The MSHA (1998) notes that drivers often overlook the use of seat belts or other such safety restraints, and that their chances of survival are better if they stay inside the cab.

Non-operational warnings and failed backup systems also contributed. These are often not corrected quickly enough, causing hazards to the driver and others. Examples include failed reversing alarms and other similar warning systems.

Other factors that have contributed to many incidents have been the failure to correctly design and maintain haul roads. Badly maintained berms on the side of haul roads and at dump points are one example (MSHA, 1995).

The MSHA (1995) also reported that workers placed themselves in hazardous locations around equipment and failed to observe protocols especially with regards to communication with equipment operators, this contributed to a number of fatalities.

Certain scenarios are identified as particularly dangerous. These include reversing to a dump point, and any scenario that involves personnel on foot (MSHA, 1995). This is due to the limited manoeuvrability, visibility, and audio warning that driver's experience when inside the cab.

Independent contractors and inexperienced workers are identified as being at a higher risk. In surface coal mines 19 out of the total of 33 deaths in the US between 1989 and 1993 were independent contractors (MSHA, 1998). In stockpile accidents 37% of the accidents involve miners with less than 1 years experience (MSHA, 1995), this proportion of accidents is significantly greater than their make up of the workforce.

3.2.1.2 Excavation Systems

The main excavation systems in open pit mines involve the use of either rope shovels or hydraulic excavators. Both are mounted on a system of crawlers and have similar operation. The excavator will typically load from one side before rotating around to dump either on a haul truck or to another location. Normally the excavator remains in the same position for the duration. This operation is shown in Figure 3.5.

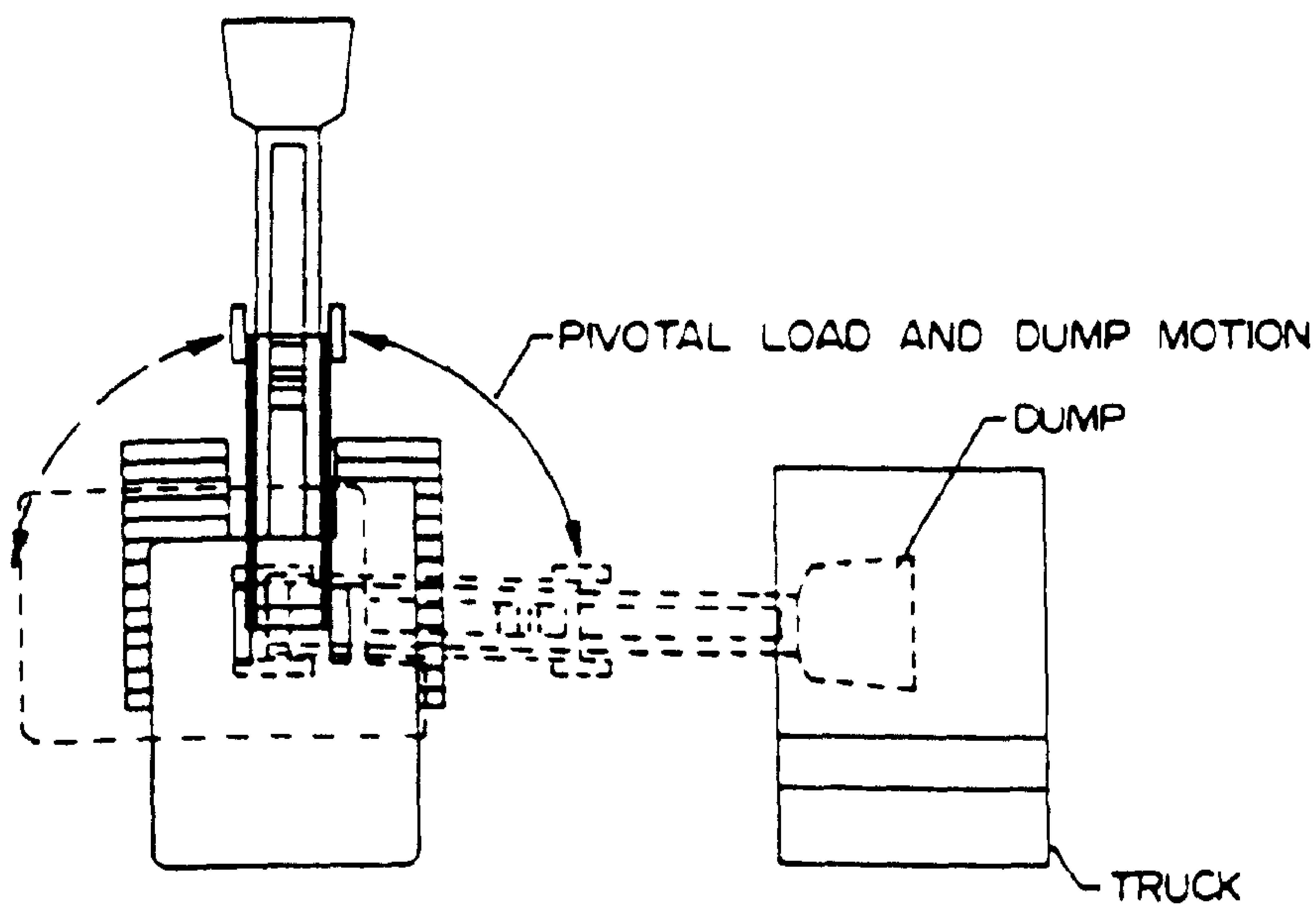

Figure 3.5 Excavator Load Motion (Denby, unpublished)

Shovel Loading Methods

There are three main loading methods used in open pit mining.

1. Double back up (see Figure 3.6).

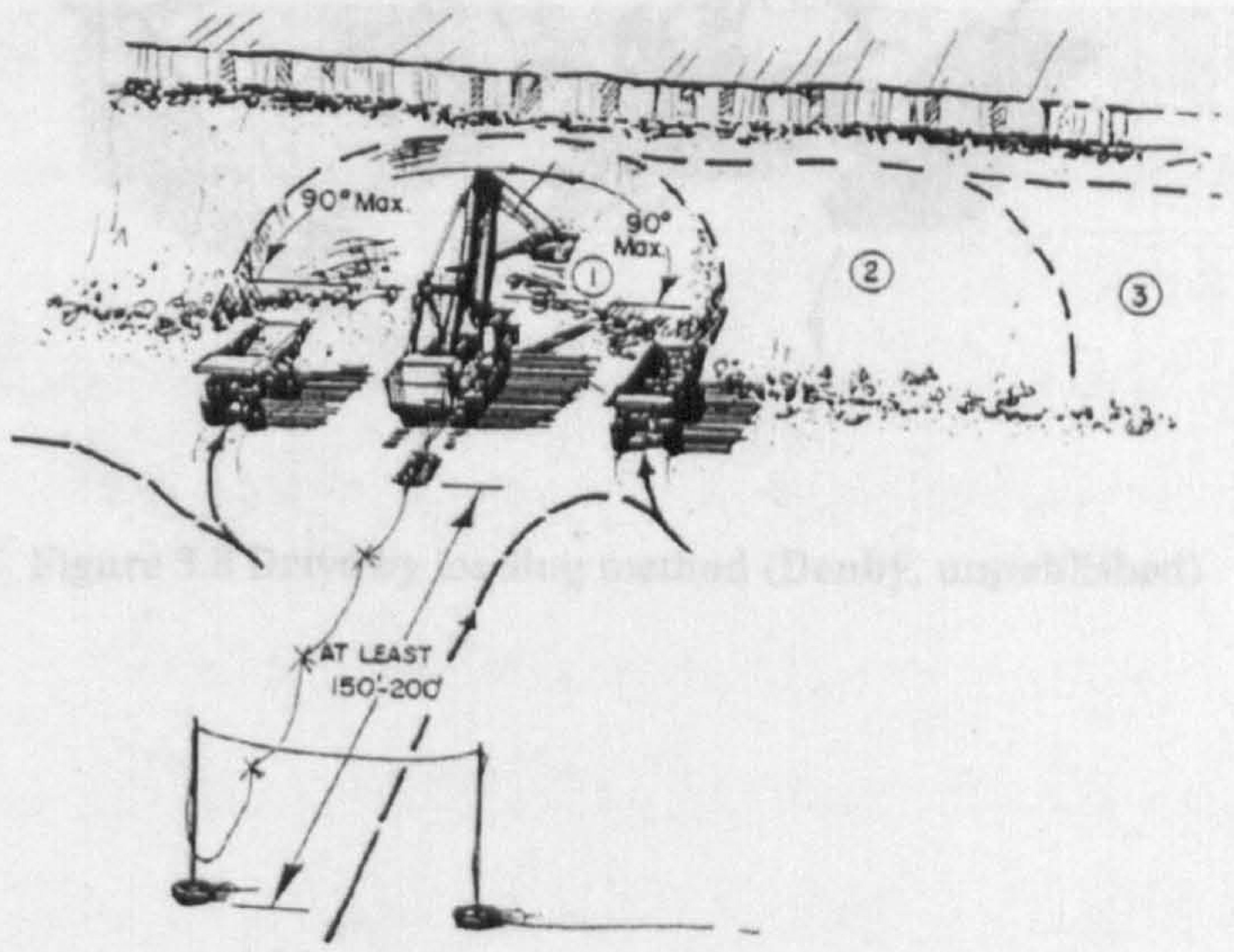

Figure 3.6 Double back up loading method (Denby, unpublished)

2. Single back up (see Figure 3.7).

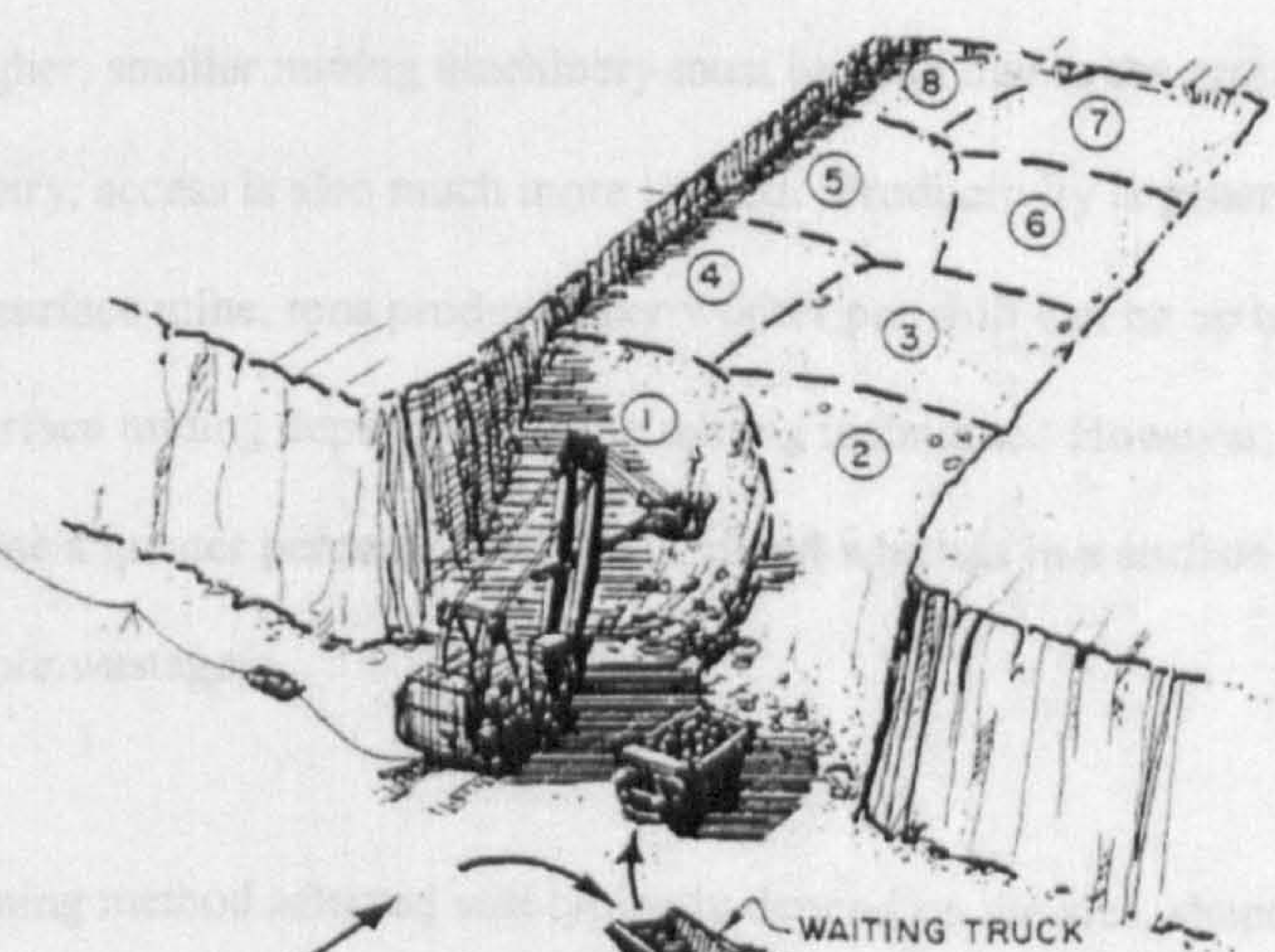

Figure 3.7 Single back up loading method (Denby, unpublished)

3. Drive by (see Figure 3.8).

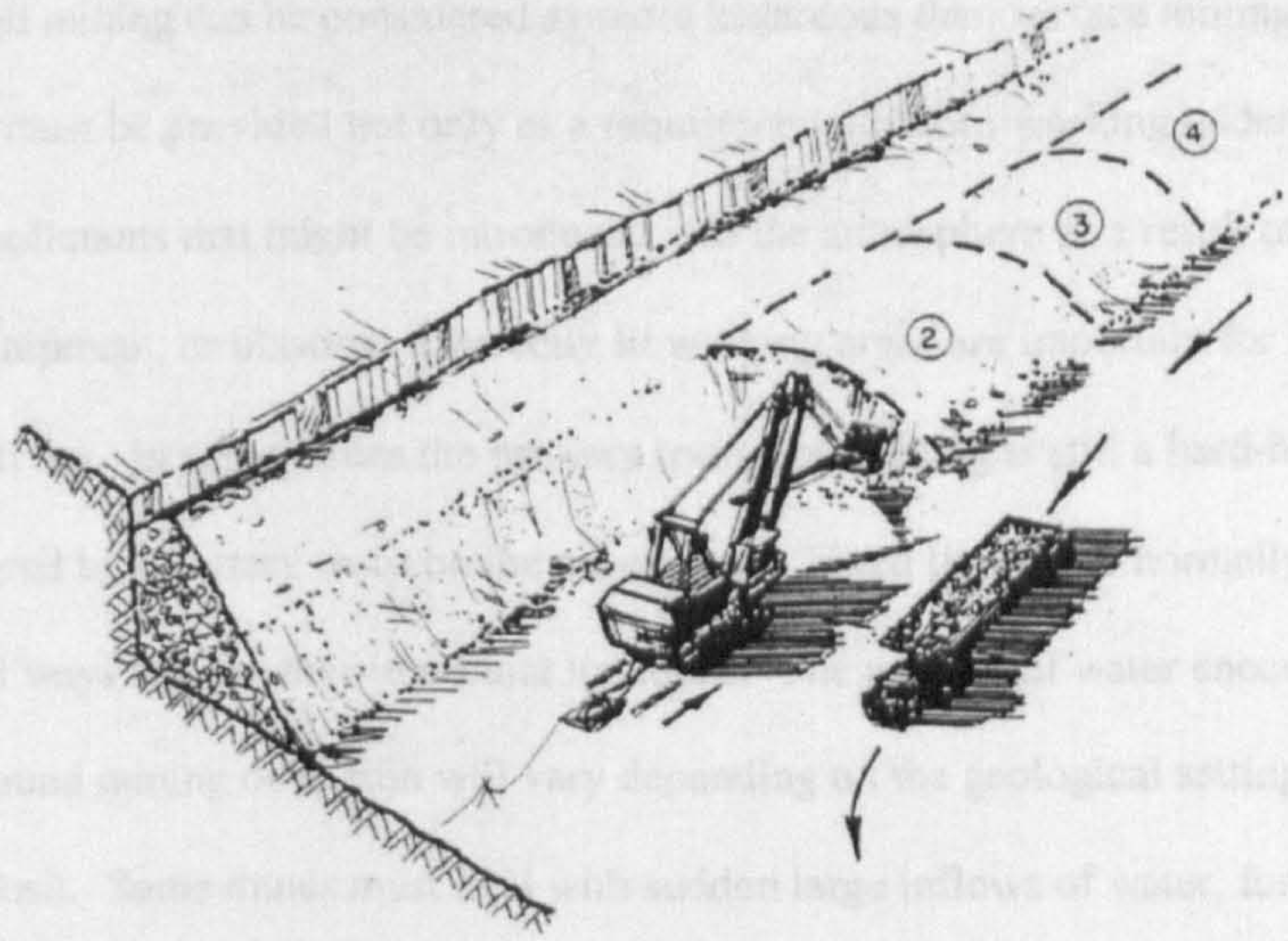

Figure 3.8 Drive by loading method (Denby, unpublished)

3.3 Underground Mining

If the ore body lies a considerable distance below the surface the amount of waste that has to be removed to uncover the ore through surface mining becomes prohibitive and underground techniques must be considered. Costs in an underground mine are considerably higher, smaller mining machinery must be used due to the ground conditions and mine geometry, access is also much more limited. Productivity is generally much lower than in a surface mine, tons produced per worker per shift can be up to 50 times lower than in surface mining depending on the mining technique. However, in an underground mine a greater percentage of ore is mined whereas in a surface mine there is considerably more wastage.

The specific mining method selected will typically depend on the size, shape and orientation of the ore body, the grade of mineralisation, the strength of the rock, and the depths involved. If the dip of the ore-body is greater than about 50 degrees then mining systems might use gravity to move the ore. If the dip is less than about 25 degrees then other ore-transporting equipment might be used.

Underground mining can be considered as more hazardous than surface mining. Ventilation must be provided not only as a requirement to those working underground but to remove pollutants that might be introduced into the atmosphere as a result of diesel powered equipment, or blasting. Correctly lit working areas are important for both safety and productivity. In some mines the primary source of lighting is still a hard-hat mounted lamp, powered by a battery worn on the miners belt. Fixed lighting is normally installed along travel ways and at other important locations. The amount of water encountered in an underground mining operation will vary depending on the geological setting and the type of deposit. Some mines must deal with sudden large inflows of water, for this reason special water doors and underground chambers are used to control the amount of water in the mine.

Many of the ore deposits retain the same horizontal orientation as when they were originally deposited. These flat-lying deposits are typically mined using either the room-and-pillar or longwall technique. Again, the technique chosen will depend on the nature of the geology.

3.3.1 Longwall Mining

Longwall mining is a common method used to extract bedded deposits. In 1979 it was the principal method of extraction in underground coal mines in Britain and has since become more widespread in the rest of the world (Thomas, 1979). Figure 3.9 shows a typical retreat mining operation.

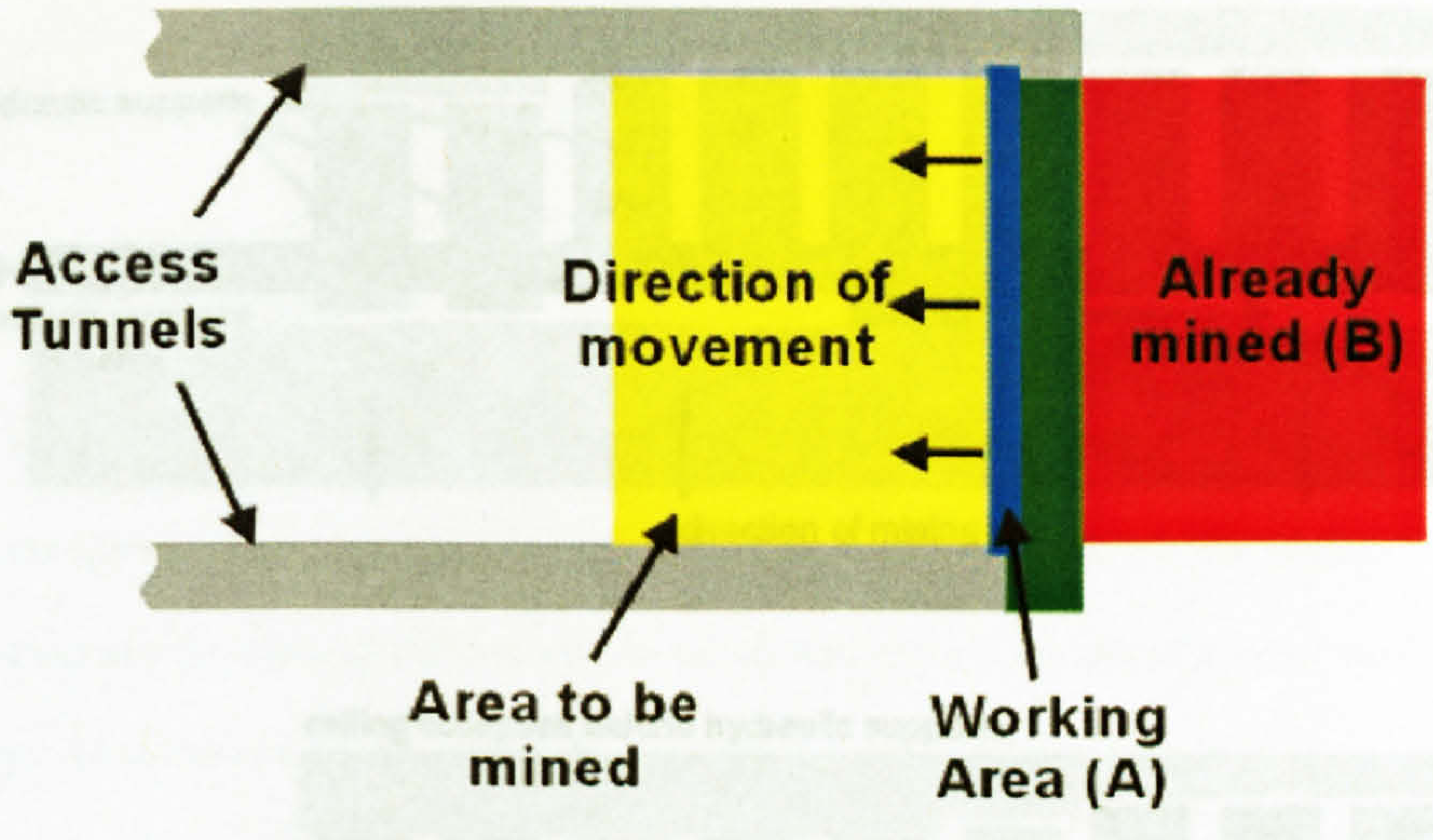

Figure 3.9 Longwall face method of work

Mining takes place along the working area (A) at an equivalent rate. As the face progresses forwards and material is removed, the region that has already been mined is allowed to collapse (B). Mining using this system will involve the use of large automated equipment. This will include a large number of hydraulic supports, a shearer, and conveyor belts to remove material. The general procedure is shown in plan view in Figure 3.10.

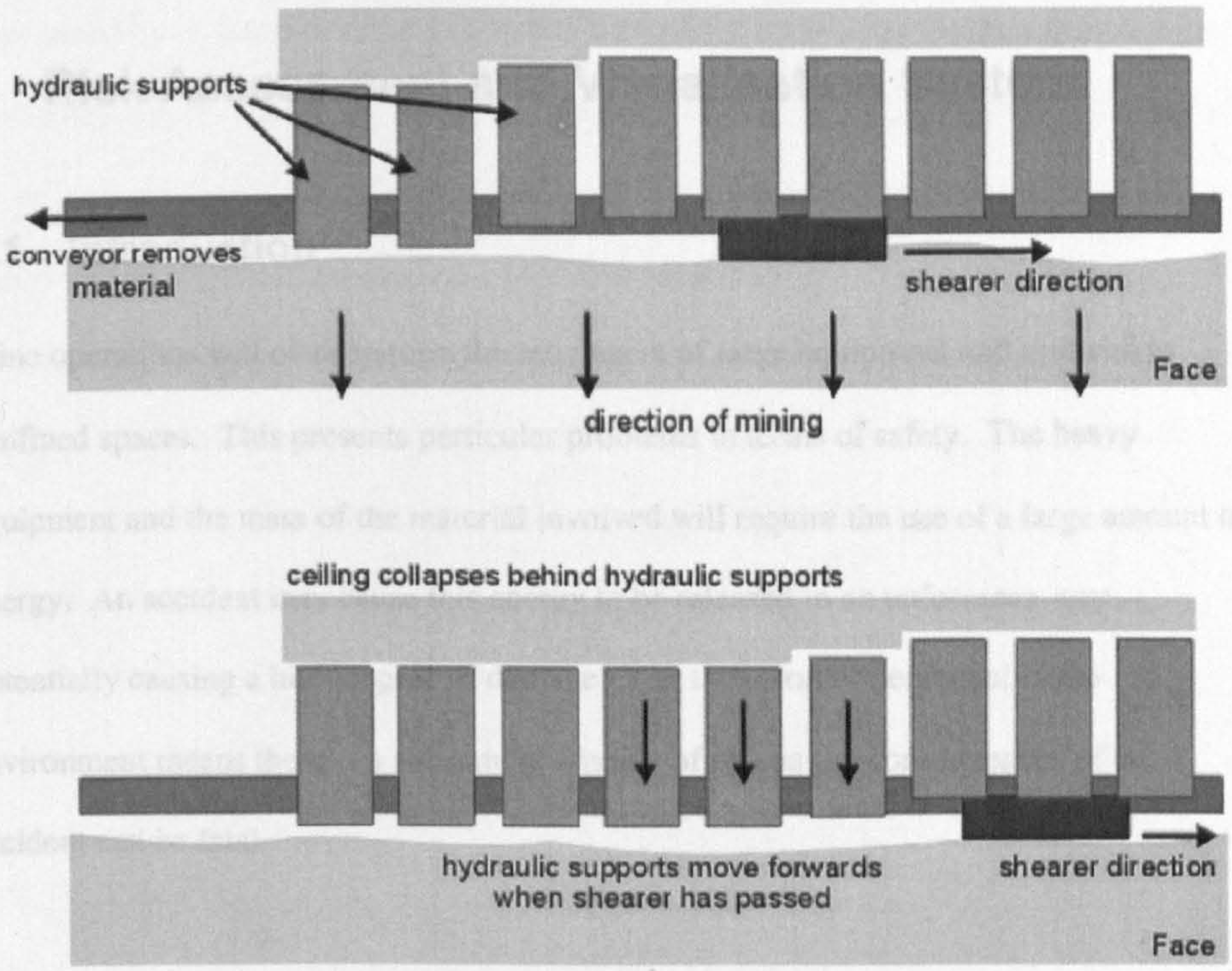

Figure 3.10 Longwall face equipment movement during normal operation

The shearer moves perpendicular to the direction of mining passing from one end of the face to the other. After each pass, the hydraulic supports, conveyor and track on which the shearer runs are moved forwards a small amount. Mining will therefore progress in the direction shown above, with material being transported out of the mine on a conveyor belt.

Once an underground face has been completely mined the heavy equipment must be moved to a new location before mining can start again. The conveyors and shearer are removed first leaving a series of static hydraulic supports. Each hydraulic support is then removed one at a time and replaced by a series of wooden supports that maintain the ceiling integrity. This process is known as 'face salvage'.

4 Risk Assessment and Visualisation System

4.1 Introduction

Mine operations will often require the movement of large equipment and material in confined spaces. This presents particular problems in terms of safety. The heavy equipment and the mass of the material involved will require the use of a large amount of energy. An accident may cause this energy to be released in an unforeseen way potentially causing a high degree of damage. The inclusion of personnel in the environment means there is a substantial amount of risk as the consequences of an accident can be fatal.

Many similar situations exist outside the mining environment. The movement of heavy equipment around factories and the movement of vehicles around a construction site are just two examples.

Risk assessment in the mining industry presents unique problems. The dynamic nature of the mining environment means that pre-emptive risk assessment is not always possible. Since the physical nature of the environment is changing on a day to day basis, a risk assessment will require that the assessor visualise the environment at some point in the future.

Assessment is often undertaken using 2D plans of the environment, this can cause problems for safety assessors who have no means of visualising the environment in 3D. Allowing the computer to perform the visualisation of the environment removes much of the interpretation of the assessor allowing them to concentrate more fully on the risk assessment. This technique is termed 'intelligence amplification' by Robert (Robert, 1992).

A 3D computer visualisation of the operations might provide the assessor with a greater understanding of both the static and dynamic components within the environment. It is hoped that this will allow additional hazards not instantly recognisable from 2D plans to be more readily identified. Additionally, once the environment has been modelled, generic tools could be developed to aid further understanding of the risk-based relationships between the equipment, the personnel and the layout of the environment. It is hoped that a better understanding of the static, dynamic and spatial relationships in the environment might help the assessor perform a better risk assessment, which in turn leads to a safer working environment.

4.2 Existing Work

Before the author started his PhD the AIMS Research Unit had already undertaken some work on what are termed 'risk regions' (McClarnon et al., 1995 and Denby et al., 1995). This work involved constructing virtual worlds from plans of the environment that were being assessed. Every object in these worlds is programmed with pre-set motion based upon the dynamics of the real world.

In the existing system volumes of space, known as risk regions, are defined around each dangerous area and piece of equipment in the environment. The risk regions around equipment are dynamic. They are able to alter their size and position as the equipment changes its position or activity. For example, the risk region around a moving vehicle might be different to that surrounding the vehicle when stationary.

The risk can be measured at specific points where 'risk markers' are placed. Risk is evaluated by calculating the number of regions in which the marker is contained. The markers are represented by coloured boxes that change from green (low risk) to yellow to red (high risk) (Denby et al, 1995). Risk markers can be placed anywhere inside the virtual world, and these record both the current and the cumulative level of risk as the application executes.

By 1995 the AIMS Research Unit had performed only limited development of this technique. Their work consisted of an evaluation of the operation of a surface mine. A screenshot of the system is shown in Figure 4.1

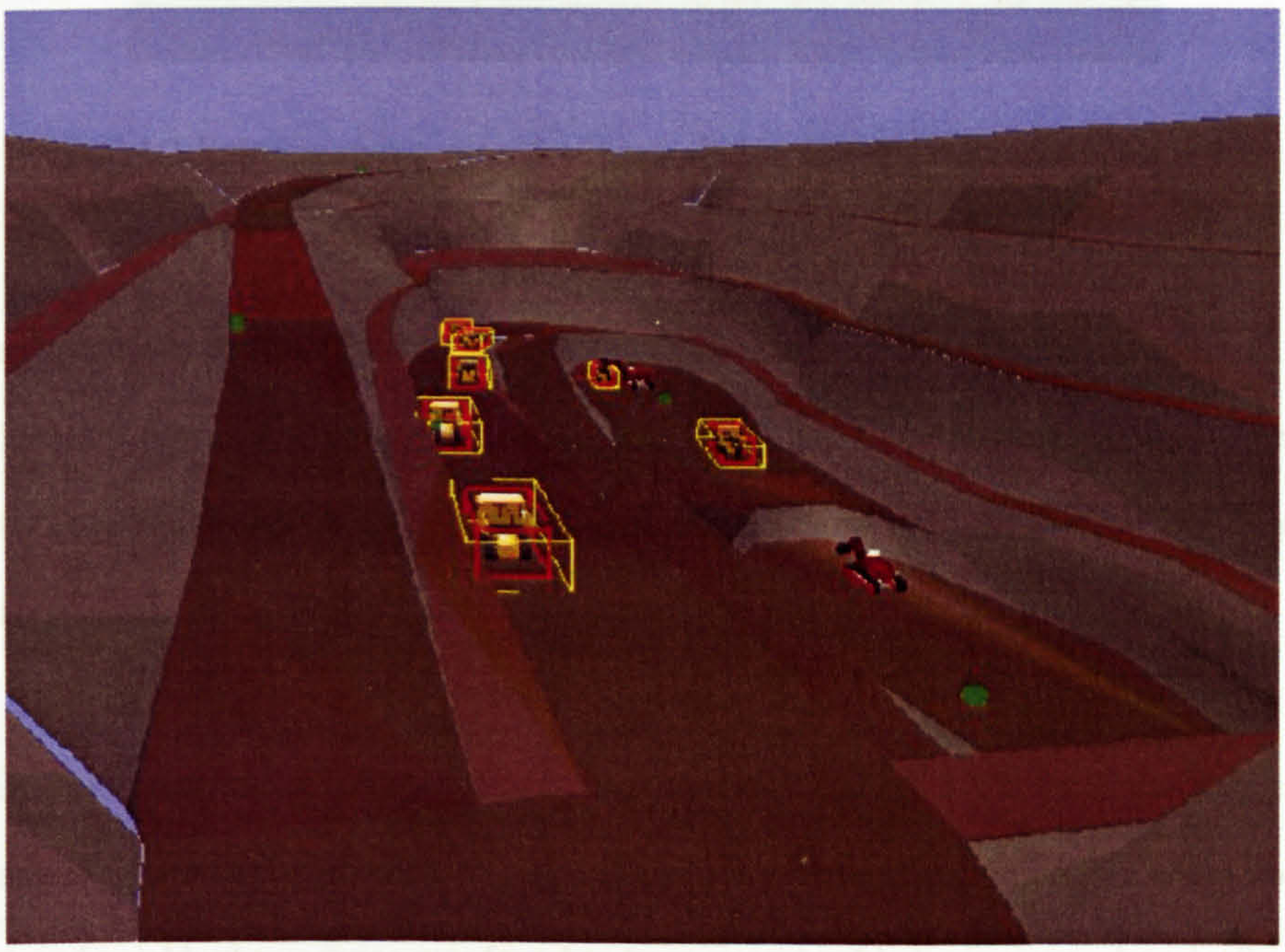

Figure 4.1 Existing open pit risk analysis system (AIMS Research Unit, 1995)

Two risk regions are visible around each of the haulage trucks. These are coloured red and yellow, indicating an area of high risk, and an area of medium risk respectively. All of the regions in the system are cuboid. Risk markers are placed in the system at pre-set locations. At each time step, each risk marker in the system calculates the number of regions it is inside. This is recorded and provided as feedback to the user in the form of a dialog (Figure 4.2) that is updated continuously as the application executes.

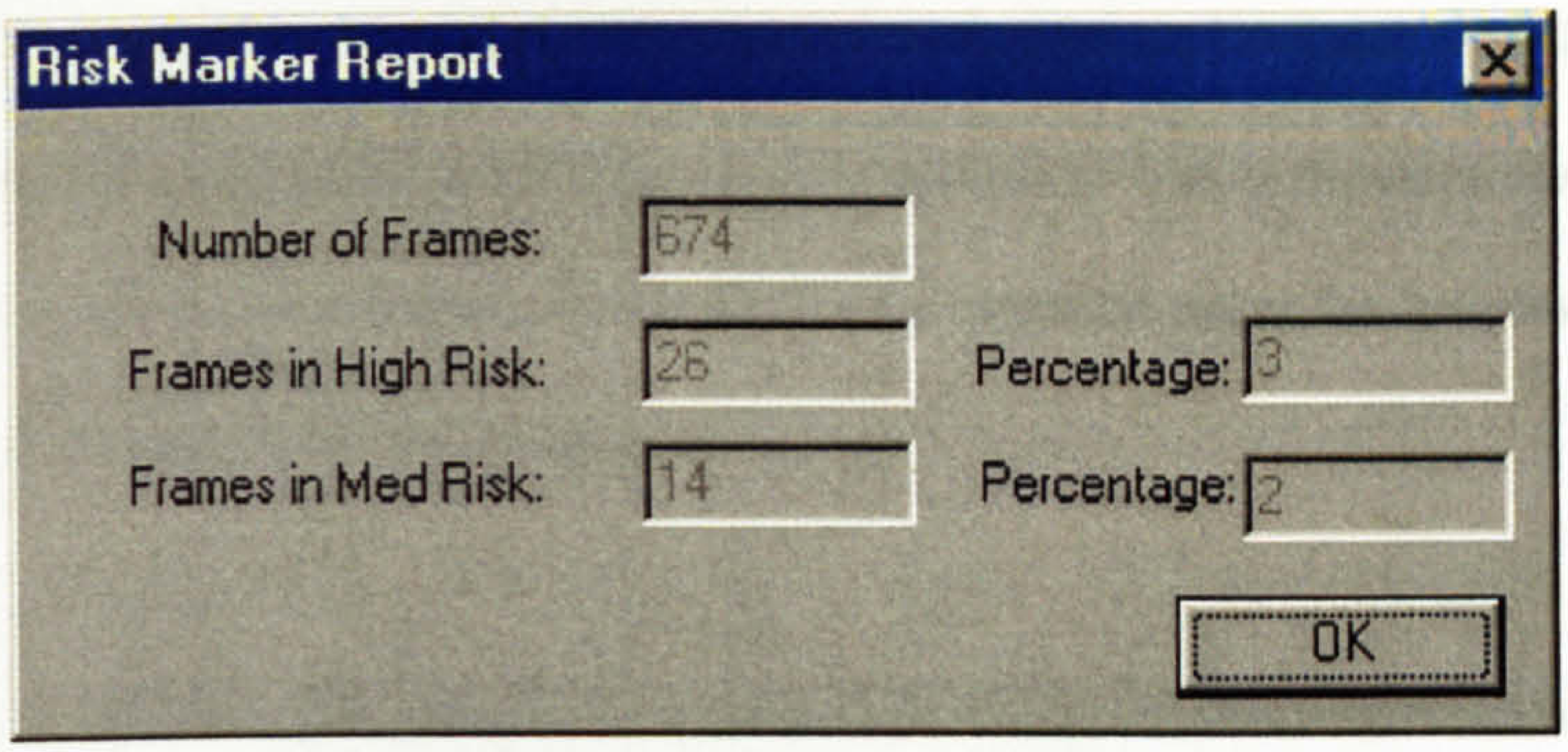

Figure 4.2 Existing risk region feedback dialog (AIMS Research Unit, 1995)

This system was demonstrated to a number of mining institutions. There was interest in the idea, but they expressed concerns about the basic and inflexible nature of the system. They particularly liked the 3D visualisation of the environment to aid risk assessment and the idea of enhancing the view with a risk-based overlay.

The existing system was written using Superscape VRT (2000), a VR world building and visualisation package. Although this package allowed a demonstration of the idea to be produced quickly the package was found to have considerable limitations when dealing with irregular shapes. In particular there was no support for non-orthogonal collision detection which severely restricted the type of worlds that could be modelled. Additionally it was felt that the quality of the graphics as well as the speed and flexibility of the system, could be improved by using a compiled language such as C++.

The author undertook additional research to develop a more sophisticated algorithm for evaluating risk as well as increasing the systems flexibility speed and graphical quality. Once this had been completed, further case studies could be performed to assess the systems effectiveness.

4.3 Risk Region Development

The question of what these regions represent was never fully answered in the previous work. According to Denby et al. (1995) risk regions are placed around each dangerous piece of equipment, or dangerous area in the environment. The conclusion was drawn that they represent some increased level of risk as a result of either the location, or the equipment with which they are associated.

The size and shape of each risk region was determined by the user and was based upon the experience and judgement of the assessor. The fact that this tool had no mathematical basis was not significant as it was intended as a tool for identifying additional hazards and analysing the risk-based relationships within the environment. Indeed individual judgement as to the level of risks is an inherent and unavoidable part of the process of risk assessment. However, if there is no basis at all for the presence of risk regions then their representation in the virtual world could be misleading.

It would seem reasonable that there were some increased risks from factors such as moving equipment or a road junction. For example, the Fatal Accident Rate (FAR) for driving a car has been calculated as 57 (no units) (Blockley, 1992). Indeed part of this work is to investigate whether or not the representation of this increased risk as regions around these hazards could be used to identify potential safety problems.

The level of risk experienced at a particular location would seem to be related to the distances from each hazard. Although the classic definition of risk does not include any consideration of proximity, this would seem to be an important consideration. For example, many people would agree that there is some increased risk when working close to an excavator. This is the basis for the increased risk being represented in the form of regions.

4.3.1 Risk Values

Risk has a basis in probability, it has been defined as:

Risk = Hazard Severity x Likelihood of Occurrence (Probability of Event Occurring)

Consider a dangerous object in isolation, this object has an associated risk region. This risk region is defined such that its boundary indicates the point at which negligible risk is experienced as a result of the dangerous object. Risk regions could therefore be considered as 3D risk contours as their boundary defines a constant level of risk. How the level of risk varies through the volume of the space represented by the region will depend on the nature of the factor that is being represented.

Using this concept the boundary of the region is assigned a risk value of zero. The choice of zero is arbitrary but considering that this effectively equates to 'no additional risk' then this would seem reasonable. Furthermore a location which experiences the maximum possible risk is assigned a value of 100. This indicates an area of extreme danger. Again, the choice of 100 is arbitrary but would seem a reasonable choice as this value represents the maximum risk.

The risk value at a given location has been defined as the level of risk experienced at that position. Risk has also been defined as a function of severity of the hazard and the likelihood of occurrence. Risk values within the system are therefore a reflection of these two factors. The possibility of using the range 0 to 1 was considered to reflect the basis in probability, but since the risk value is a reflection of two factors (likelihood and severity) it seemed logical to assign a different scale.

4.3.2 Risk Region Modelling

The nature of the hazard will define how the level of risk varies through the volume of space defined by the risk region. Two factors are considered below to illustrate the modelling of risk regions.

4.3.2.1 Road Junction Risk Region

The risk surrounding a road junction could be represented by a risk region that includes the area shaded yellow in Figure 4.3. The area would be represented in the virtual world by a 3D region, but is shown here in 2D plan for simplicity.

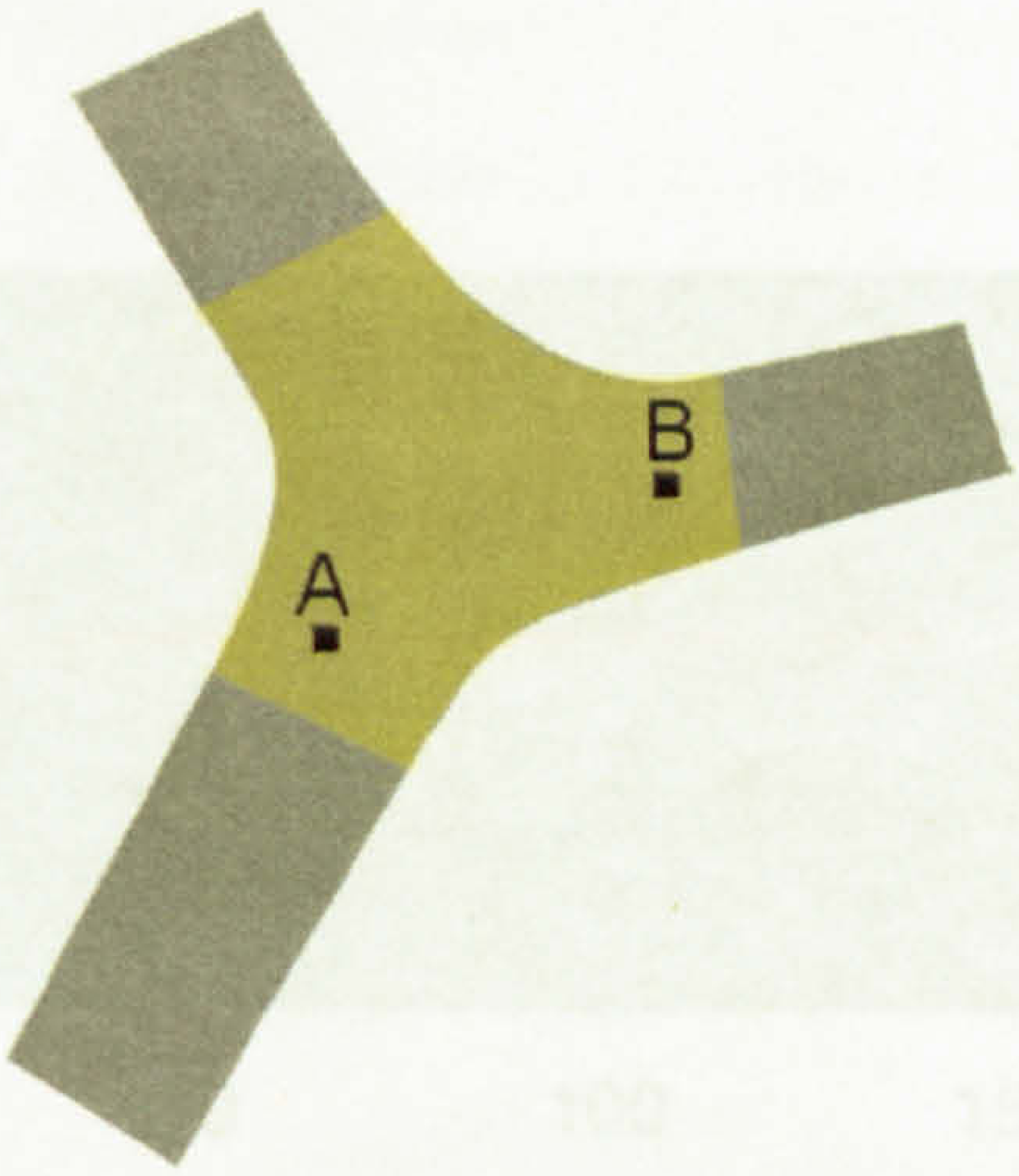

Figure 4.3 Risk region around a road junction

The level of risk throughout the yellow region could be interpreted as approximately constant. There is approximately an equivalent increased risk at location A as at location B as a result of the road layout. In this case the entire shaded region is considered to increase the level of risk by some factor, the entire shaded region is therefore assigned a constant risk value.

Looking at the risk value solely as a result of the road junction, as an object passes through the region it might experience a change in the risk value similar to that shown in Figure 4.4. For this example a risk value of 50 was chosen for the entire region.

The calculation of a risk value at a given location within the system described above is a simple procedure. It must first be determined whether the location is inside the region. If the location is inside the region then the location has a risk value of 50, if it is outside then it is assigned a risk value of zero.

The graph in Figure 4.4 shows the change in the risk value as an object passes through the risk region. Once inside the region the value remains constant throughout.

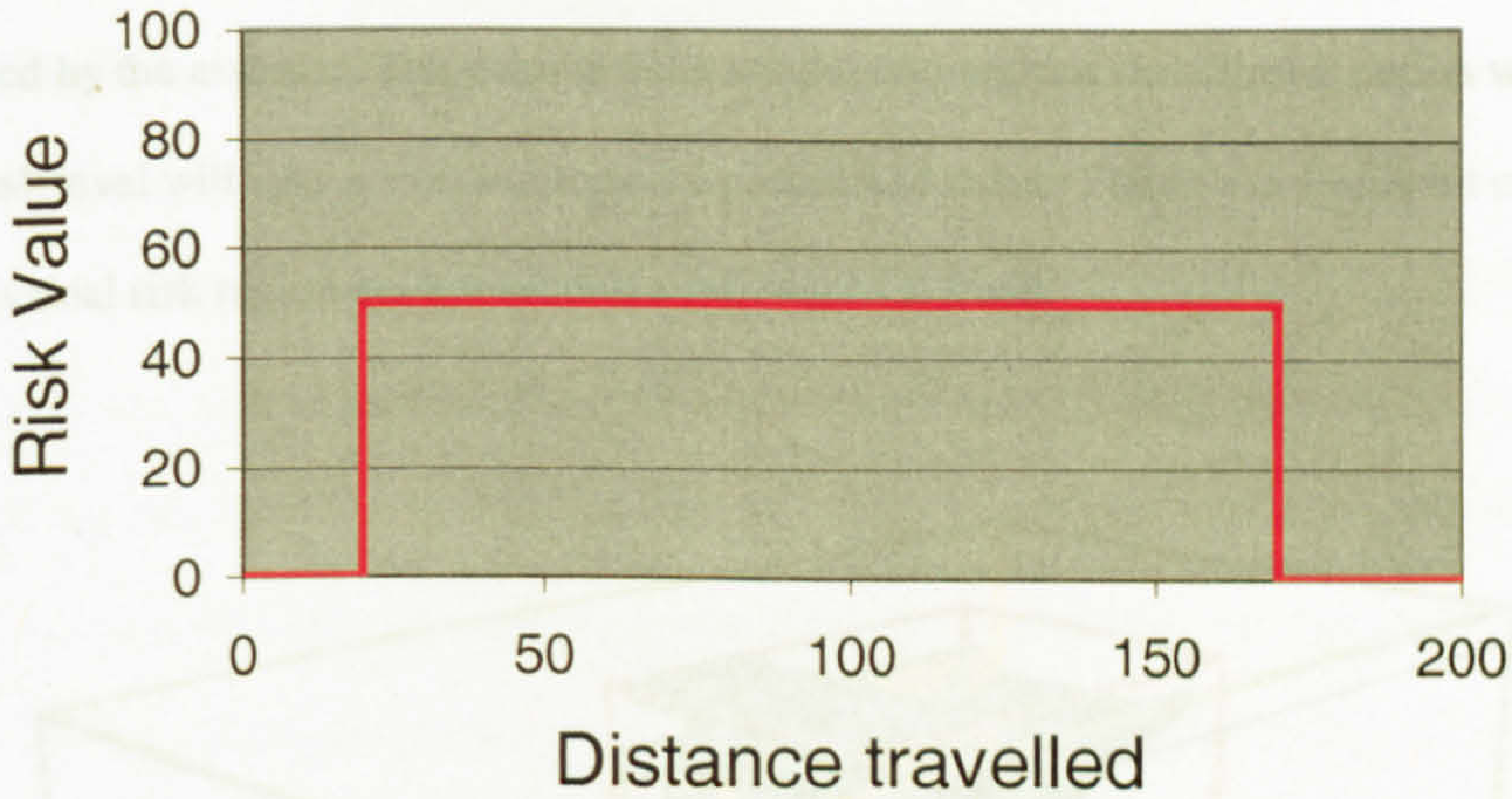

Figure 4.4 Change in risk value as object passes through a constant risk region

4.3.2.2 Haulage Truck Risk Region

A haulage truck has many possible states, for example it could be stationary, moving, dumping or loading. Both the shape and size of the region associated with the truck might need to be modified depending on its current activity.

From the definition of a risk region, the edge of a risk region represents the point at which there is negligible additional risk as a result of the dangerous object. Furthermore, contact with the vehicle would be extremely dangerous if the vehicle was moving. For this reason, unless the vehicle is at rest, the volume of space defined by extents of the vehicle is seen as an area of extreme danger, this is assigned a risk value of 100. How the risk level is modelled between these two locations is open to interpretation. The author developed a method that could be used to model the risk associated with other equipment or objects.

Two risk regions are used, one is always completely contained by the other and for this reason they are termed the inner and outer regions respectively. The outer risk region defines the point at which the risk becomes significant, the risk value at the boundary of this outer region is defined as zero. The volume enclosed by the inner region defines a constant level of risk, and within this volume the risk value is set at a constant value defined by the assessor. The volume between the two regions describes a region where the risk level will vary according to some predefined rules. Figure 4.5 shows an example of this dual risk region system around a moving haul truck.

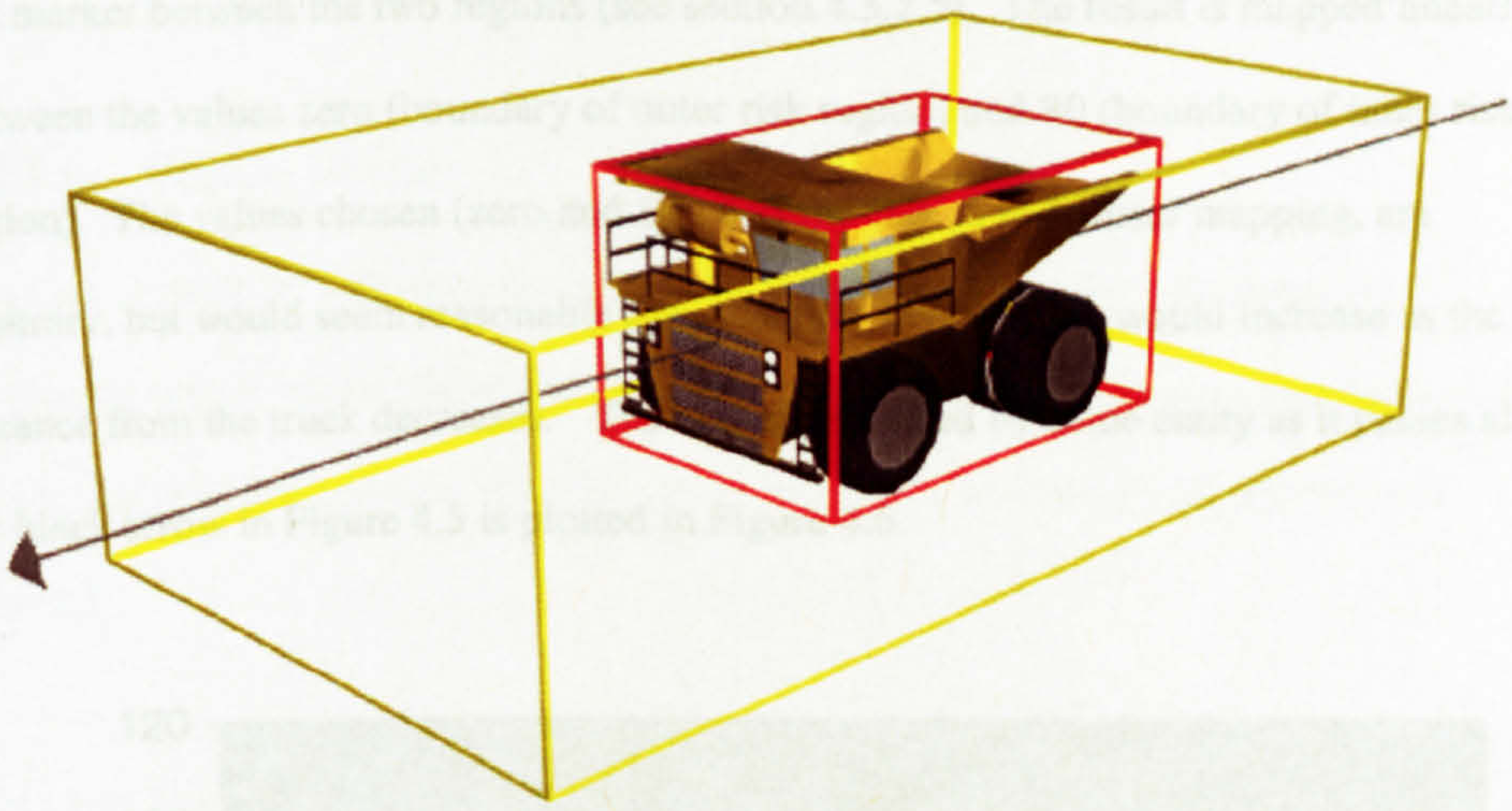

Figure 4.5 Dual risk region system around a haul truck

The calculation of the increased risk value at a given location, as a result of the dual inner and outer risk regions falls into one of three categories.

1. **Outside the outer risk region.** If the location is outside both regions the increased risk is effectively zero as the location lies outside the boundary that defines negligible risk.
2. **Inside the inner region.** If the location is within the inner risk region then the risk value is increased by some constant value as defined by the assessor.
3. **Outside the inner region, but within the outer region.** In this area, mathematically

defined by A – B where A is the outer region and B the inner, the risk value is defined by some function that maps the relative distance between the inner and outer regions onto some risk value.

Given the moving haul truck example shown in Figure 4.5, parameters for the risk region could be chosen as follows. When the marker is located inside the inner risk region the risk value is assigned a constant value of 100. This would seem reasonable given that any location inside the inner risk region would almost certainly indicate contact with the truck itself, and is therefore an area of high risk. When the marker is located outside the inner but inside the outer region, the risk value is calculated based upon the relative distance of the marker between the two regions (see section 4.3.2.5). The result is mapped linearly between the values zero (boundary of outer risk region) and 80 (boundary of inner risk region). The values chosen (zero and 80), and the choice of a linear mapping, are arbitrary, but would seem reasonable given that the level of risk would increase as the distance from the truck decreases. The risk experienced by some entity as it passes along the black arrow in Figure 4.5 is plotted in Figure 4.6.

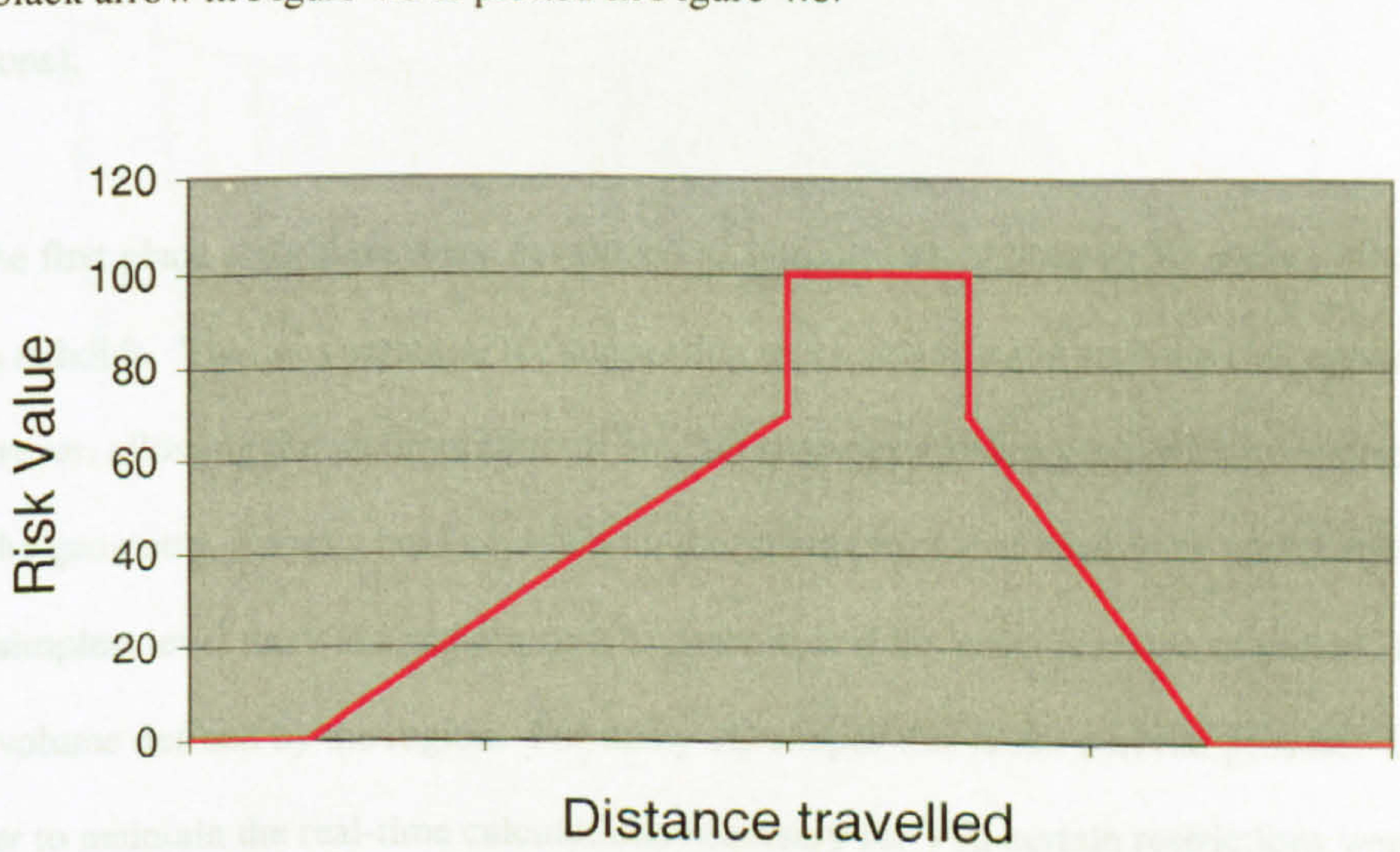

Figure 4.6 Risk value through the haul truck risk regions

4.3.2.3 Dynamic Properties of Risk

As objects move around within an environment, they alter their state depending upon the activity that they are performing. This may result in changes to a number of their attributes including their speed, their current activity or their mass. It is reasonable to expect that the size and shape of the objects associated risk regions will alter as each of these variables change.

To reflect the change in the risk generated by each factor risk regions must be dynamic. They must have the ability to change their position, size, shape and type of region depending upon the state of the objects whose risk they are modelling.

4.3.2.4 Region Shape

The requirement for calculations to be performed in real-time limit the amount of processing which can be realistically undertaken. The calculations are concerned with the interaction between multiple 3D points (risk markers) and multiple 3D shapes (risk regions).

In the first place algorithms were developed to support risk regions in 3D shapes other than cuboids. This was essential for supporting more flexible and realistic risk regions. However, allowing the incorporation of any 3D shape as a risk region, with no restrictions on the geometry, places a heavy burden on the calculations that need to be performed. At the simplest level there is a requirement to determine if the point is inside or outside the 3D volume defined by the region. For many 3D shapes this is not a trivial process. In order to maintain the real-time calculations necessary for VR, certain restrictions were placed on the types of 3D shapes that could be used. The author defined a procedure for constructing risk regions, this had the effect of restricting the type of 3D shape that could be constructed.

The 3D region is created from a 2D convex polygon that is first drawn in plan view. This 2D shape is extruded along the elevation to create the 3D-risk region. This process is illustrated in Figure 4.7.

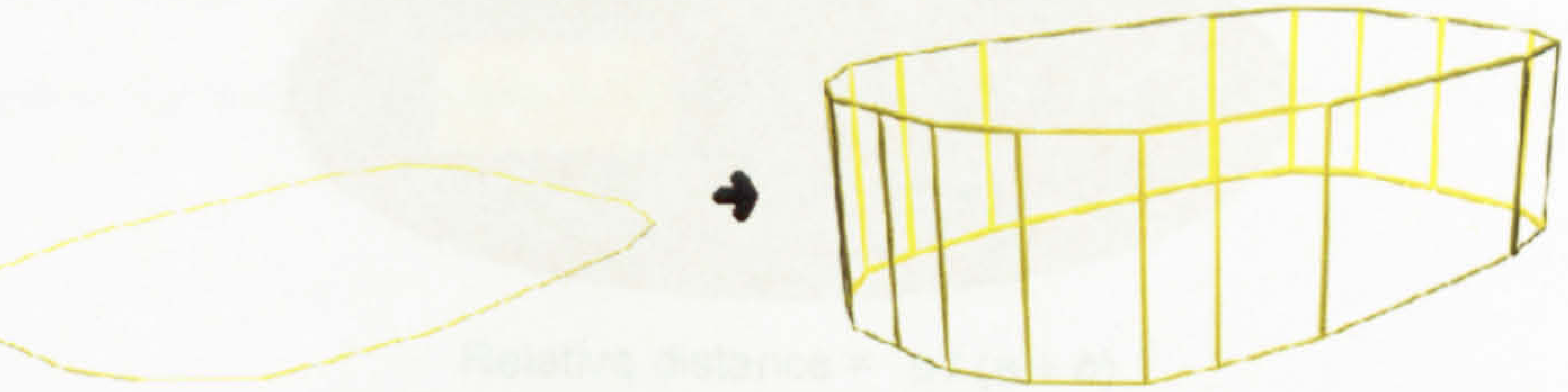

Figure 4.7 Two stage construction of a 3D risk region

This allows the representation of the risk associated with vehicles and areas to be described and evaluated in more detail whilst limiting the computational effort required. Representations of the possible risk region systems for a vehicle are shown in Figure 4.8.

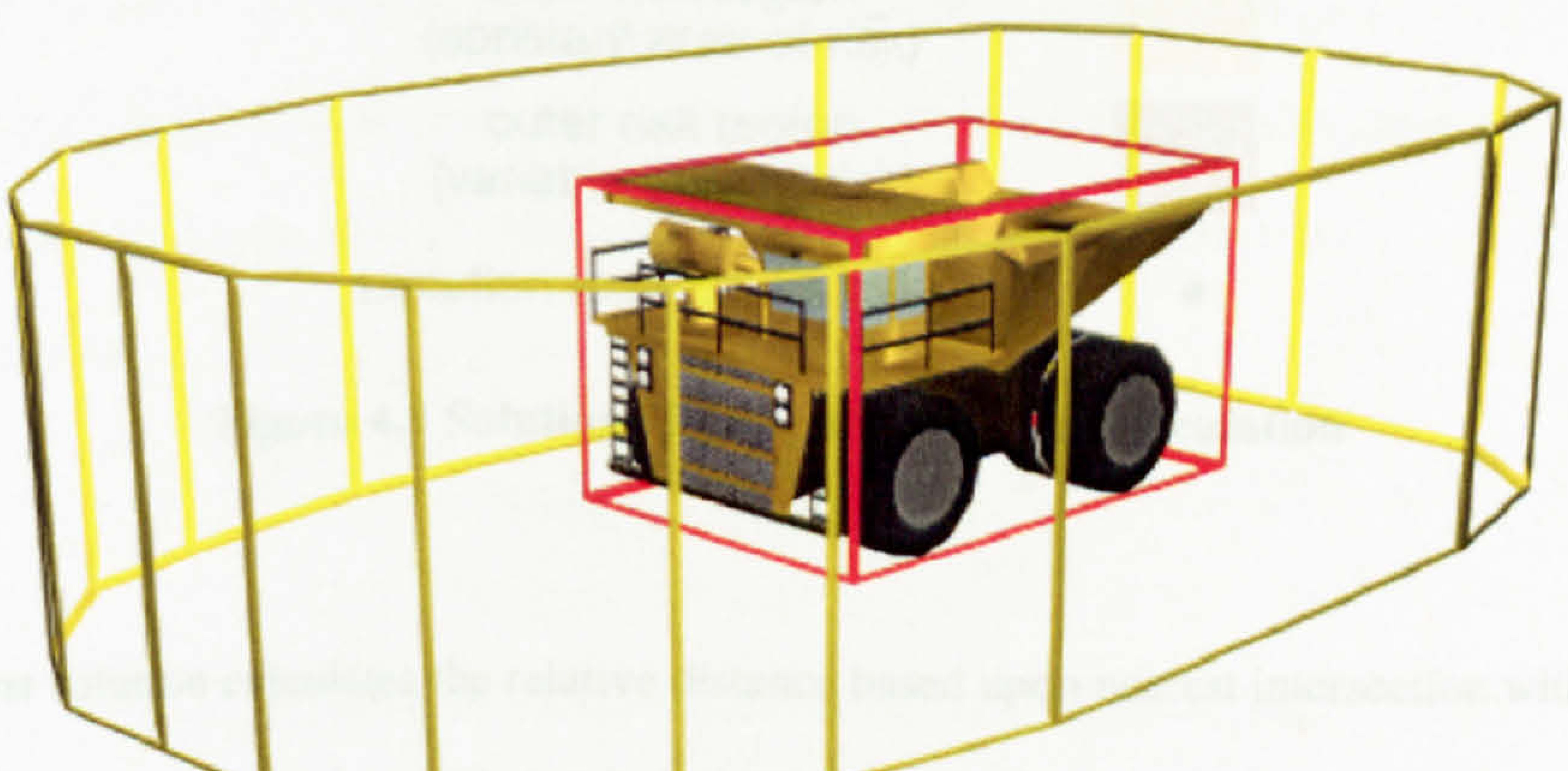

Figure 4.8 Example risk regions for a haul truck

4.3.2.5 Relative Distance Calculation

The relative distance calculation is performed when a marker is located between an inner and outer region in a dual risk region system. Two possible solutions to the problem were considered.

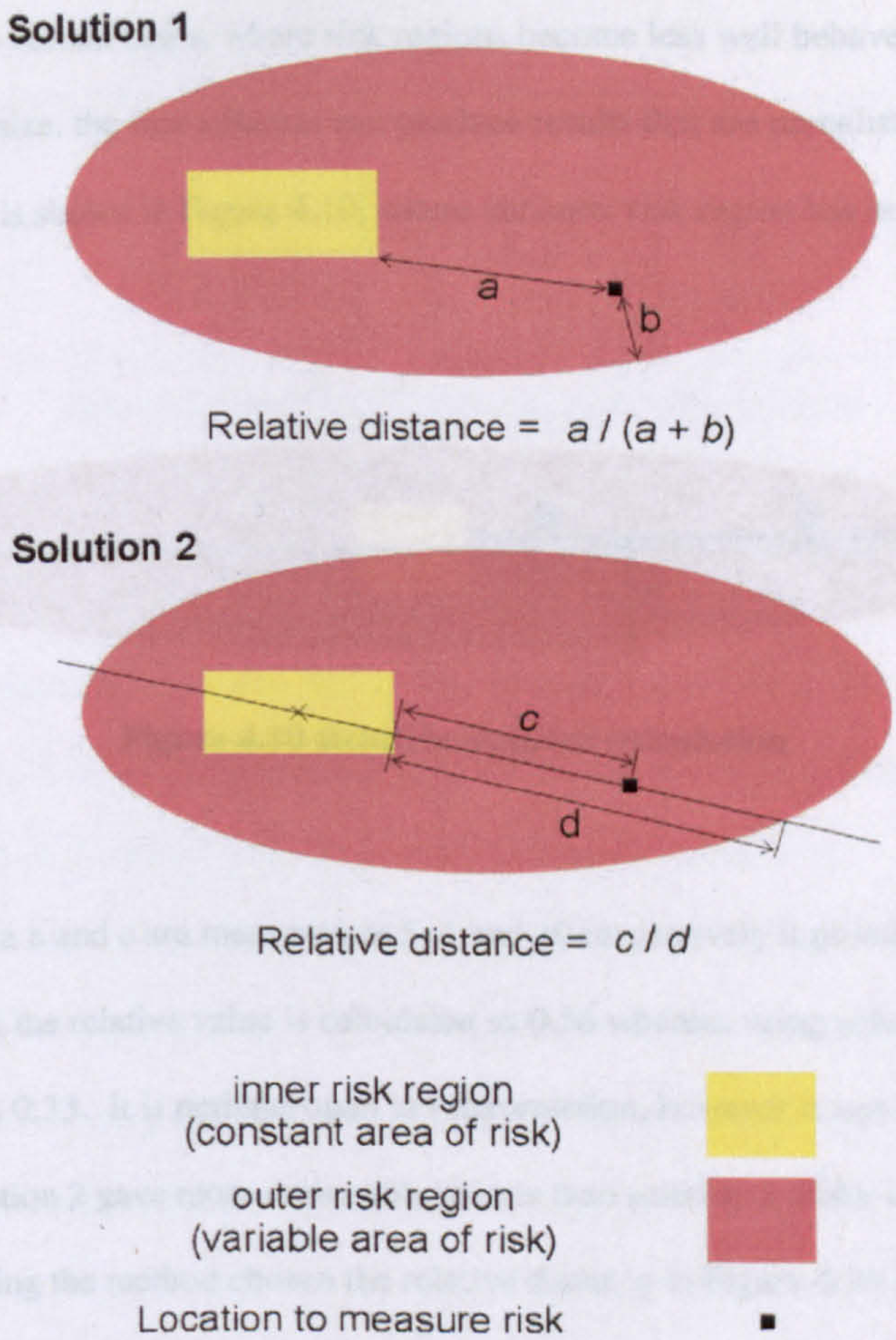

Figure 4.9 Solutions for relative distance calculation

The first solution calculates the relative distance based upon nearest intersection with the inner and outer risk regions, this is labelled 'Solution 1' in Figure 4.9. Solution 2 calculates the relative distance using a line defined by two points, the centre of the inner risk region, and the location at which the risk is being measured. The relative distance is now the distance along this line from the location to the inner risk region divided by the distance along this line from the inner to the outer region, this is labelled 'Solution 2' in Figure 4.9.

Both methods could be considered as valid, however the author chose the second method for two reasons. The results produced provide a more direct connection to the observable positions and sizes of the region, this can be illustrated by the second reason for choosing this solution. In certain cases, where risk regions become less well behaved in terms of their shape and size, the first solution can produce results that are unrealistic. One example of this is shown in Figure 4.10, where the outer risk region has become long and thin.

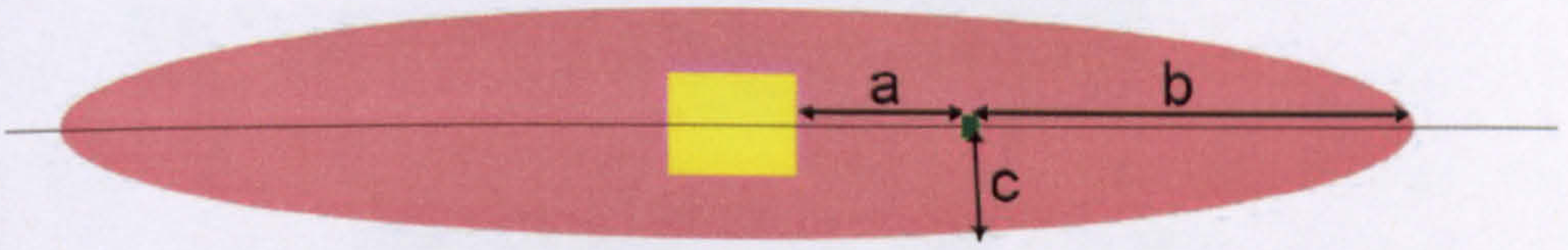

Figure 4.10 Relative distance calculation

If the values of a b and c are measured as 5, 4 and 10 respectively it possible to see that using solution 1 the relative value is calculated as 0.56 whereas using solution 2 the relative value is 0.33. It is perhaps open to interpretation, however it was believed by the author that solution 2 gave more reasonable results than solution 1 under these and similar conditions. Using the method chosen the relative distance in Figure 4.10 is given by Equation 4.1.

$$\text{Relative Distance} = \frac{a}{a+b}$$

Equation 4.1 Relative distance (as in Figure 4.10)

4.3.2.6 Cumulative Properties of Risk

It is important to define how a marker should evaluate the risk when it finds itself inside two or more risk region systems. In the original work by Denby et al. (1995), risk regions were added together, the level of risk was then classified according to the resulting value as described in Table 4.1.

Number of risk regions that the marker is inside	**Classification**
0	Low risk
1	Medium risk
2 or more	High risk

Table 4.1 Classification of risk in existing system

The author developed new rules to define the risk value when two or more risk region systems overlap. A simple addition as used in the old system was not satisfactory since the probabilistic properties of the defined risk value are not conserved.

The method used to combine two or more risk values when regions overlap is similar to that used when combining probabilities. Given that risk value has a basis in probability this would seem a reasonable method to use.

The probability of rolling a one when using a six sided die is 1/6. According to the rules of probability, the probability of rolling two ones using two separate dice will be 1/36. This fraction is a measure of both events occurring in any given test. When combining two risk values it is useful to think of them as the probability of some event occurring leading to some increased level of risk. The cumulative risk value is a measure of the probability of an event being generated by either factor. To calculate this probability and the subsequent risk value we consider the probability of no event occurring as a result of either factor. An example of the procedure for calculating the risk value at location A (in Figure 4.11) is shown in Table 4.2.

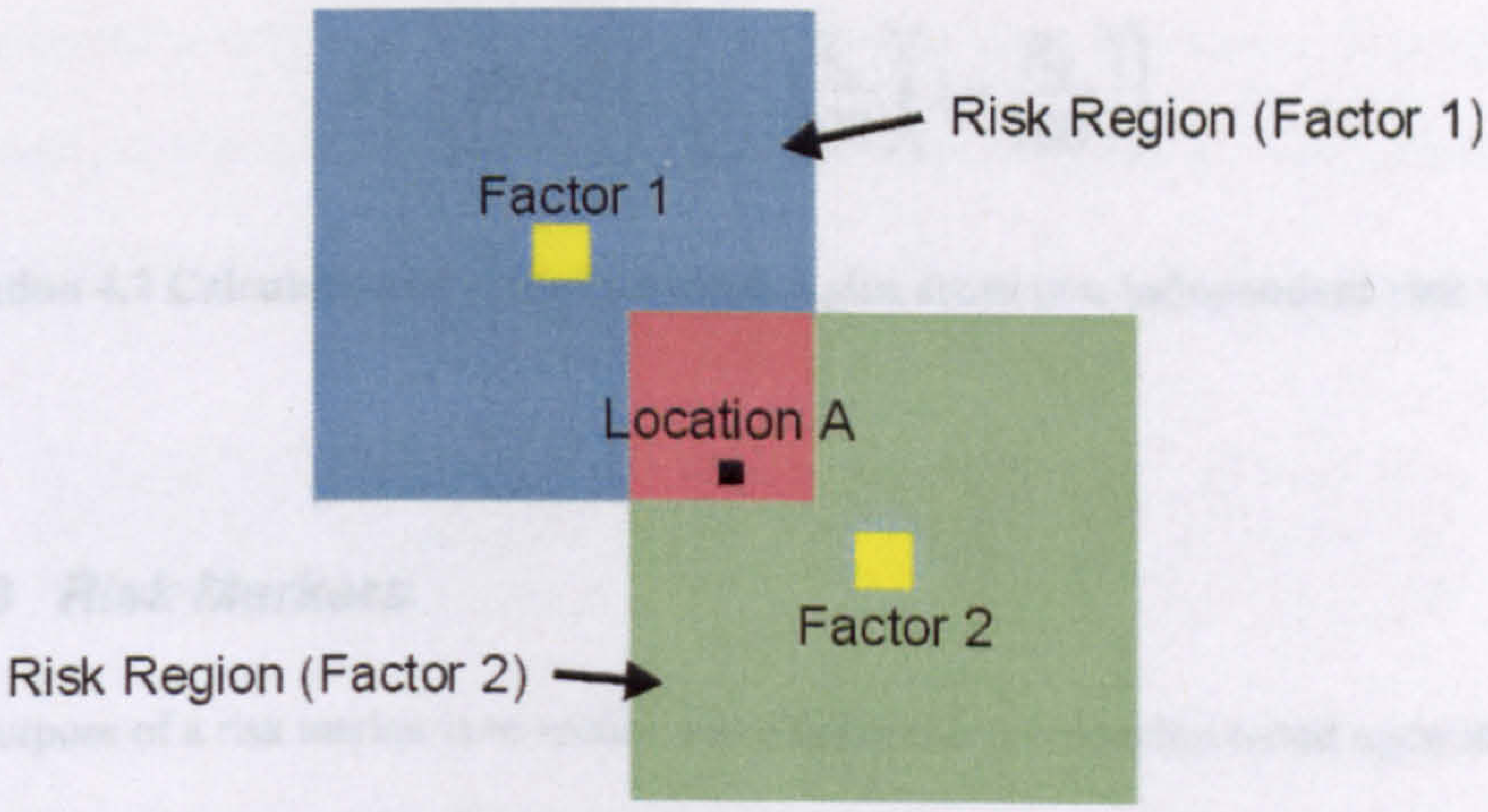

Figure 4.11 Combining risk regions (plan view)

First calculate individual values:

Risk level resulting from factor 1 at location A = 30

∴ probability of no event occurring causing increased risk = 1 – (30 / 100) = 0.7

Risk level resulting from factor 2 at location A = 60

∴ probability of no event occurring causing increased risk = 1 – (60 / 100) = 0.4

Now combine individual values:

Probability of no event occurring causing increased risk Location A

∴ based on the law of probability = 0.7 x 0.4 = 0.28

Probability of event occurring leading to increased risk = 1 – 0.28 = 0.72

∴ risk value for location A = 72

Table 4.2 Procedure for combining risk values

The general equation to calculate the resulting risk value from two independent risk regions is given in Equation 4.2.

$$R_T = 100 \times \left(1 - \left(1 - \frac{R_a}{100}\right)\left(1 - \frac{R_b}{100}\right)\right)$$

Equation 4.2 Calculation of cumulative risk value from two independent risk values

4.3.3 Risk Markers

The purpose of a risk marker is to record and display risk information based upon its current location in the world. This information is updated at each discrete time step. The calculation of the risk level at a given location is achieved through the algorithm in Table 4.3.

```
no_incident_chance = 1
FOR ( each region R in the world )
    IF ( Inside_Region(marker_location, R) )
        no_incident_chance = no_incident_chance * Evaluate_Risk(marker_location, R) / 100
    END
END
Risk_Level = 100 * ( 1 – no_incident_chance )
```

Table 4.3 Procedure for calculating risk markers value

Statistics also recorded by each risk marker include the average (mean) value of risk during their lifetime, as well as the maximum risk to which they have been exposed. Log files containing the position and risk value for each marker at each discrete time-step in the virtual environment are produced. This data can be imported into a spreadsheet package, where a more detailed analysis can be undertaken.

Risk markers are also able to provide visual feedback on the current level of risk to which they are being exposed. In the original system, markers changed from green (no risk), to yellow (medium risk), to red (high risk). Using a higher resolution scale, a larger number of colours can be used to highlight smaller changes in the level of risk. The scale that has been adopted is shown in Figure 4.12.

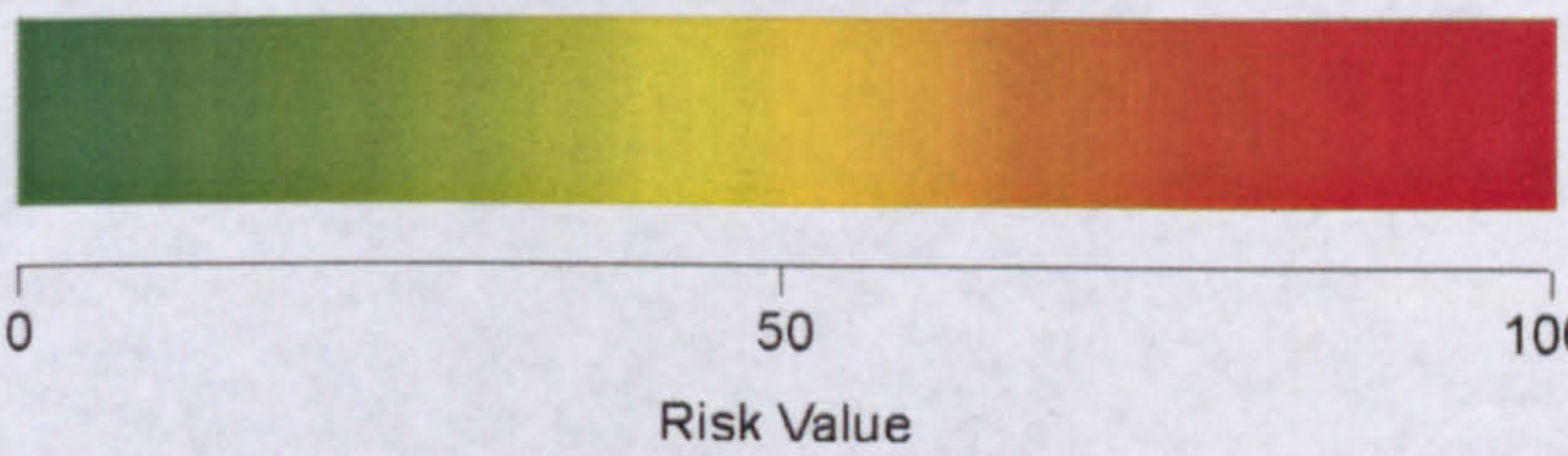

Figure 4.12 Range of colours used in risk markers

4.4 The Application

The author wrote a Windows based application that could be used to demonstrate the new risk region system. The application was originally written for Windows 3.11 but has subsequently been translated to Windows 95/98. Both versions were written in C++ using an object-oriented approach, and use Renderware as the graphics API. The interface was written using the Microsoft Foundation Classes (MFC) and has the typical Windows 'look and feel'.

The application allows the user to execute one simulated environment but provides the ability to open multiple views onto the same world (see Figure 4.13). The user is able to navigate through each 'window' onto the world independently via the mouse. No barriers were imposed on the positioning or orientation of the users view. This allows the world to be viewed from literally any position or angle, for example the user may stand 'inside' the rock of an underground mine whilst observing an activity being performed at the face. This allows considerable flexibility when observing the movement of objects and personnel in a confined space.

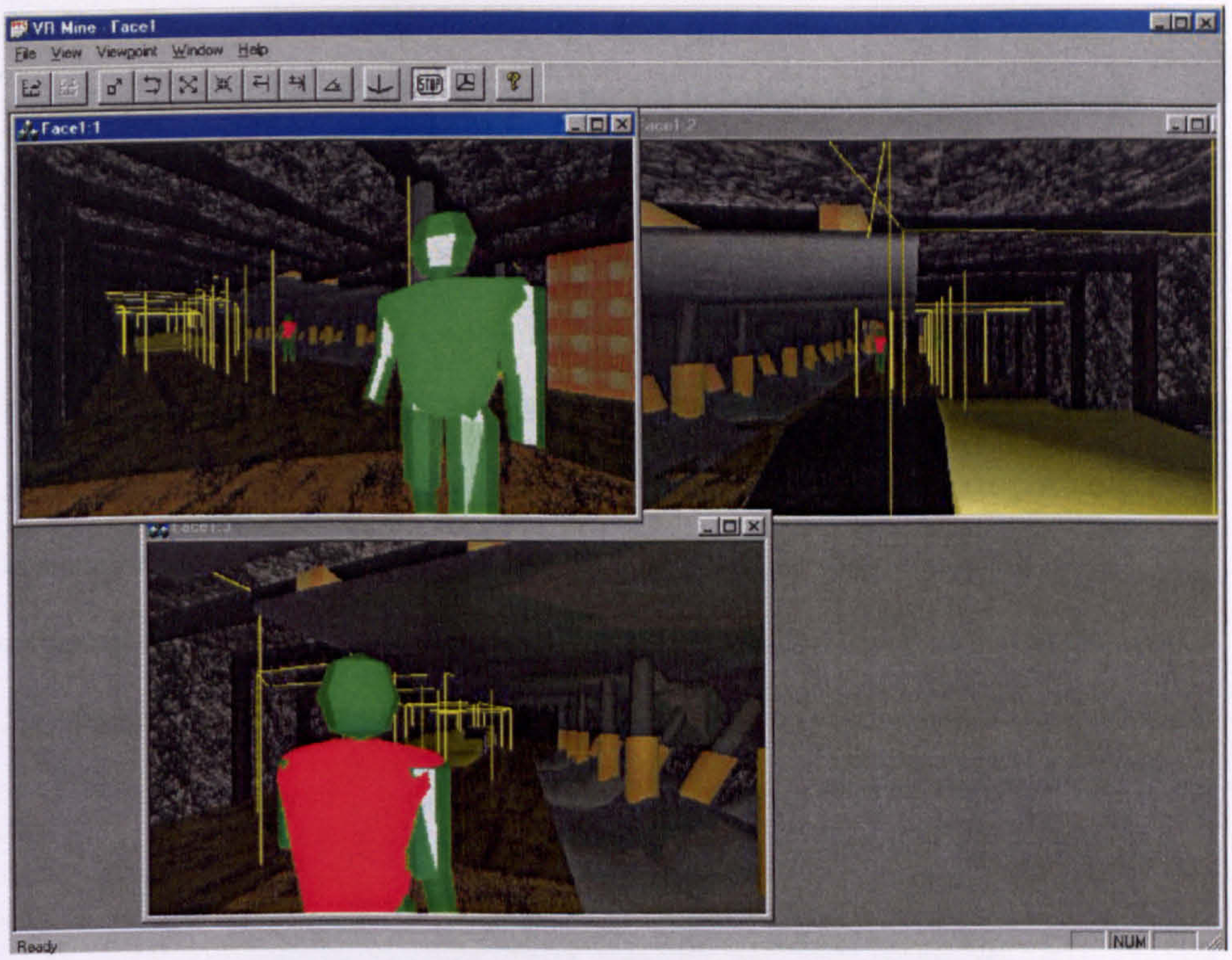

Figure 4.13 Screenshot of application showing multiple views onto the same environment (Face salvage)

4.4.1 Modelling the Environment and Equipment

The objects used to represent the equipment, personnel and the environment were built in 3D Studio MAX (Kinetix, 1999). The geometry of the objects and their appearance (colour and texture) are defined at this stage before converting the resulting files into Renderware's (Criterion, 2000) own format. Once converted the objects are loaded by the application during initialisation.

4.4.2 Controlling Objects in the Virtual World

The application must be able to change the values of attributes of the equipment during run-time. Such attributes might include an object's position, orientation or state. When modelling a real world situation on computer it is important to be able to accurately specify the position, orientation and state of each object at a given time. There are numerous strategies for achieving this within a virtual world.

One common method used in 3D modelling is to use a key-frame technique. This is ideal for the reconstruction of scenarios as it allows the modeller to specify the position, orientation and other such attributes at given points in time. Additionally it is computationally inexpensive which is an important consideration for a VR application. Key-frames must be defined programmatically during the construction of the application.

4.4.2.1 Animation and Key-frames

The movement and state of objects within the application are programmed as a function of time from the start of the application. The application maintains a global frame counter for the environment under consideration. This frame counter is assigned a value of 0 when the application is started and is typically increased each time every visible 'window' has been rendered. As such the frame counter is not strictly a measure of time, but rather a measure of progress through the animation defined by the key-frames. However if a change of one in the frame counter is taken to be a period of one second in the simulation, by computing the time taken to render each image and updating the frame counter by an appropriate amount it is possible to view an operation in real time. Further modifying the value added to the frame counter can allow an operation to be viewed in slow (or accelerated) motion, allowing a user to more fully investigate a given scenario.

Key-frames can be defined for many of the attributes of a given object or piece of equipment. The value of each attribute at a specific frame can then be determined by considering the previous and next key-frames and the type of transition. The type of transition is dependent on the nature of the attribute being considered. This is illustrated by the following examples of continuous and discrete transitions.

Position and Orientation

Consider the position of a vehicle in two dimensions. Two key-frames might be defined at frame f = 0 and at f = 10. At f = 0, the position attribute might be specified at location p = (0, 0), whilst at f = 10, position (p) might be defined as (20, 0). Assuming the vehicle is moving at a constant speed then the position varies linearly over the specified range of frames. At frame f = 5 the vehicles position can be calculated as shown in Table 4.4.

At f = 0, position is	(0, 0)
At f = 10, position is	(20, 0)
∴ each frame	(2, 0) is travelled
At f = 5, position is	(0, 0) + 5 * (2, 0)
=	(10, 0)

Table 4.4 Calculation of vehicle position using key frame technique

Since the value of the attribute is directly proportional to the distance between the previous and next frames, this is linear interpolation. The orientation of the vehicle is also interpolated linearly.

State Flags

In many instances, there is a need for a given attribute to be in a number of discrete states, in many cases there are simply two of these states ('on' and 'off'). Examples of these attributes might be indicating when a vehicle's engine is running or whether a conveyor belt is switched on or off.

The transition between these two states is instant, there is no interpolation as the attribute is either in one state or another (a discrete transition).

Slow Motion

Every time each window has been rendered, the attributes of the objects within the environment are updated based upon the value of the frame counter. Under normal conditions, the frame counter is incremented by one each time the world is updated. However, it is possible to adjust the value of this increment resulting in a change in speed (and resolution) of the animation. The use of key-frames when determining the values of the attributes allows the environment to be investigated given any frame counter value. Consider a vehicle whose position attribute varies linearly between two key-frames that are defined as follows:

$$[f = 0, p = (0, 0)]$$

$$[f = 10, p = (20, 0)]$$

It is possible to calculate the position of the vehicle given frame values that are not integers. For example at f = 1.5:

$$\frac{(20 - 0)}{(10 - 0)} \times 1.5 = 3$$

$$\frac{(0 - 0)}{(10 - 0)} \times 1.5 = 0$$

$$\therefore p_{(1.5)} = (3, 0)$$

Changing the value of the increment will alter the total number of frames in a complete animation cycle. Choosing to increment 0.5 after each render instead of 1.0 will double the number of frames in a complete cycle, assuming the time taken to render each frame remains constant this will result in a halving of the speed of operation in the virtual world.

Additionally, the resolution of the attributes of each object will be halved. Considering the position attribute using a frame increment of 0.5 the distance moved by an object is effectively half that when using a value of 1.0. It should be noted that subsequent reductions in the value of the frame increment result in corresponding reductions in the distance moved for each object. Theoretically this would allow the assessor to investigate operations on an extremely small scale.

This has important implications when investigating the positional relationships of objects in the virtual environment. The user is able to observe an operation that might take a second in the real world unfold over longer period of time in the virtual world, or perhaps consider the movement of an object on a much smaller scale than would normally be possible. It is conceivable that this might lead to a fuller understanding of the positional relationships within the environment modelled.

4.4.3 Adding risk elements

The risk elements used in assessing the risk value within the system developed comprise two components, the risk regions that surround each dangerous objects or area in the environment and the risk markers that are placed within the environment to measure the risk values. Each of these components is considered within the system as a distinct object.

4.4.3.1 Risk Regions

The risk regions were modelled in 3D Studio MAX (Kinetix, 1999) and converted into an ASCII Renderware (Criterion, 2000) format before being loaded into the virtual world. In order to satisfy the geometry requirements for the system, the order of the vertices in the generated Renderware file is important. Following a specific modelling procedure within

3D Studio will ensure that this requirement is fulfilled. This is a simple procedure, involving first creating a two-dimensional shape aligned in the XY plane, then extruding it along the Z-axis. 3D Studio provides a two-dimensional shape editor for the creation of the initial shape, this is then transferred into the three-dimensional editor where the shape is given height.

Once created and loaded into the application, the regions are 'attached' to specific objects or locations in the world. Each given object or location may have any number of associated risk region systems. Only one risk region system is used to represent the risk at any given time, this is known as the current risk region system, and will be dependent on the object's state. The current region's position and orientation reflects the position and orientation of the object to which it is attached. Additionally, the region may be scaled depending on the state of the object.

4.4.3.2 Risk Markers

Typically a solid coloured cube is used to represent each risk marker. The colour of the cube is adjusted at run-time to reflect the current calculated risk value. Risk markers can be defined before the application starts, or created during run-time. The position of the risk markers can be adjusted whilst the application is executing.

The values of each risk marker are recorded in a log-file, which can be inspected once the application has finished executing. In addition the current value of each marker can be inspected at run-time by clicking on the object in the virtual world.

4.5 Case Study 1: Longwall Face Salvage

4.5.1 Operation Overview

An example of the need for infrequent process planning is the movement of pieces of static mining machinery underground. This will often involve the use of a Free Steered Vehicle (FSV), in a confined space.

'Face salvage' is one such procedure where a number of large hydraulic supports are removed from a completely mined longwall face operation. The cost and number of each of these hydraulic supports prohibits mine operators from leaving them underground, thus they must be salvaged and used again to be cost-effective.

4.5.1.1 Face Salvage

RJB Mining (UK) provided plans and a 'Method of Work' document for a face salvage operation undertaken at Bilsthorpe colliery. Some extracts from these plans are shown in Figure 4.14 and Figure 4.15.

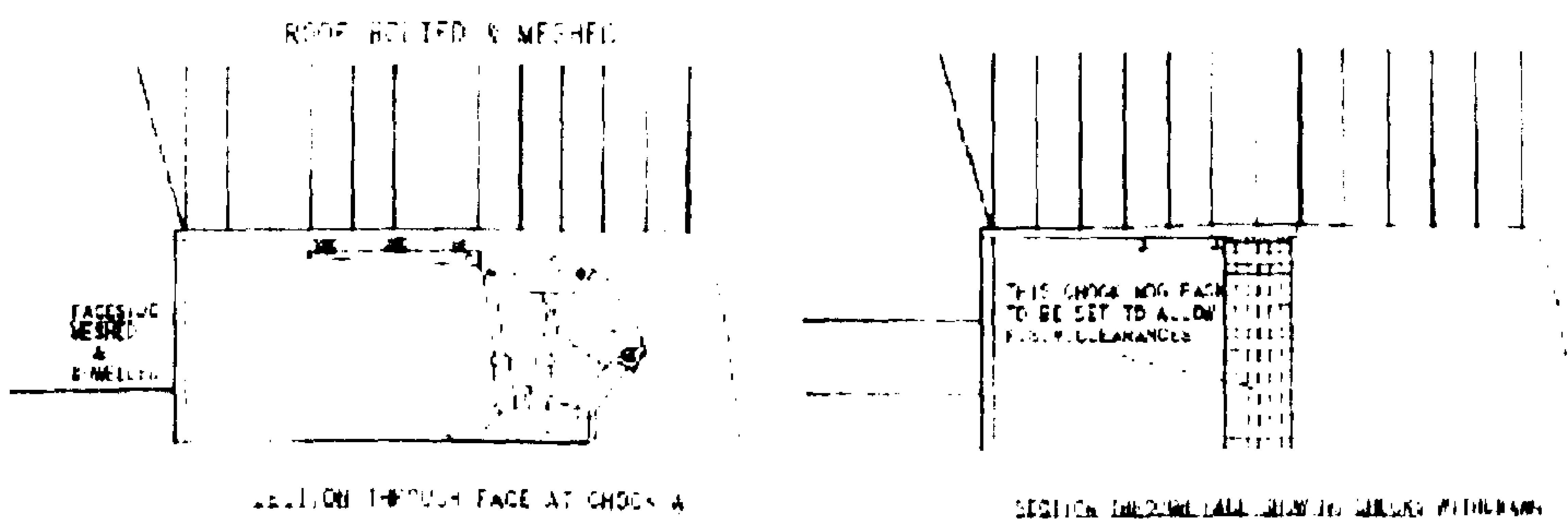

Figure 4.14 Section through face before and after hydraulic support removal

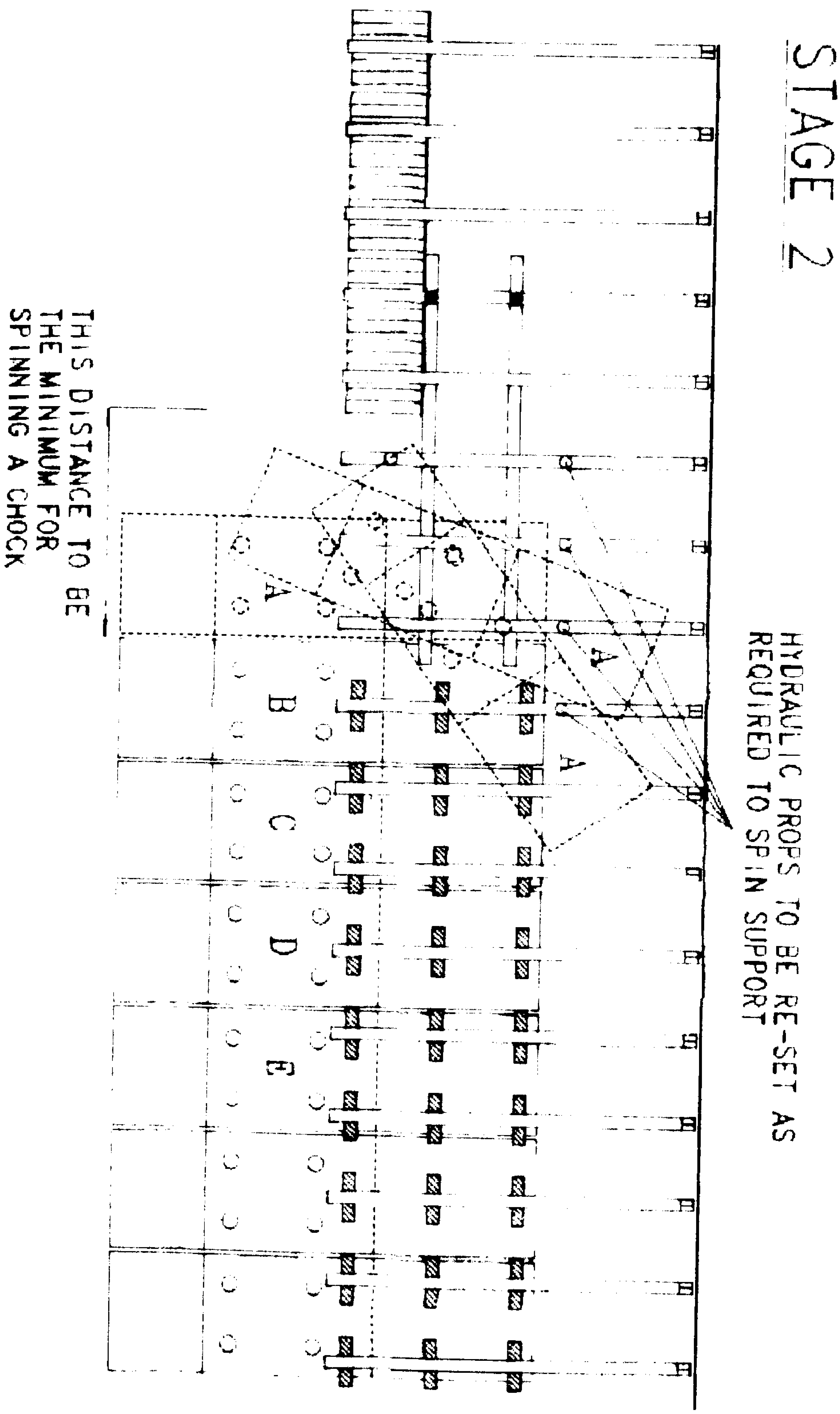

Figure 4.15 Plan view of face during one phase of hydraulic support (chock) removal

The procedure for removing a hydraulic support (46S Chock) from the face is specified by RJB Mining, and is provided in Appendix 2, this is summarised below.

1. Prepare chock for removal. Remove and secure debris, disconnect from neighbours and attach a remote control unit.
2. Lower adjacent chocks, pack between chock beam and previously set rings with chock wood, reset chock.
3. Lower off salvage chock as far as possible, slide bars forwards and secure them to the beams, these bars should be reinforced with hydraulic props as per the support plan.
4. Drive up to the chock with the FSV, and attach chains to chock pontoon and to hydraulic winch on the FSV (see Figure 4.16).

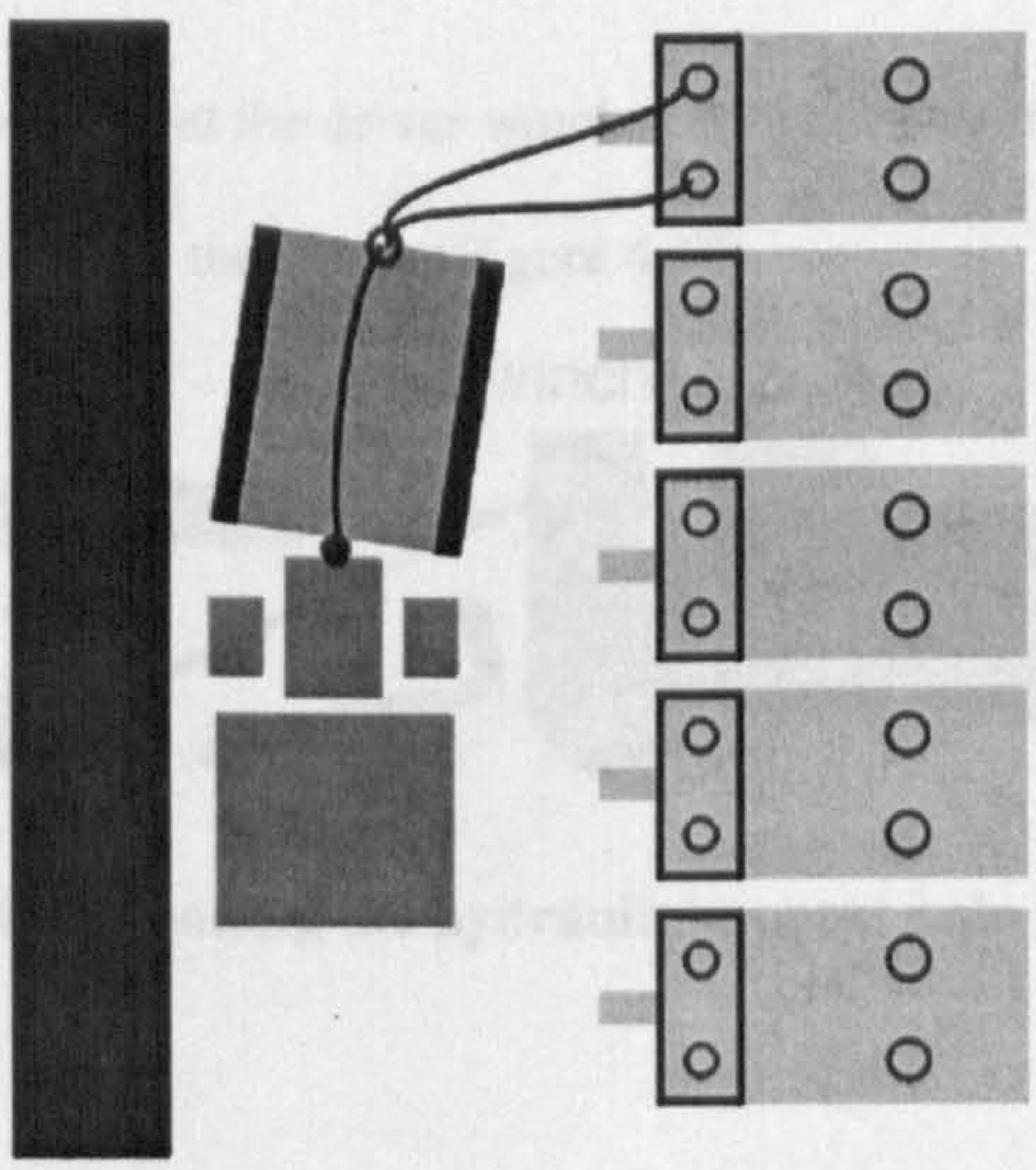

Figure 4.16 Attach chains to hydraulic support and FSV

5. Lower and spin the chock by pulling the base around the base of its neighbour. Whenever the chock is being moved the exclusion zone must be cleared. If difficulty is experienced in spinning the chock out of line install a pulling bolt. Using the chock ram, ease the chock forward and release the ram (see Figure 4.17), then repeat the procedure for spinning.

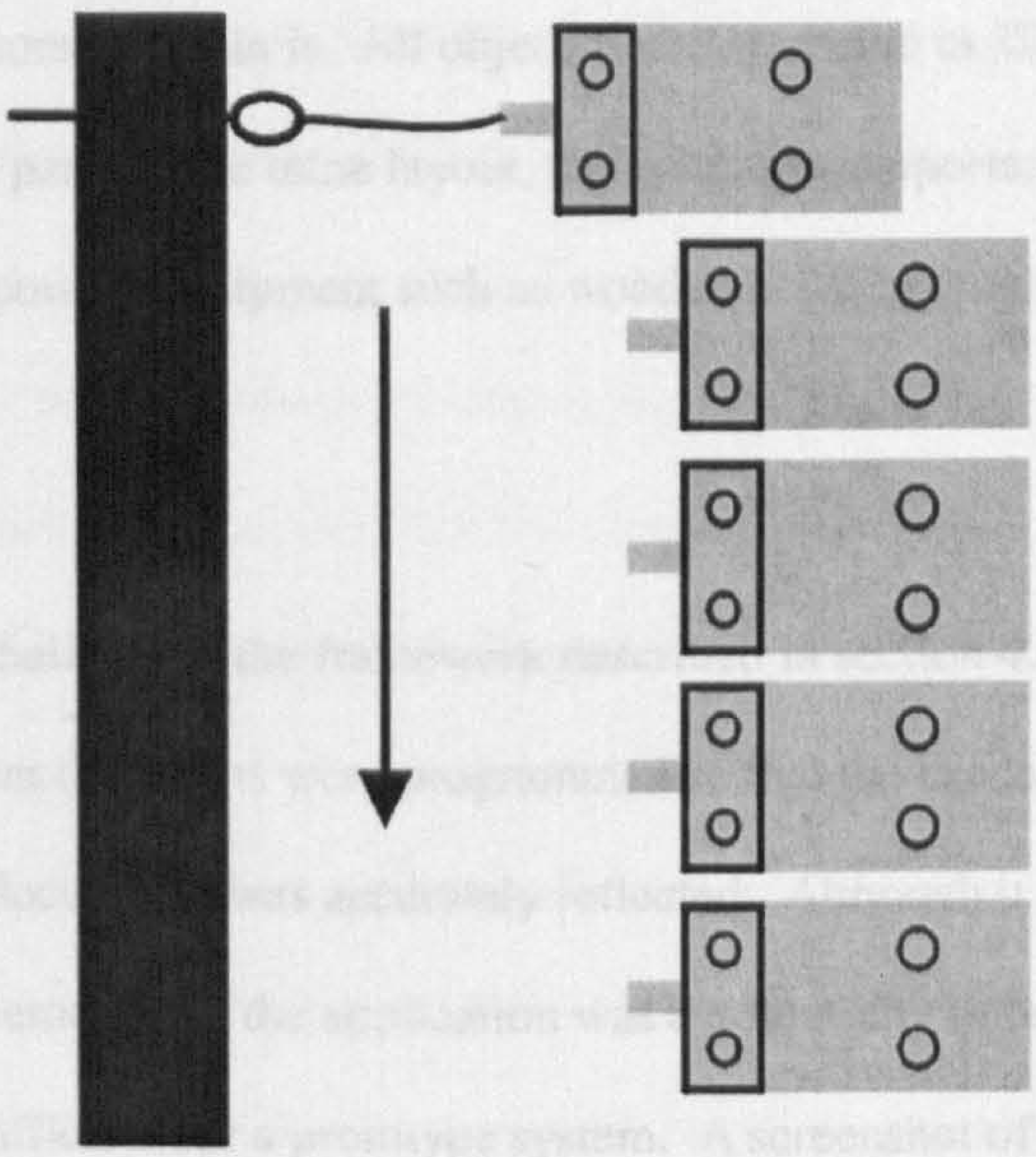

Figure 4.17 Install a pulling bolt to ease the chock forward

6. The operators withdraw and the driver winches the chock up the flatbed. The chock will be held in position by the winch (Figure 4.18).

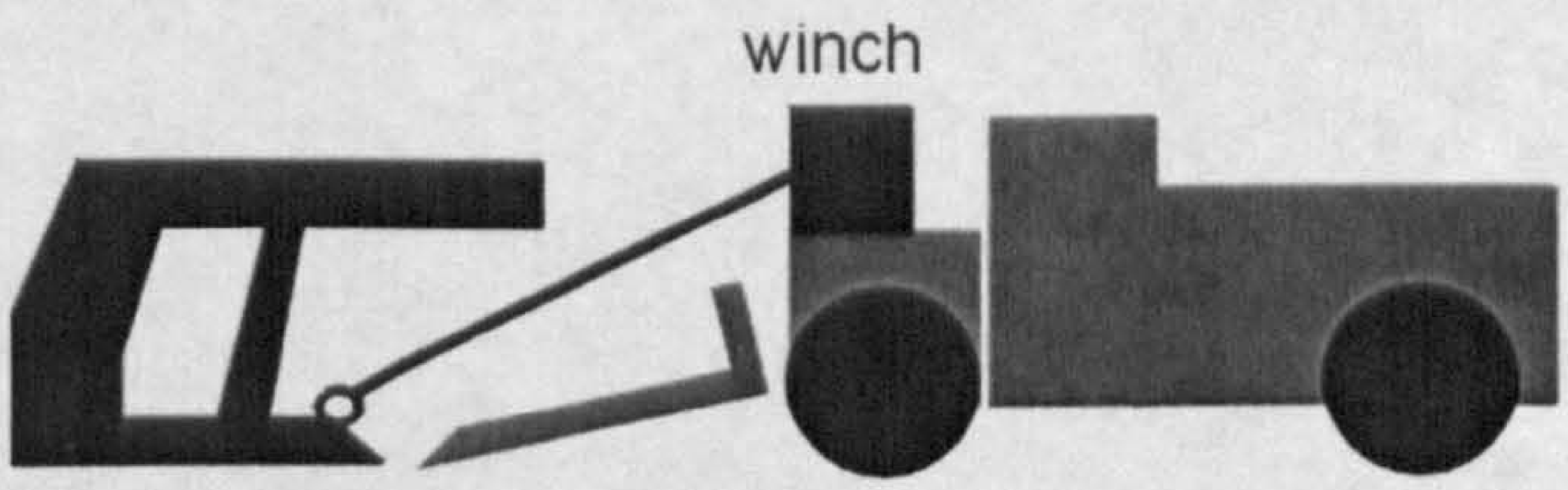

Figure 4.18 Loading the hydraulic support onto the FSV

7. The FSV route is cleared and the chock transported out of the area.
8. A line of girders is established with solid wooden nogs under each joint down the centre of the face line, extending each time enough room is available.

4.5.2 Modelling the Environment

The environment was constructed according to the method of work documents provided by RJB mining. These describe the type, and movement of equipment, the dimensions of the mine and the personnel within it. All objects were modelled in 3D Studio, these included the relevant parts of the mine layout, the hydraulic supports, an FSV, personnel and various roof supporting equipment such as wooden nogs, hydraulic props and metal girders.

The application was built using the framework described in section 4.4. Key-frames defining the movement of objects were programmed so that the procedure described by the method of work documents was accurately reflected. Although it was recognised that hard coding this movement into the application was a potentially inflexible solution, it was felt that it was sufficient for a prototype system. A screenshot of the virtual world is shown in Figure 4.19.

Figure 4.19 Screenshot from longwall face salvage risk visualisation, view of face (no risk regions)

4.5.3 Risk Modelling

One of the advantages of performing a visual risk assessment is the identification of dangerous factors arising from spatial conflicts. That is, identifying areas that could cause problems as a result of the layout, movement and/or the state of equipment. Attention was focused on the FSV, the hydraulic supports and the personnel in the environment as these were considered the key objects. Although it is recognised that there are other factors that might influence the risk assessment such as the stability of the roof and the nature of the geology in the area, these were not included at this stage.

Modelling the risk regions involves deciding where to place regions, what they should be attached to, what size and shape they should be, and what values to attach to them. These decisions should be made by a risk assessor and be based on their experience and judgement. One possible interpretation of the risk assessment for this particular task is outlined below.

Risk regions were attached to the FSV and to each of the hydraulic supports in the world. Risk markers were attached to the torso of each person in the environment so that the risk to which they had been exposed could be evaluated.

4.5.3.1 Free Steered Vehicle

The removal of a hydraulic support requires the operation of an FSV in a number of states. Four states were identified:

1. Stationary (FSV is stationary, not loaded).
2. Approach to load area (FSV is in motion, not loaded).
3. Loading hydraulic support (FSV is stationary, loading).
4. Exiting loading area (FSV is in motion, loaded).

For each of these states it is conceivable that the risk regions surrounding the vehicle might differ in size and/or shape, the values associated with each of the regions might also change. To accommodate these changes two sets of dual risk regions were used to represent the risk for an FSV, one set for the front and one set for the rear of the vehicle.

Two different shapes of risk region were used to represent each of the states. These are shown in Figure 4.20.

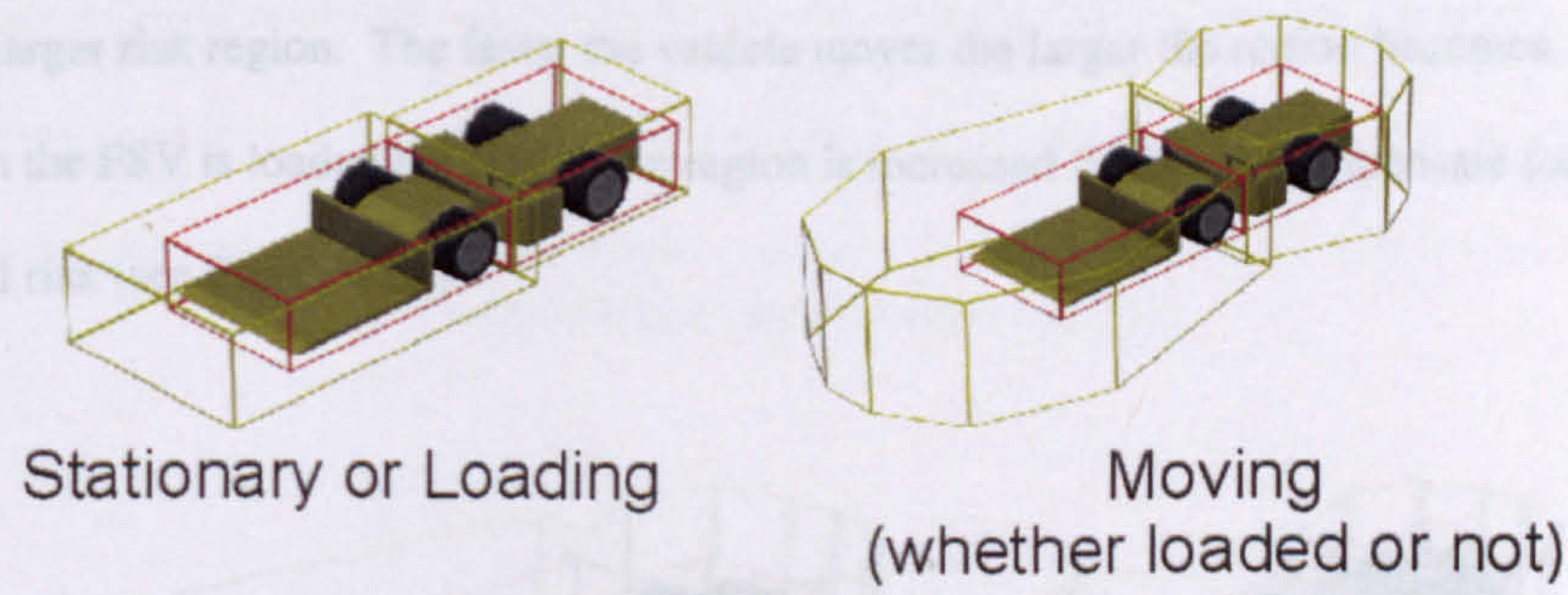

Figure 4.20 Variation in risk region shape for different FSV states

When the FSV is stationary or loading, the risk regions are represented by cuboids. However, it could be reasonable to expect that during the loading operation there is some increased risk. Both an increase in the risk value associated with the front inner region (see Table 4.5) and an increase in the size of the front risk region (see Figure 4.21) represent this extra risk when loading. The risk regions remain constant in size during loading, and during the time the vehicle is stationary.

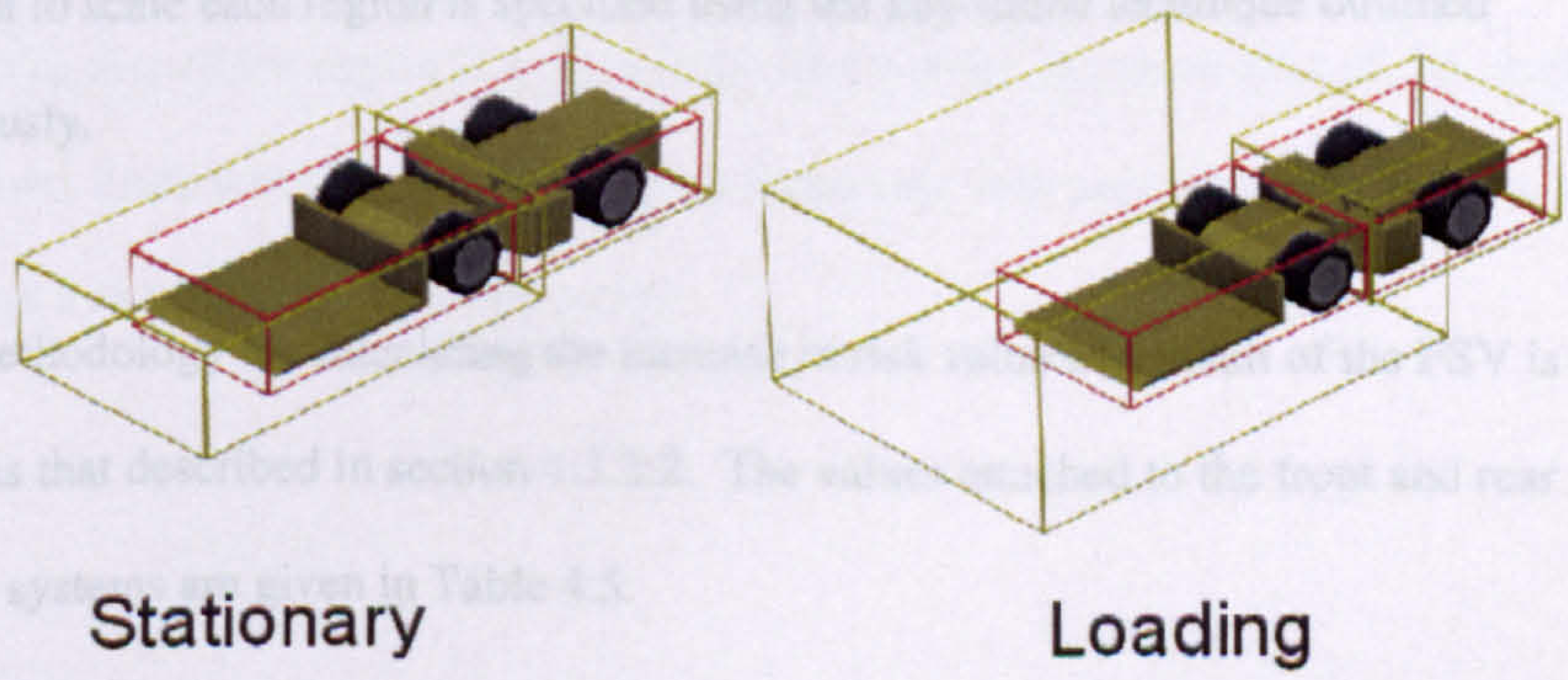

Figure 4.21 Risk regions around stationary and loading FSV

When the FSV is moving it is conceivable that the risk associated with the vehicle will increase as the speed of the vehicle increases. It is also likely that the risk associated with a moving and loaded FSV is significantly larger than with an FSV moving at the same speed but not loaded. The increased risk is due in part to the driver of the loaded vehicle experiencing reduced visibility and also an increased stopping distance.

This increase in risk with a moving and/or loaded FSV is represented within the system by a larger risk region. The faster the vehicle moves the larger the region becomes. When the FSV is loaded the size of the region is increased further to compensate for the added risk (see Figure 4.22).

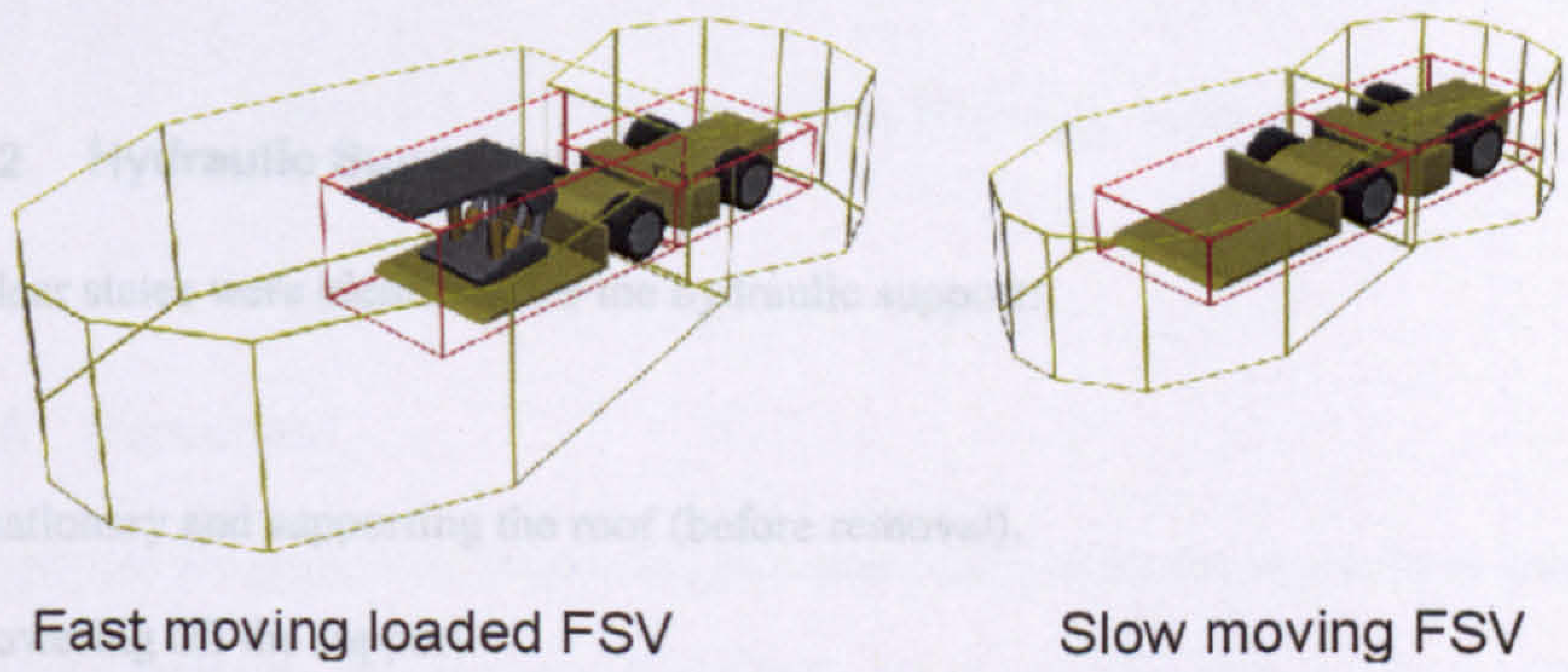

Figure 4.22 Risk regions for a moving FSV

Changes in risk region size are accomplished by scaling in the X, Y or Z-axis. The amount to scale each region is specified using the key-frame technique outlined previously.

The methodology for calculating the increase in risk value as a result of the FSV is the same as that described in section 4.3.2.2. The values attached to the front and rear risk region systems are given in Table 4.5.

FSV State	Front Region System		Rear Region System	
	Inner (constant)	Outer (variance)	Inner (constant)	Outer (variance)
Stationary	60	0-40	60	0-40
Loading	90	0-70	90	0-70
Moving	100	0-100	100	0-100

Table 4.5 Risk region values for FSV

4.5.3.2 Hydraulic Supports

Five clear states were identified for the hydraulic support:

1. Stationary and supporting the roof (before removal).
2. Lowering off the support.
3. Moving the support out from the face.
4. Loading the support onto the FSV.
5. Stationary, support is loaded on the FSV.

A single constant risk region represents each of these five states, this is shown in Figure 4.23. The size of the region is increased to represent the increased area of risk during states two, three and four. The risk region associated with each hydraulic support was assigned a risk value of 30 for all states.

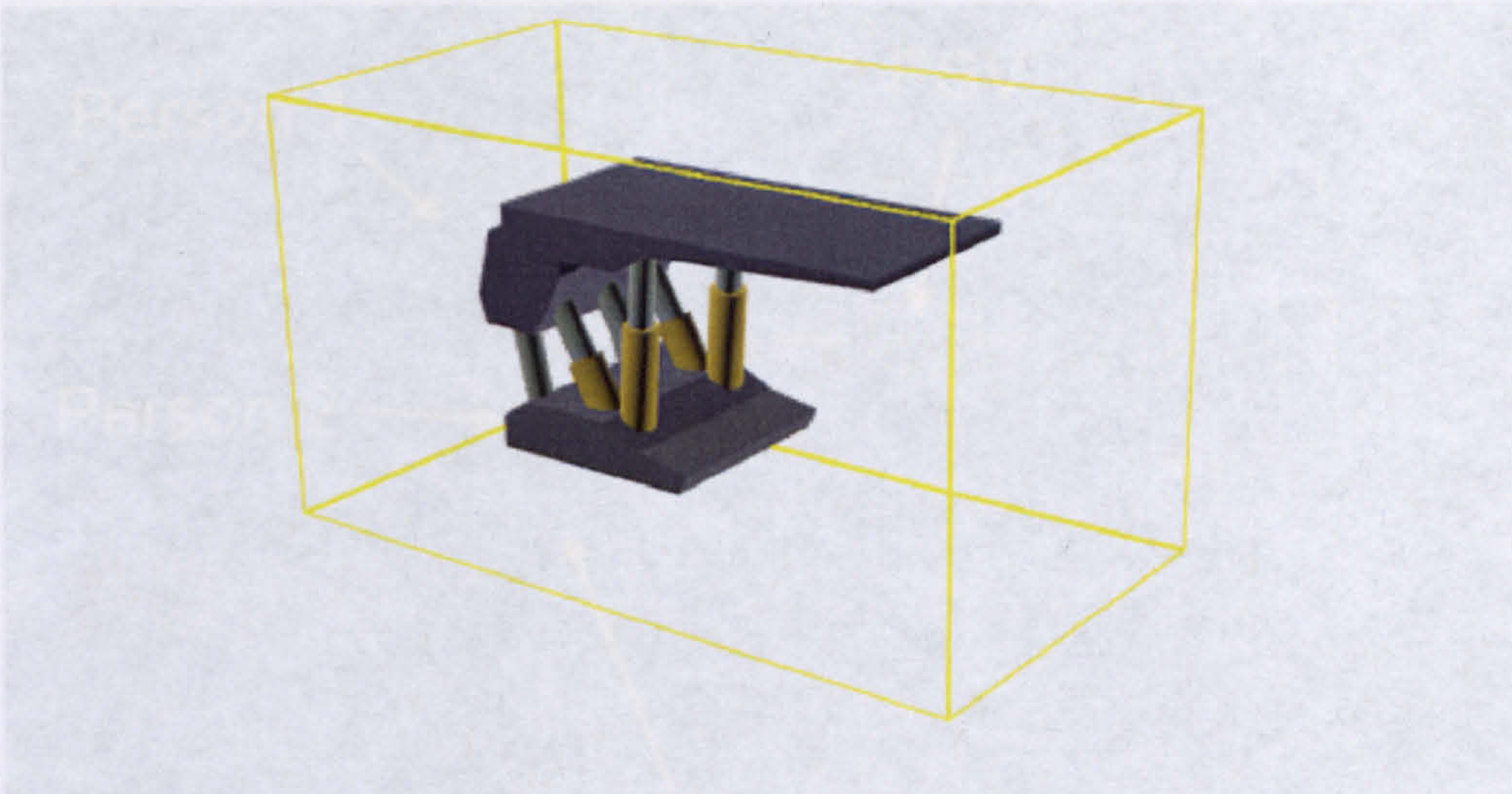

Figure 4.23 Risk region for a hydraulic support

4.5.3.3 Personnel

The personnel are required to remain in close attendance whilst the operation is being performed, this makes the operation particularly dangerous. Attaching markers to the personnel in the environment allows the risk experienced by each person to be monitored as they move.

4.5.4 Results

Within the application the main objects under consideration were labelled as in Figure 4.24.

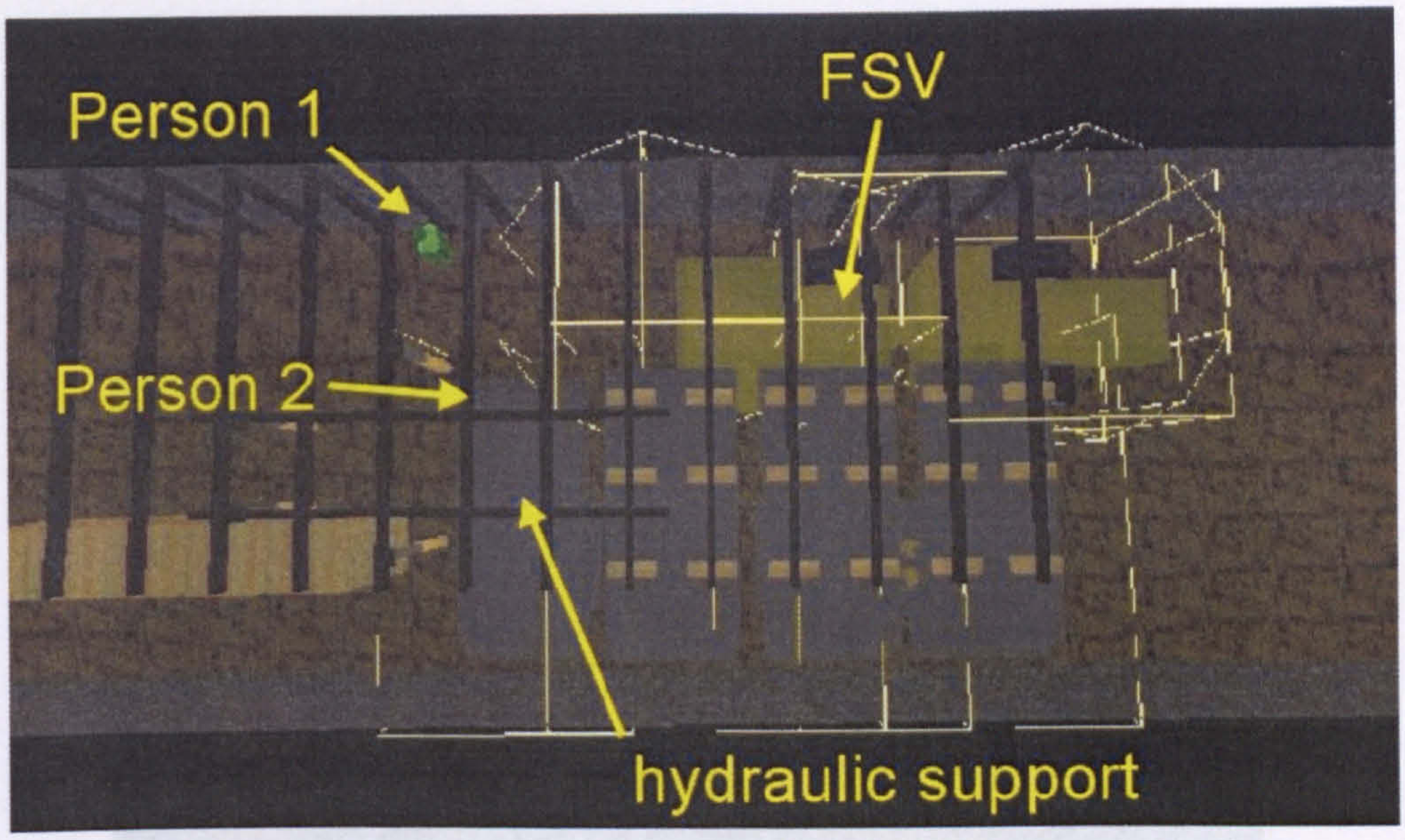

Figure 4.24 Main objects under consideration

The risk values from the markers attached to each person within the environment are shown in Table 4.1. The values here represent those after three hydraulic supports have been removed.

Risk Marker	Minimum Risk Value	Maximum Risk Value	Mean Risk Value
Person 1	0	56	34
Person 2	0	77	45

Table 4.6 Risk marker values from longwall face simulation

These values are the quantifiable output from the system. They indicate that the risk marker attached to second person experiences higher levels of risk than the marker attached to the first.

Navigating through the virtual environment a close-up inspection of the risk regions, markers and equipment interactions can be performed (see Figure 4.25). Evidence from this walkthrough of the environment supports the initial conclusions drawn from the values of the risk markers. Additionally, the relatively high proportion of activity around Person 2 could be cause for concern, particularly as the movement of heavy equipment is not focused in one particular direction, but in front of, to the side, and behind him/her.

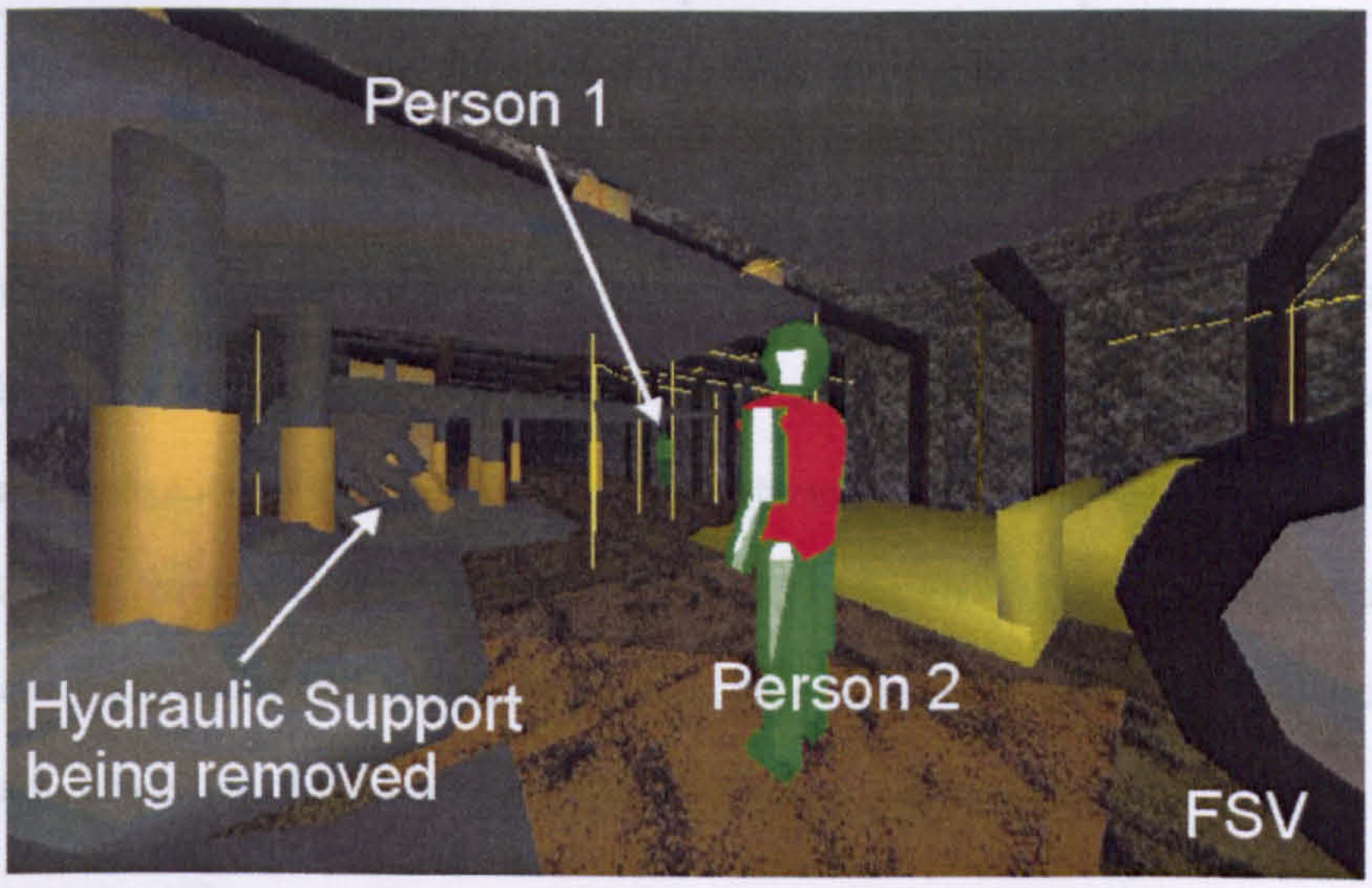

Figure 4.25 Investigating the virtual world

Further results can be obtained from the system by considering the whole operation in two distinct parts. The first part considered is the removal and positioning of the hydraulic support, the second is loading the support onto the FSV. The risk values from the system for these two separate operations are shown in Table 4.7 and Table 4.8.

Risk Marker	Minimum Risk Value	Maximum Risk Value	Mean Risk Value
Person 1	0	45	26
Person 2	0	55	34

Table 4.7 Risk marker values from hydraulic support removal

Risk Marker	Minimum Risk Value	Maximum Risk Value	Mean Risk Value
Person 1	0	56	44
Person 2	0	77	52

Table 4.8 Risk marker values for loading the support onto the FSV

Examination of the values for these two distinct operations helps to identify the most hazardous aspects of the operation, in this whilst loading the support onto the vehicle. Further investigation of the environment reveals the main reason for this being that the personnel are required to operate in close proximity to the FSV. The separation of the entire operation into two distinct tasks helps to identify the most hazardous aspects of the work task, this is one of the key reasons for performing a risk assessment

The correlation between the overall expected and overall measured risk values indicated promise in the new methodology for calculating risk values.

4.6 Case Study 2: Surface Mining

A surface mine operation was modelled and evaluated using the same risk algorithms used in Case Study 1. Although the types of hazards in this environment are different from a face salvage operation, the purpose of performing the study is the same. Many spatial conflicts can arise in a surface mine, this is partly the result of large machinery (haul trucks, excavators) moving in a confined space (load/dump area, junctions, blind spots in the road). Additionally smaller machinery such as Land Rovers or surveying personnel might be required to operate in the same environment. One reason for performing this case study was to identify potential danger areas in the surface mine. Attention was focused on the movement of equipment through the mine, particularly the progress of haul trucks to and from the load point.

The scale of the operation modelled is much larger than the previous case study, equipment moves over kilometres rather than metres. The environment is not as confined as an underground mine, though equipment is still required to operate within certain spatial limits.

4.6.1 Operation Overview

The operation of a surface mine has been described in section 3.2.

4.6.2 Modelling the Surface Mine

A surface mine environment was designed, this included a haul road and the specification of a load point. This was subsequently constructed in 3D Studio, resulting in the environment shown in Figure 4.26.

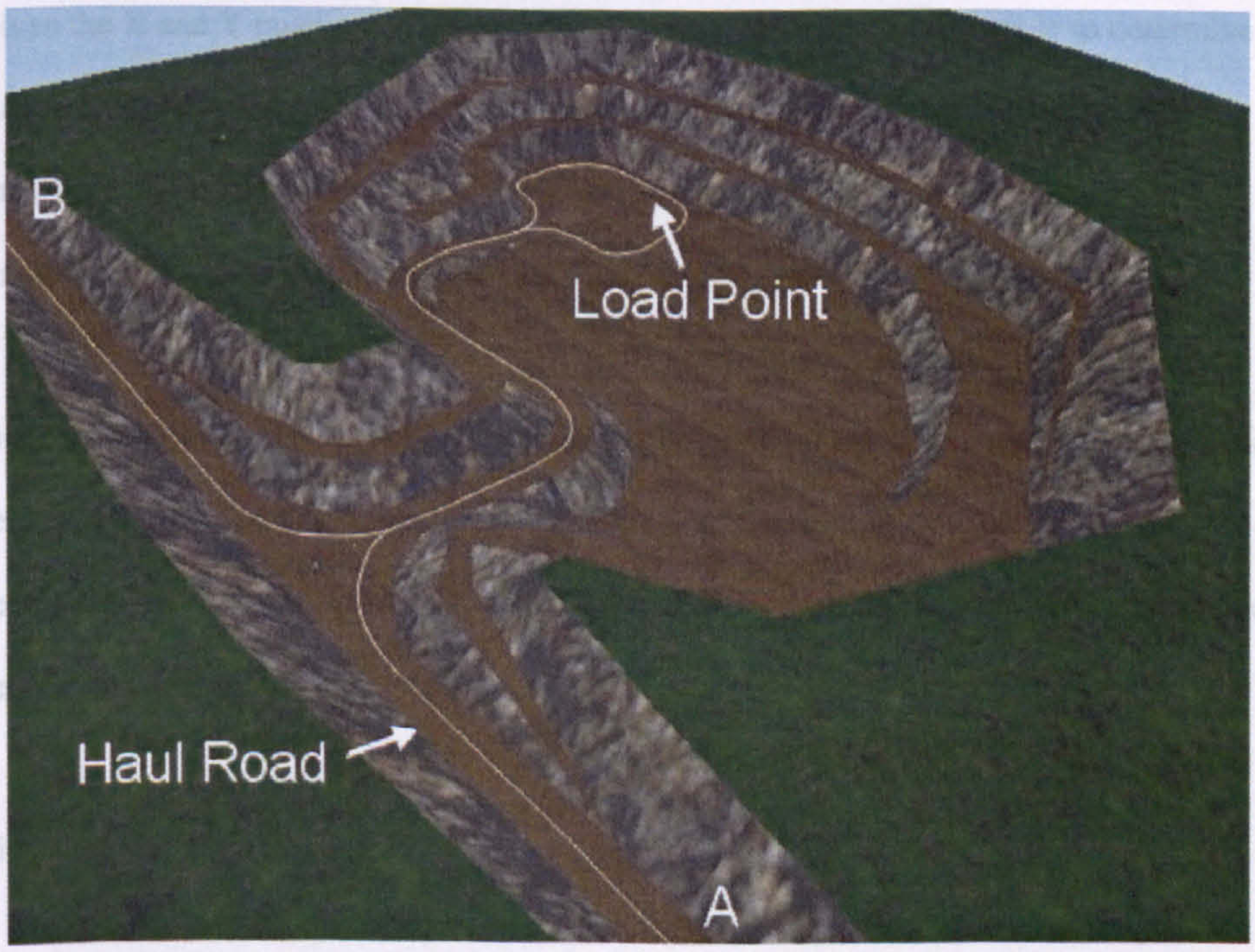

Figure 4.26 Surface mine environment

Six haul trucks and an excavator were included in the environment. The haul trucks start at different points on the haul road and proceed to the load point. Once at the load point they wait for a specified period, whilst being loaded by the excavator. After being loaded, they exit the mine to the dump point via B in Figure 4.26.

4.6.2.1 Haul Truck Movement

Key-frames were used to define the movement of haul trucks. Key-frame information must be provided for both position and orientation to obtain realistic movement. A haul-truck starting at point A in Figure 4.26 and proceeding via the load point to point B requires approximately 60 key-frames to maintain realistic movement. The calculation of the position and orientation for each of these key-frames is a time consuming task. A more general method was developed that reduced the number of parameters that need to be specified for each key-frame.

Given the X and Y position of the key-frame over a landform, it is possible to determine the Z co-ordinate (height) of the landform. Additionally, if the direction of travel is known, it is also possible to determine the objects respective orientation over the landform in terms of yaw, pitch and roll.

Since the direction of travel can be determined based upon the position of the current and next key-frames the only information needed is the XY position over the landform. The height above the landform, the direction of travel and the orientation of the vehicle can all be calculated from this information.

This procedure can be considered in three steps.

1. Define the XY positions (these must be over the landform).

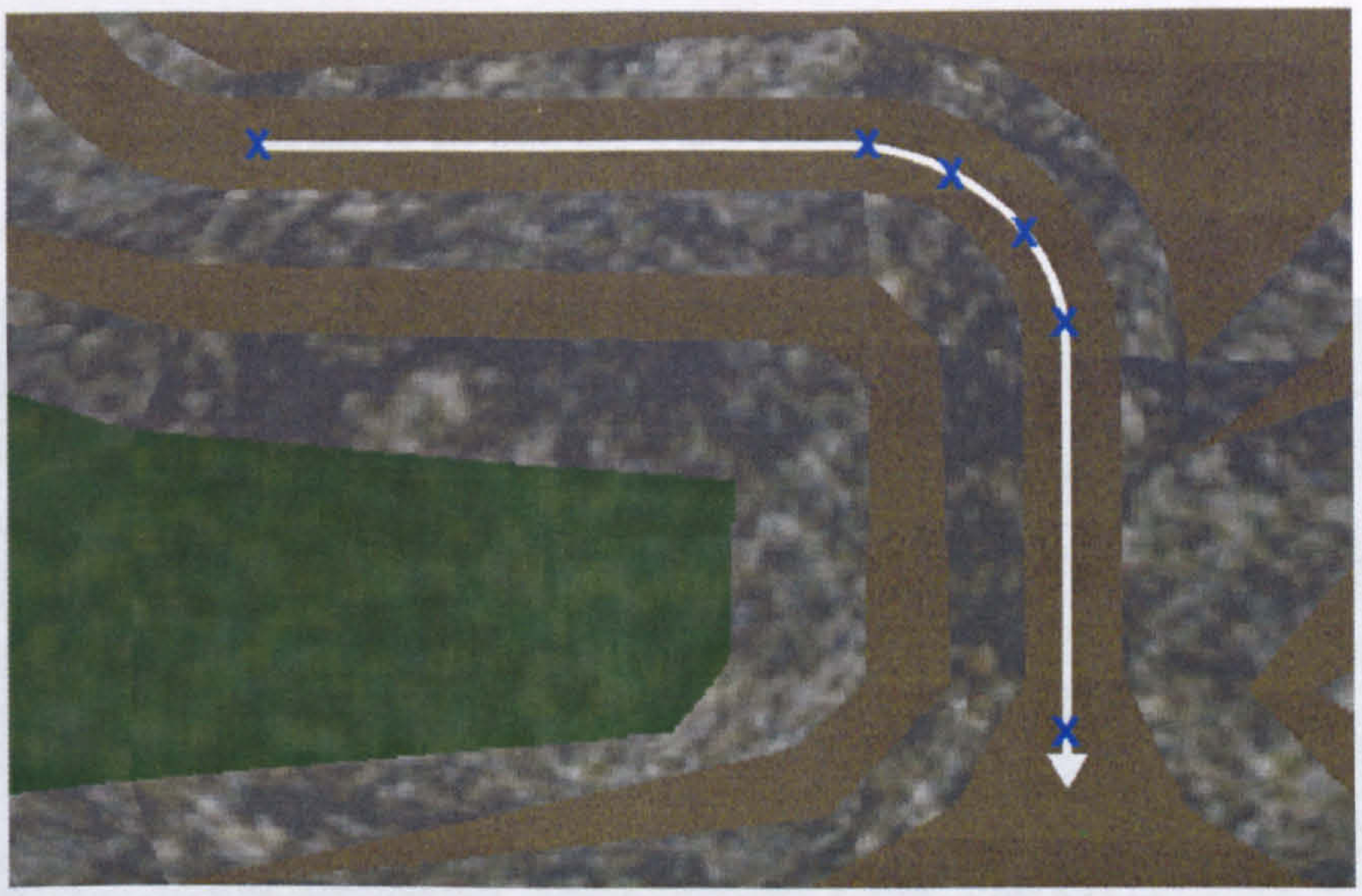

Figure 4.27 XY positions are defined for each of the key-frames (shown as blue crosses)

2. Project each XY position to the height of the terrain, this effectively calculates the Z co-ordinate given the X and Y co-ordinates. The height of the terrain can be found by identifying the relevant face on the terrain then calculating the intersection between that face and the line defined by the XY co-ordinates projected vertically downwards (or upwards).

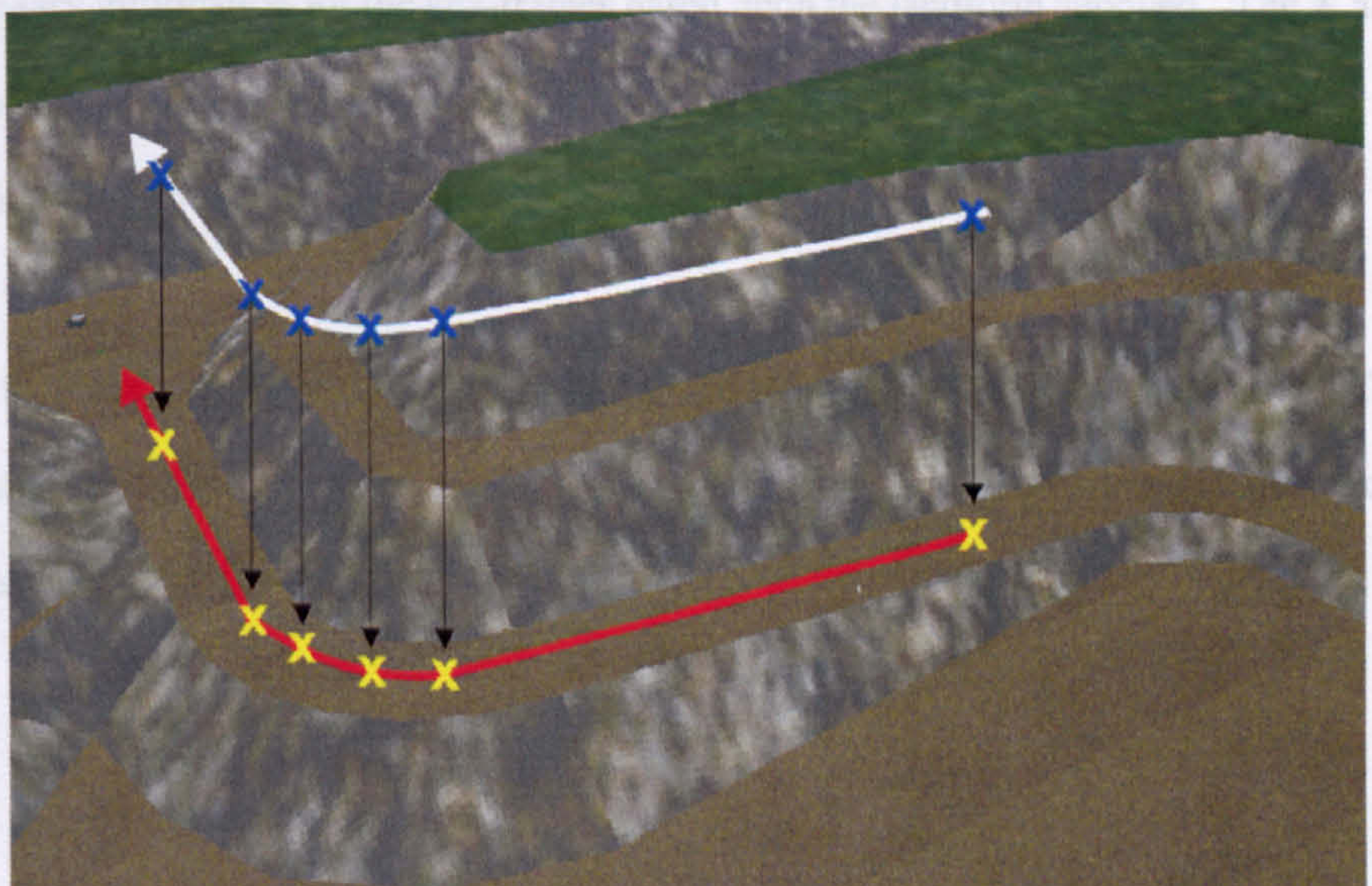

Figure 4.28 XY position is projected to the height of the terrain (shown as yellow crosses)

3. Calculate the direction to the next key-frame position and the orientation of the vehicle based upon the orientation of the terrain.

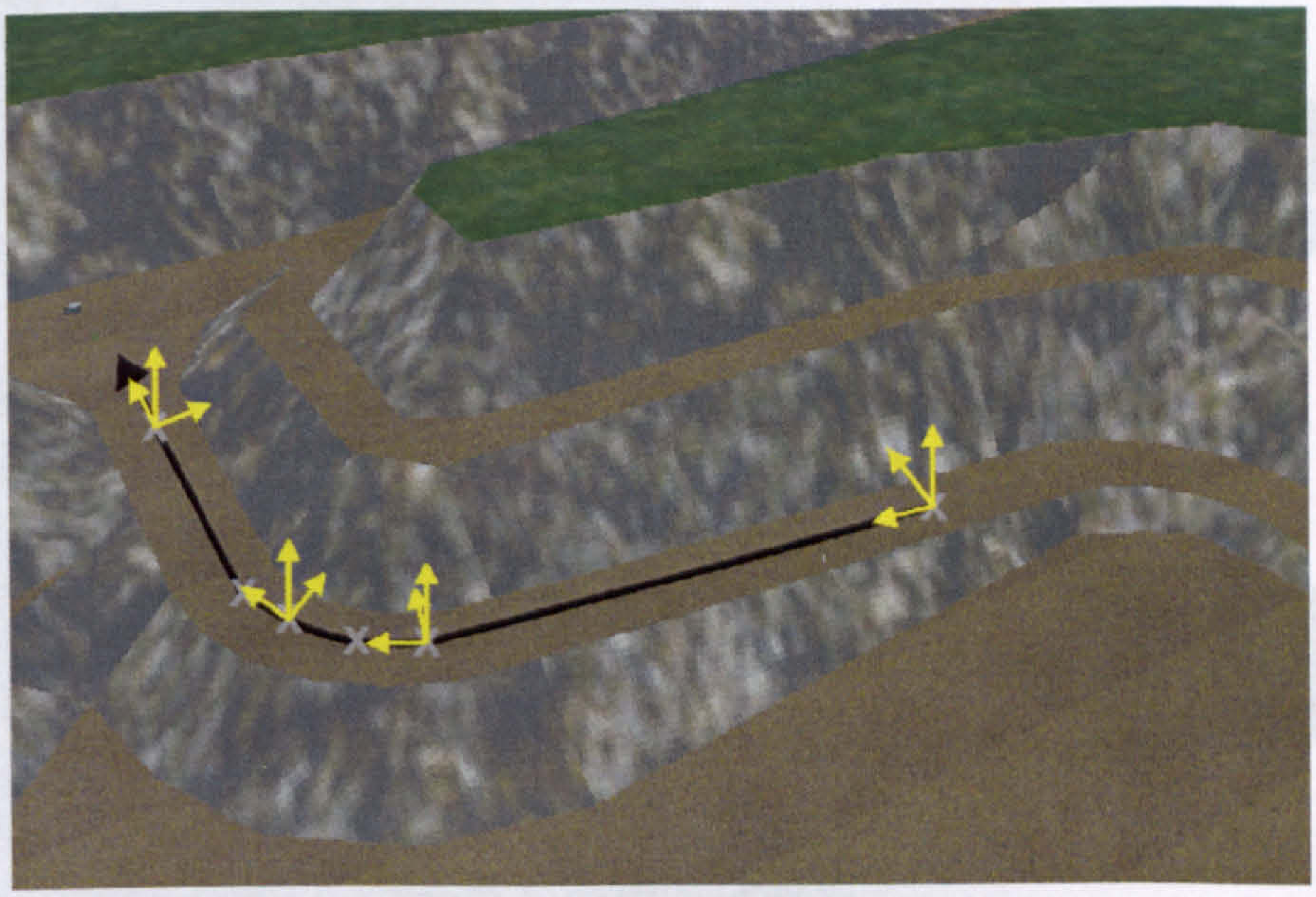

Figure 4.29 Orientation of the vehicle is calculated at each key-frame (the principal axes are shown in yellow for selected key-frames)

The application written reads a series of X and Y co-ordinates, and computes all other necessary information for the key-frames based upon the landform supplied. The X and Y co-ordinates are specified as a list of points in an ASCII file that is passed to the application during initialisation.

The key-frame information is calculated during the initialisation of the application. This helps to reduce the computational load during normal execution of the application and hence increase the frame rate.

4.6.2.2 Excavator Movement

Although the excavator remains at the same location throughout the duration of the simulation, it is required to load stationary haul trucks. This requires a complex movement of its body and hydraulic load arms, see Figure 4.30.

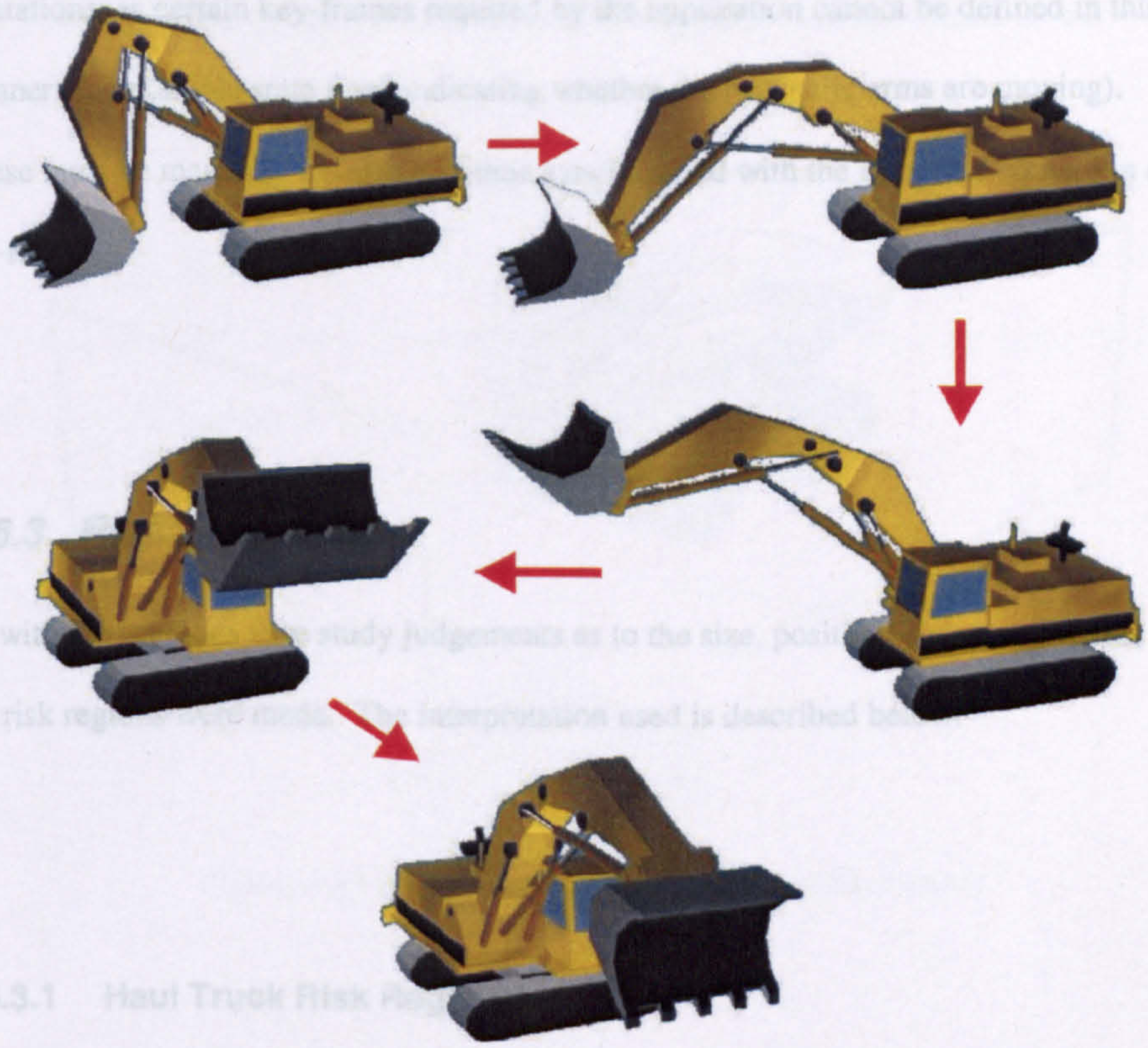

Figure 4.30 Excavator Movement

As with other graphical objects, the excavator was modelled within the 3D Studio package. However, rather than construct the animation data manually, it was added to the model from within 3D Studio. This animation data was converted into the Renderware format before being loaded into the application at run-time.

Defining the animation within the 3D Studio package allows a high degree of detail to be modelled. The excavator consists of over 20 sub-objects (windows, hydraulic arms, tyre-treads etc.), and the animation has approximately 420 key-frames to describe one complete load cycle for the excavator. This includes keys controlling position, rotation and scaling.

The method adopted for the excavator removes the need for the manual calculation of these key-frames and allows the animation to be interactively modelled from within the 3D Studio package. Although this allows more detailed movement, this method has limitations, as certain key-frames required by the application cannot be defined in this manner (for example state flags indicating whether the hydraulic arms are moving). These must be manually defined and then synchronised with the imported animation at run-time.

4.6.3 Risk Modelling

As with the previous case study judgements as to the size, position, shape and values for the risk regions were made. The interpretation used is described below.

4.6.3.1 Haul Truck Risk Region

The following states of operation for a haul truck within the surface mine environment modelled were identified:

1. Approach to load area (haul truck is moving, but not loaded).
2. Loading the haul truck (haul truck is stationary, and loading).
3. Leaving the load area (haul truck is moving, and loaded).

Although it might be conceivable that the shape of risk regions might be different between three states identified, the same shape of risk region was used for all. Since the operation is on a much larger scale and particular consideration is being given to the movement of haulage trucks through the mine, it was not considered necessary to model the regions shape to a high degree of detail. The low number of faces for each risk region system also helps to reduce the computation power required and consequently increase the frame rate. However, the size of the region was altered considerably between the three states. It would seem reasonable that the size of the region for a moving haul truck will be larger than that of a loading haul truck, and that once loaded the region will be larger still. An example of the risk region system used for haul truck is shown in Figure 4.31 (the values and size of the risk regions will depend on the haul truck's state).

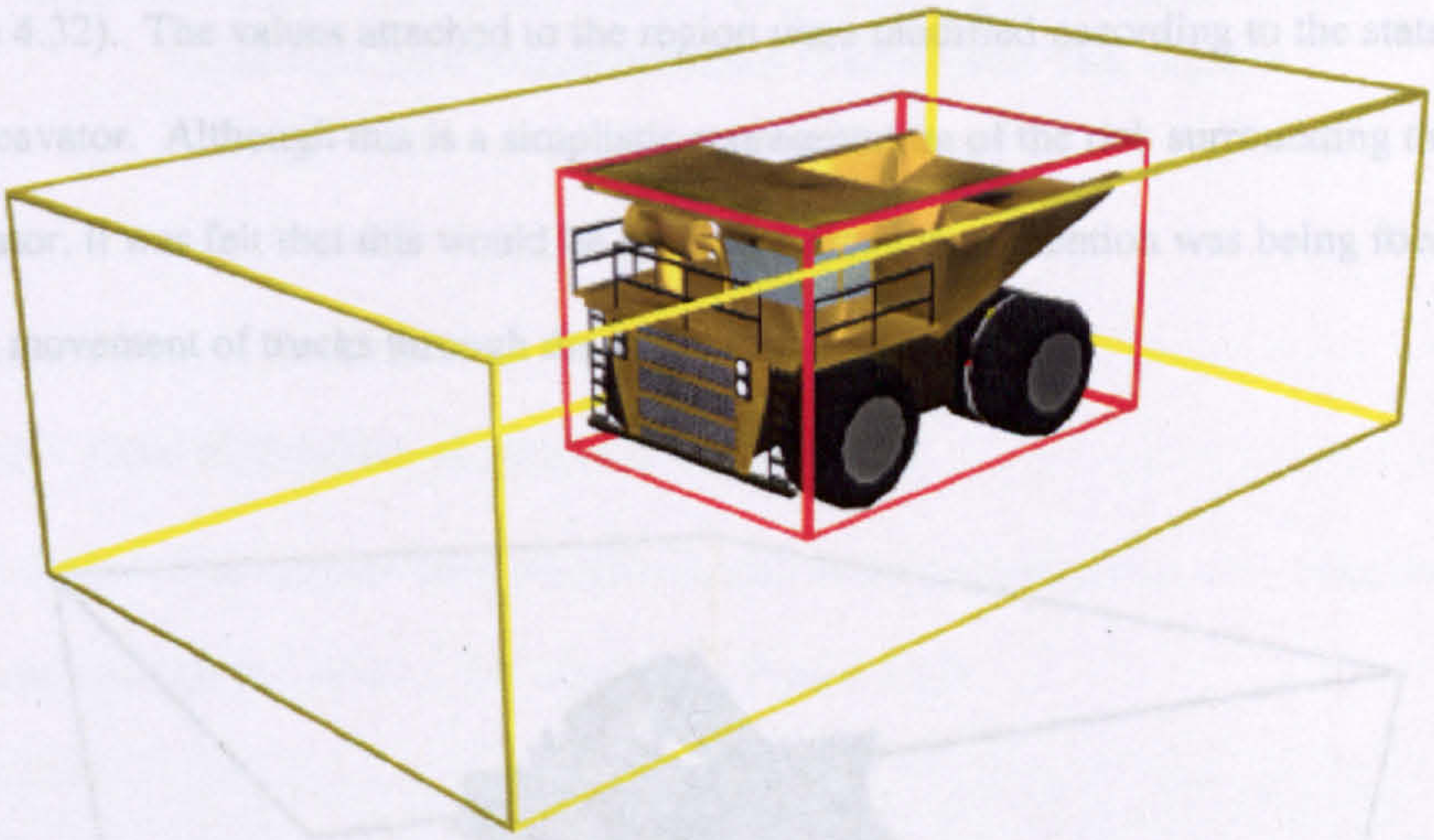

Figure 4.31 Risk region system used for a haul truck

The values attached to the inner and outer regions for each of the three states is shown in Table 4.9.

Haul Truck State	Inner Region Constant Value	Outer Region Variance
Moving (not loaded)	100	0-80
Loading (stationary)	100	0-100
Moving (loaded)	100	0-80

Table 4.9 Risk values attached to haul truck risk regions

4.6.3.2 Excavator Risk Region

Two states were modelled for the excavator:

1. Stationary (no movement of hydraulic arms).
2. Stationary (moving hydraulic arms).

A single constant risk region was used to represent the excavator in both states (shown in Figure 4.32). The values attached to the region were modified according to the state of the excavator. Although this is a simplistic representation of the risk surrounding the excavator, it was felt that this would be sufficient given that attention was being focused on the movement of trucks through the mine.

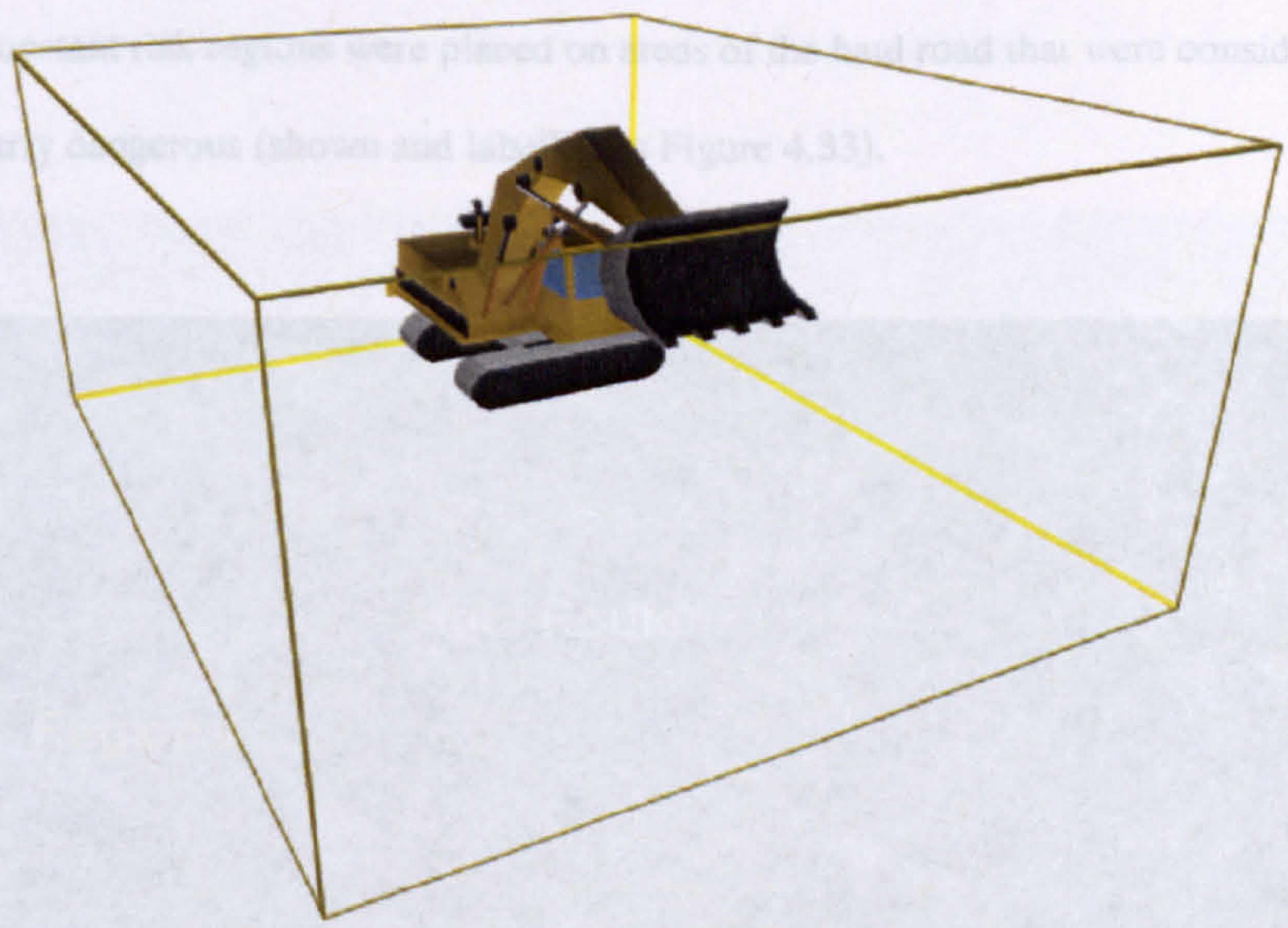

Figure 4.32 Risk region system for an excavator

If the loading of a haul truck by an excavator was the main operation under consideration the risk regions surrounding both the truck and the excavator could be modelled in substantially more detail.

The values attached to the region are shown in Table 4.10.

Excavator State	Constant Region Value
Stationary (no movement of hydraulic arms)	50
Stationary (movement of hydraulic arms)	80

Table 4.10 Risk values attached to excavator risk regions

4.6.3.3 Haul Road Risk Regions

Single constant risk regions were placed on areas of the haul road that were considered as particularly dangerous (shown and labelled in Figure 4.33).

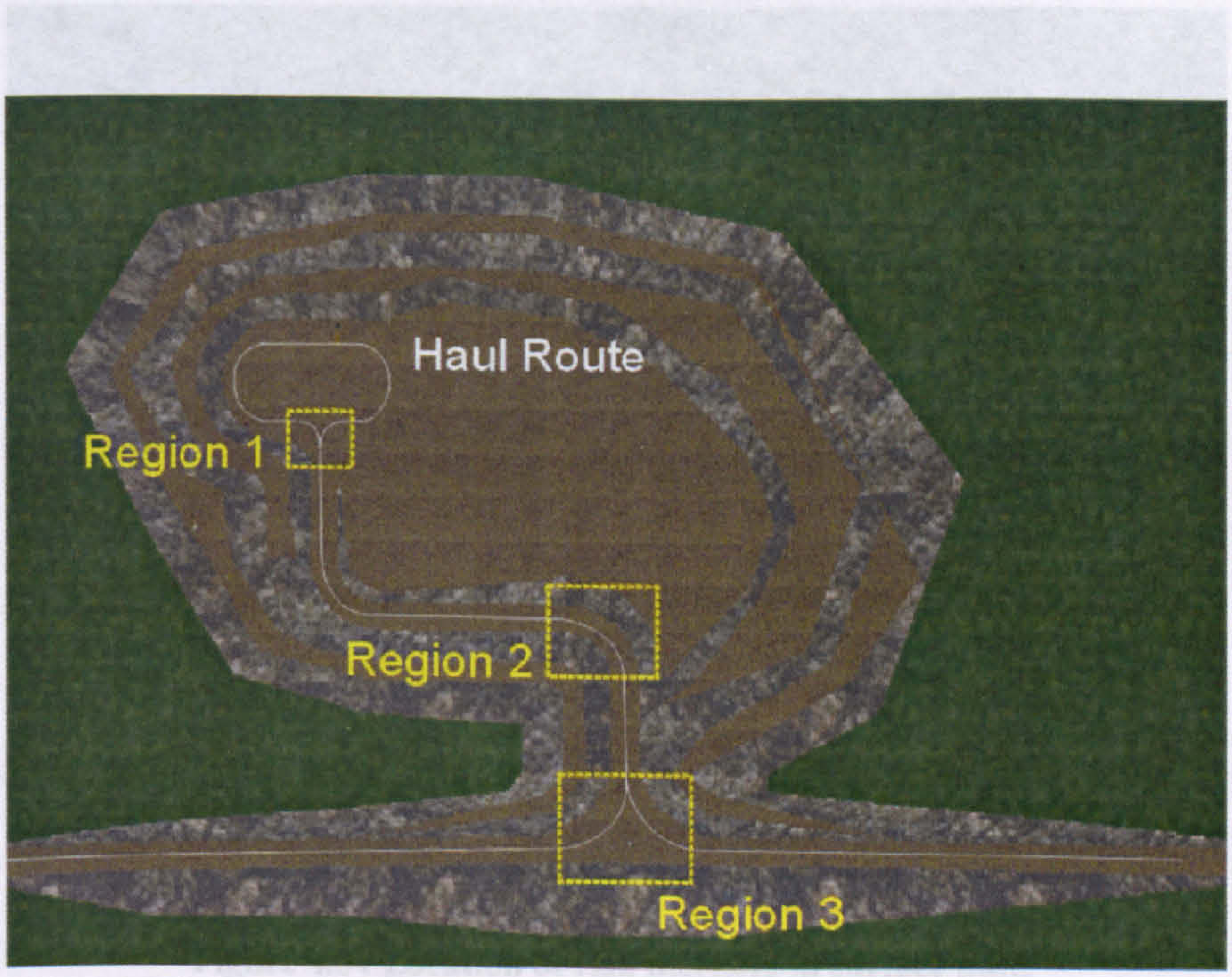

Figure 4.33 Position of haul road risk regions

Each of these areas is modelled with a constant risk region. The values attached to each of the regions are shown in Table 4.11.

	Region 1	Region 2	Region 3
Risk Value	30	30	45

Table 4.11 Values for haul road risk regions (see Figure 4.33)

4.6.3.4 Risk Markers

Five risk markers are pre-defined in the application, these were located as shown in Figure 4.34. Small cubes are used as markers within the virtual world, the colour of the small cube reflects the level of risk that the marker is experiencing.

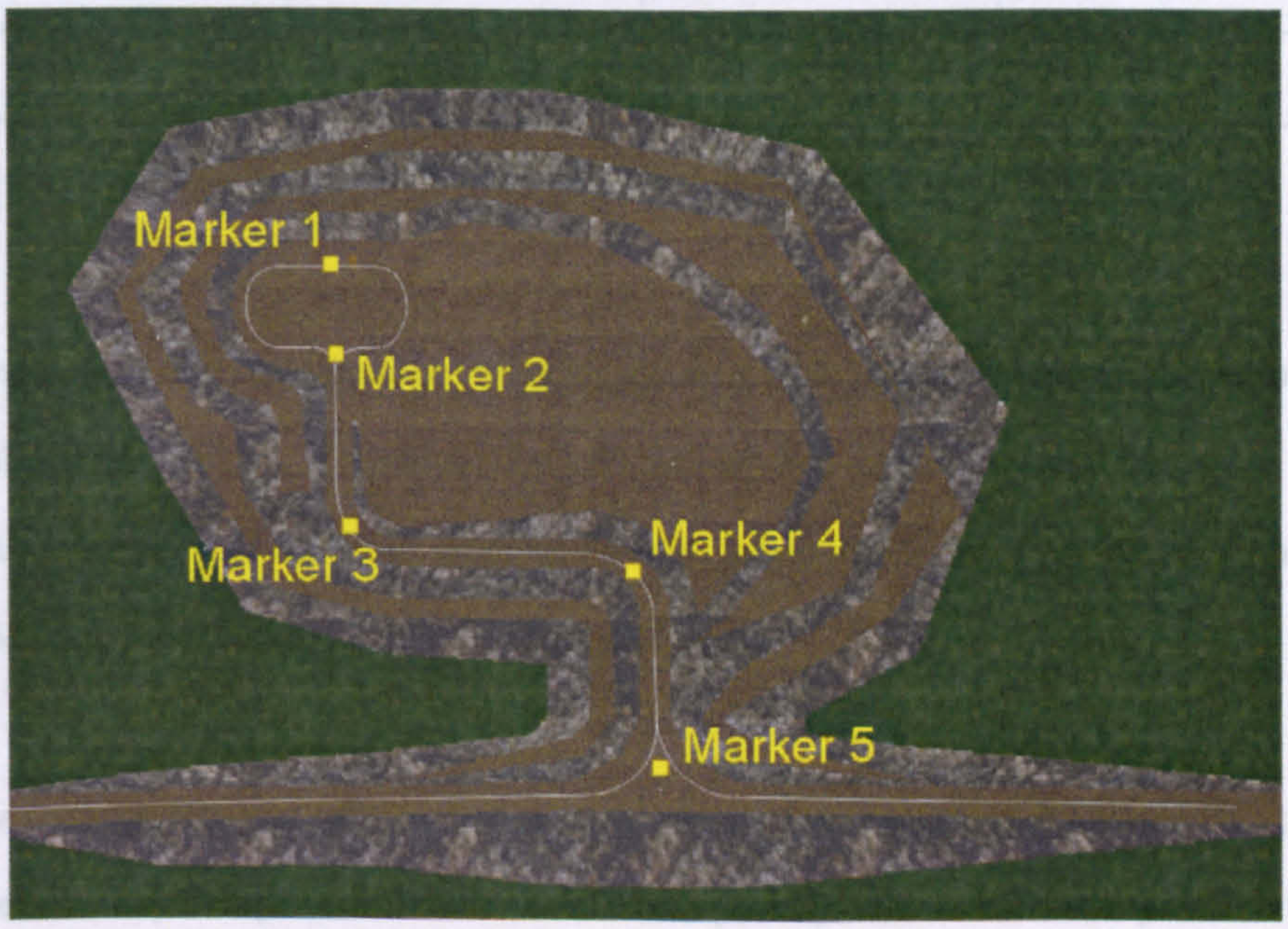

Figure 4.34 Location of risk markers in surface mine

The markers were placed to monitor the risk at various positions on the haul road. In particular at the load point, at road junctions and at turns in the road.

4.6.4 Results

The values of the pre-defined risk markers on completion of movement in the virtual world are shown in Table 4.12.

Risk Marker	Minimum Risk Value	Maximum Risk Value	Mean Risk Value
Marker 1	50	86	62
Marker 2	30	66	37
Marker 3	0	45	12
Marker 4	30	64	42
Marker 5	45	72	47

Table 4.12 Risk marker values from surface mine simulation

Navigating through the virtual environment allows a close up inspection to be performed on all the risk markers. The values obtained for each risk marker in terms of their minimum, maximum and mean value would seem to be reasonable, given their proximity to the equipment and the operations being performed.

Examining the levels at each marker over the period of the simulation it is evident that there is a sharp change in the risk levels as trucks pass by. This is not entirely unexpected, however, it should be noted that the sharp change in levels of risk may be cause for concern.

The marker experiencing most risk is the marker located at the loading point, it would seem reasonable that the level of risk at this point would be higher than at most points in the surface mine. The results also show that the level of risk is also increased at a junction. As with the previous case study there is a good correlation between the expected and calculated level of risk.

4.7 Summary

An introduction to the existing risk visualisation system was provided. The potential for further development of a risk visualisation system and tools to aid risk assessment was discussed. Limitations of the existing system meant that any the proposed work would require a new methodology for analysing the relationships and the development of a new application.

A tool was developed that allows the level of risk surrounding a hazardous factor to be represented by a volume of space (termed a risk region). The tool provides for the fact that the shape, size, position and levels of risk associated with the region may change depending on the state of the hazard with which the risk is associated. A further framework was defined to allow the level of risk to be calculated at any location, based upon these risk regions.

A VR application was written that incorporated the new methodologies. The application included techniques to allow the basic simulation of a virtual world and also provided tools to visualise the risk regions and the levels of risk within the environment.

Two case studies were performed to evaluate the new tools and methodologies developed. Both showed that the calculated levels of risk were reasonable given their location within the virtual environment.

5 Haulage Training and Assessment Simulator

5.1 Introduction

One of the major issues in the operation of a surface mine is the transport of material around the site. The large amount of material involved will often require the use of large haulage trucks sometimes with a capacity of over 300 tonnes. They offer high manoeuvrability in confined spaces, a large capacity and the ability to handle gradients of 10% when fully loaded. However, their huge size introduces many associated safety hazards. In the United States mining industry alone, surface accidents accounted for 17% of fatalities in mining accidents between 1989 and 1993. Of the 95 that died during the period, 72 involved haulage trucks (MSHA, 1998). The Occupational Health and Safety Administration (OHSA, 1995) in the United States found that in 1995 industrial trucks were still the second leading cause of fatalities in the private sector behind only highway vehicle fatalities. They found on average 107 fatalities and 38,330 injuries occurred annually in the workplace, furthermore they found present training standards to be ineffective in reducing the number of accidents involving powered industrial trucks

Current haulage training methods often involve paper-based questionnaires that describe an environment and a situation, then present the trainee with a multiple-choice response. There are limitations to using such a paper-based approach, particularly on the amount of information retained by the trainee. Although haul truck drivers do receive some at-the-wheel training this is often limited due to the high cost of resources involved.

VR has often proved effective in situations when working conditions are hazardous and interaction with expensive and often unavailable equipment is required. Under these conditions VR offers the ability to expose trainees to dangerous situations without ever putting them in any real danger.

Although the development of a VR based driver training system is not a realistic alternative to experience in the real world it may be possible to complete some aspects of training and assessment in the simulator. The provision of a VR environment may help to improve the effectiveness of current training and assessment programmes, ultimately leading to a safer operation. This may also translate into cost savings, as expensive equipment is operational for a greater period of time and is not required on 'unproductive' training or assessment tasks.

5.2 Justification for Development

Even though there is only limited evidence that behaviour in on-road simulators translates directly into the real world some commercial driving simulators have demonstrated positive results. Many of these simulators do not concentrate on teaching the ability to control the vehicle but rather focus on driver behaviour.

Although the ability to control the vehicle is an important factor in the skill and safety of the operation of a haul truck, the ability to identify and anticipate dangerous situations and the subsequent decision on which (if any) corrective action should be taken would seem equally important. Existing work on road driver training and safety has shown that drivers with better hazard perception scores have had fewer accidents, and that hazard perception scores can be improved through training (DETR, 2000). The author believes that it is not unreasonable to expect that these results would translate to haul truck operation in a surface mine.

Mills et al. (1998) investigated the effects of hazard perception training. They were able to improve hazard identification capabilities of subjects using either classroom simulation or on the road training. They believed that by refining the systems used more promising results could be achieved. Improving driver anticipation, or reducing the time taken to identify hazards, would allow drivers more time to take corrective action, and perhaps avoid a potential incident. VR would seem to provide a way of refining the hazard identification systems used. The flexibility and interactivity of a virtual environment allied with its ability to engage the trainee might provide an ideal medium for hazard identification training.

Squelch (1998) employed a hazard spotting mechanism in a VR walkthrough of an underground mining environment. In this environment the trainee walks through the virtual environment and identifies potentially hazardous situations by clicking with a mouse on the associated hazardous object. Once a hazardous object has been identified, the trainee is presented with a number of possible actions. The choices made at each stage affect the progress of the trainee through the world. Squelch employed a low-cost VR system for his hazard spotting system and achieved some positive results. Some of his results indicated that:

- VR as a medium received an extremely positive response from trainees.
- Increased levels of interest in the course content when using VR.
- VR based simulators can successfully be used to raise the level of hazard awareness training in the mining industry.

Using a hazard spotting approach similar to that used by Squelch (1998) has important implications for the type of system developed. Although the level of interaction and immersion is important, it is questionable whether the cost of high-end VR components is necessary and can be justified.

The author chose to develop a VR driving simulator that employed hazard identification techniques similar to those used by Squelch (1998). The proposed system would use similar hazard identification techniques, and also require the subject to demonstrate additional knowledge, such as correct safety procedures. A hazard identification framework was developed for this purpose and incorporated into the system.

5.3 Features of the Proposed System

It is the intention that the proposed VR system will be used within industry, for this reason the system must consider the costs of development and deployment. The ultimate cost of the VR system will have an impact on the type and scope of training and assessment that can be conducted.

High end driving simulators often include features such as motion platforms, force-feedback input devices, and highly detailed modelling of vehicle performance. The benefits of developing such a high cost simulator are questionable, indeed there is evidence to suggest that much work being done in high cost simulators can be achieved in lower cost equivalents. Given that the system is targeted at a cost conscious industry, careful consideration must be given to each component to see if it could be justified.

The use of hazard identification affects the relevant importance of different aspects of the system. High-end driving simulators model a large number of factors so that the dynamics of the driven vehicle can be simulated accurately. This might include modelling factors such as a vehicle's suspension, the friction between the tyre and the ground and the resistant force on the steering wheel and pedals. Although it is important that vehicle performance is modelled realistically, it was not considered necessary to model to this level of detail. Reducing the level of detail from the simulation decreases the amount of complexity and computation necessary to maintain a real-time system. Additionally the need to provide force-feedback and motion effects to the trainee is similarly reduced. Although this might ultimately reduce the levels of immersion, it should be noted that VR systems without motion or other 'high-end' effects are still able to engage the user. The main areas of importance for supporting the hazard spotting approach were considered to be high quality visuals and realistic audio. These are considered vital cues when attempting to identify hazards.

Although it was not the main aim of the system to teach or to improve basic vehicle control skills, the system should provide a natural interface for trainees. They should be able to become familiar and feel comfortable in the simulator in a short period of time. Similarly the representation of the vehicle cab should be sufficient to allow the trainee to recognise and function within the environment.

It would seem reasonable that the best type of environment in which to train is that which the trainee is likely to face in reality. It therefore follows that to teach the safe operation of haul trucks, the environment should reflect that which is faced in the real world. In the real world drivers experience the environment from within the cab and they control the vehicle through the use of a steering wheel and pedals. Views should therefore be provided from the driver's cab and the trainee should interact with the system in a similar manner as in the real world, through a steering wheel and pedals.

As the construction of a virtual environment can be a time consuming process, it is important that the expense involved with creating new scenarios was kept to a minimum. Despite the pressure to keep costs low, it was considered important to allow trainers to create scenarios tailored to their and their trainees needs. If scenarios could be constructed on-site, then this might allow the geometry of the local area to be incorporated into the training system. The MSHA (1998) believe that haul truck drivers should be familiar with the road layout and traffic movement of a mine before operating at the site. It was important therefore to provide geographically realistic and easily customisable scenarios for the following reasons:

- To allow trainees to familiarise themselves with the layout of the surface mine in a way not previously possible using traditional map based methods.
- To allow trainees to be exposed to as many different scenarios as possible.

A hazard identification framework should be developed that allows the trainee to demonstrate their knowledge about hazards and safety procedures and to allow some measurement of trainee performance. This will provide valuable feedback allowing any improvement or decline in skills to be identified.

Once haul truck drivers have become familiar with the system there should be no barrier to them performing 'exercises' by themselves. They should be able to use the system without the need for additional support personnel. The system should provide an assessment of the trainee's performance, and perhaps logs of their behaviour in the simulator. These may either be reviewed with a qualified trainer or used as a means of self-assessment.

The improvements in rendering power available on low cost PC's, and the development of reasonable input and output devices such as surround sound audio systems, touch-screen monitors and other input devices, meant that the author believed it should be possible to develop a low cost system. Using PC technology significantly reduces cost, not only in terms of initial outlay, but also in terms of maintenance and retraining, as many people are already familiar with technology built on this platform. The low cost of such a system would allow a surface mine or organisation to maintain machines on-site allowing drivers to undertake frequent refresher training or assessment at relatively low cost. The remote location of many mines often makes the maintenance and support of computer systems difficult. Using low-cost, common technology should lessen the importance of these considerations.

Further areas were identified that might benefit from a system such as the one proposed. Some potential uses of the system are given below:

1. Generic equipment driver training or assessment. The flexibility of VR might allow other vehicles to be simulated and controlled, providing the possibility of using the system to train other personnel.
2. Review of trainee performance. In the review phase of a training session, the system may be used to examine situations that were faced by the trainee.
3. Demonstrating dangerous situations. Examples of dangerous situations can be presented to trainees.

4. General surface mine operation training. For personnel other than those who drive vehicles, the system could be used to familiarise them with the general operation or layout of the surface mine.

The inclusion of risk regions as outlined in previous sections, could provide a useful tool for highlighting potential areas of risk around moving equipment.

Three distinct modes were identified that would allow the system to satisfy all of the identified potential uses.

1. Driver Training. The user is presented with a view from the inside of the vehicle cab and they are able to drive this vehicle around the surface mine.
2. Driver Demonstration. Similar to driver training, the user is presented with a view from inside the vehicle cab, however, the vehicle is controlled by the computer.
3. General Operation. The user controls the view of the virtual environment but is not restricted in any way and is therefore free to move to any location and orientation.

5.4 System Components

5.4.1 Hardware

It is important to consider the available components of a VR system, given the financial implications of providing a commercial system and the large differences in cost between a desktop based and other high-end systems.

The vast majority of VR systems available today are either PC or workstation based. Many high end driving simulators use UNIX based system from manufacturers such as Silicon Graphics as these provide the best combination of graphics and processing performance available in the marketplace today. However, a number of factors were considered before choosing the target platform

- Evidence suggests that systems developed using PC technology are more easily ported to the industry due to reduced costs, the existing user base and the familiarity of PC technology (Schofield, 1994).
- It is a requirement of some mine operators that PC based systems are used. This has been experienced as part of the previous work undertaken by the AIMS Research Unit. A common reason cited for this is the difficulty to recruit and retain experienced UNIX technicians in remote locations.
- Although Silicon Graphics machines currently offer the best performance, the power of PC's to provide low-cost high graphical and audio quality is improving quickly through the use of 3D graphics acceleration.

A wide field of view might potentially be important to the system. This would allow the system to provide views similar to that experienced inside the cab. Three configurations were identified that would increase the field of view over a stand-alone monitor, these included using a head mounted display, a projection system or additional monitors.

The majority of driving simulators today do not use head mounted displays (HMD), whilst they provide a 360 degree field of view at a reasonably low cost, they have many associated problems. This includes related health and safety issues preventing the trainee spending a reasonable amount of time using the system, and a relatively poor display resolution limiting the quality of the visuals.

The use of a projection system and multiple monitors is illustrated in Figure 5.1.

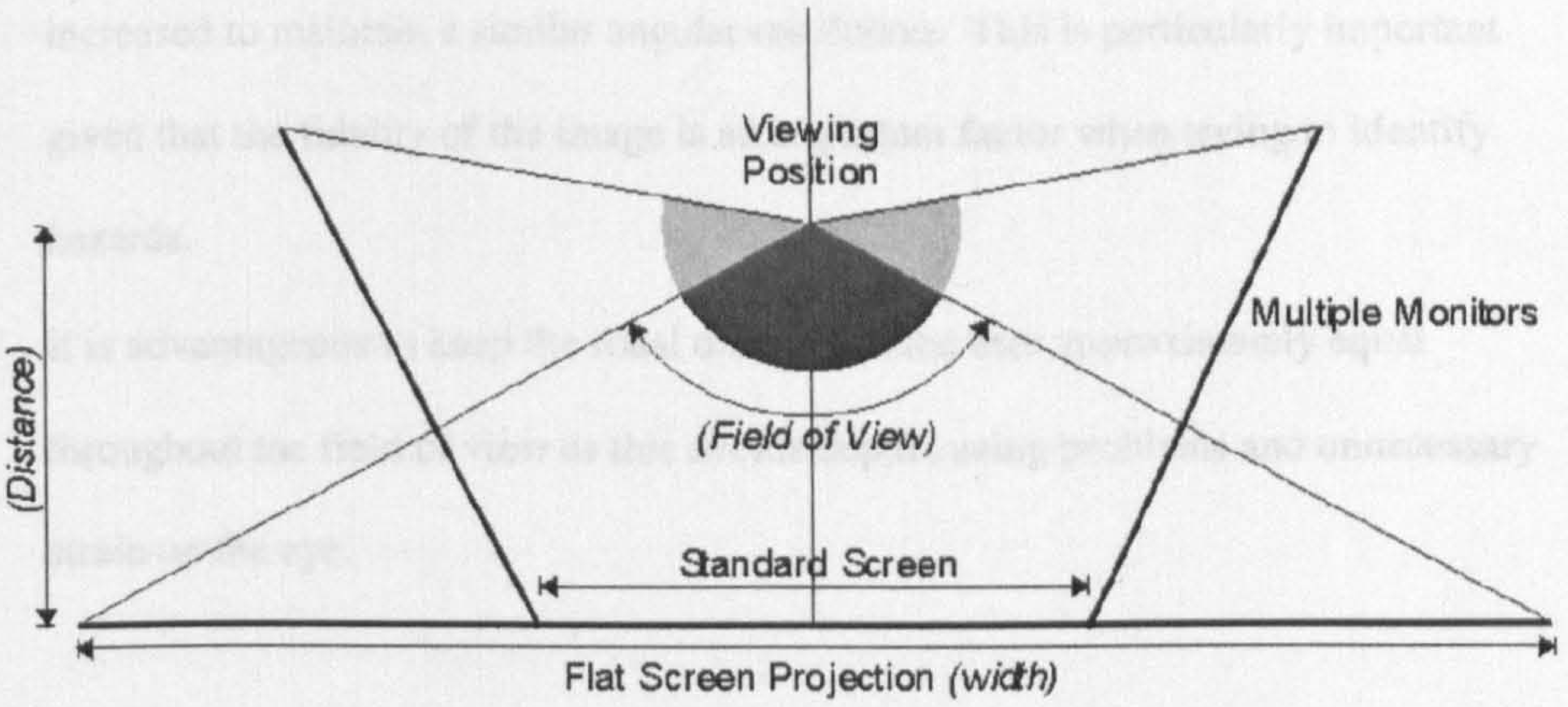

Figure 5.1 Multiple monitors vs. single projection screen

The use of a projection system could increase the standard field of view. Such a system is often used during group training or demonstration sessions. However projection systems suffer from the following problems:

- They are relatively expensive, costing significantly more than a large screen monitor.
- They take up a large amount of space, and are sensitive to the environment in which they operate (low light).
- Since the aspect ratio must be maintained there is often an unnecessary overhead in rendering top and bottom portions of the world.
- As the area of projection is increased, the corresponding increase in field of view becomes less, the relationship is given by the equation in Figure 5.2. This could be compensated for by using a curved projection screen, however this introduces additional problems not least when trying to focus the projector.

$$\text{Field of View} = 2\tan^{-1}\left(\frac{\frac{1}{2}\text{width}}{\text{distance}}\right)$$

Figure 5.2 Calculation of field of view for single projection system

- As the area of projection is increased the resolution of the rendered image must be increased to maintain a similar angular resolution. This is particularly important given that the fidelity of the image is an important factor when trying to identify hazards.

- It is advantageous to keep the focal distance of the user approximately equal throughout the field of view as this avoids depth cueing problems and unnecessary strain on the eye.

Additional monitors could also be used to provide extra views, although this increases the rendering requirements of the computer. The trend towards 3D hardware accelerated PC's might help to offset the required increase in performance. This potentially provides a number of benefits:

- Resolution of each image can be maintained separately.
- The use of 3 large (17 inch +) monitors is still significantly less expensive than a single screen projection system (the cost of 17inch monitor is currently around £200).
- The use of three monitors provides a wider field of view than a single projection screen.
- The focal distance is approximately equal throughout the entire field of view.
- Allows the use of touch-screen input devices.

Providing stereoscopic real-time images to the user by using 3D glasses such as Crystal-Eyes would also be possible. However, studies by the Simulator Systems Research Unit (Goldberg, 1996) have shown that stereoscopic images are superior only when users have to perform tasks in which they have to interact with objects at distances of less than three metres. At longer distances they found monoscopic viewing worked just as well. During typical operation in a haul truck the only objects that appear at distances of less than three metres are those inside the drivers cabin. It is expected that there will be little interaction within the cab and for this reason it is unlikely that depth perception would be necessary.

Wilson et al (1996) claims that the degree of immersion and interaction offered by a desktop system is limited, however he also believes they offer advantages and these include amongst others.

- Greater graphics quality.
- User comfort and convenience, leading to greater lengths of time that the user can spend with the system
- Adaptability for work patterns.
- Lower capital cost of the hardware, software and peripherals.

It is extremely important that graphics are displayed in sufficient resolution and detail to allow the correct identification of potential hazards. It is also necessary that the user feel comfortable, and is able to spend time a reasonable portion of time using the system.

Many input and output devices now exist for a desktop PC, these include steering wheels, touch screens, spaceballs and six degree of freedom joysticks. However, as with other devices, these should be used only when they provide significant added value. A steering wheel with pedals was chosen as the main input device for the system, it was hoped that providing haulage drivers with a familiar interface would help them to navigate through the world more naturally and reduce the time taken to learn how to use the system.

A typical configuration of the proposed system is shown in Figure 5.3.

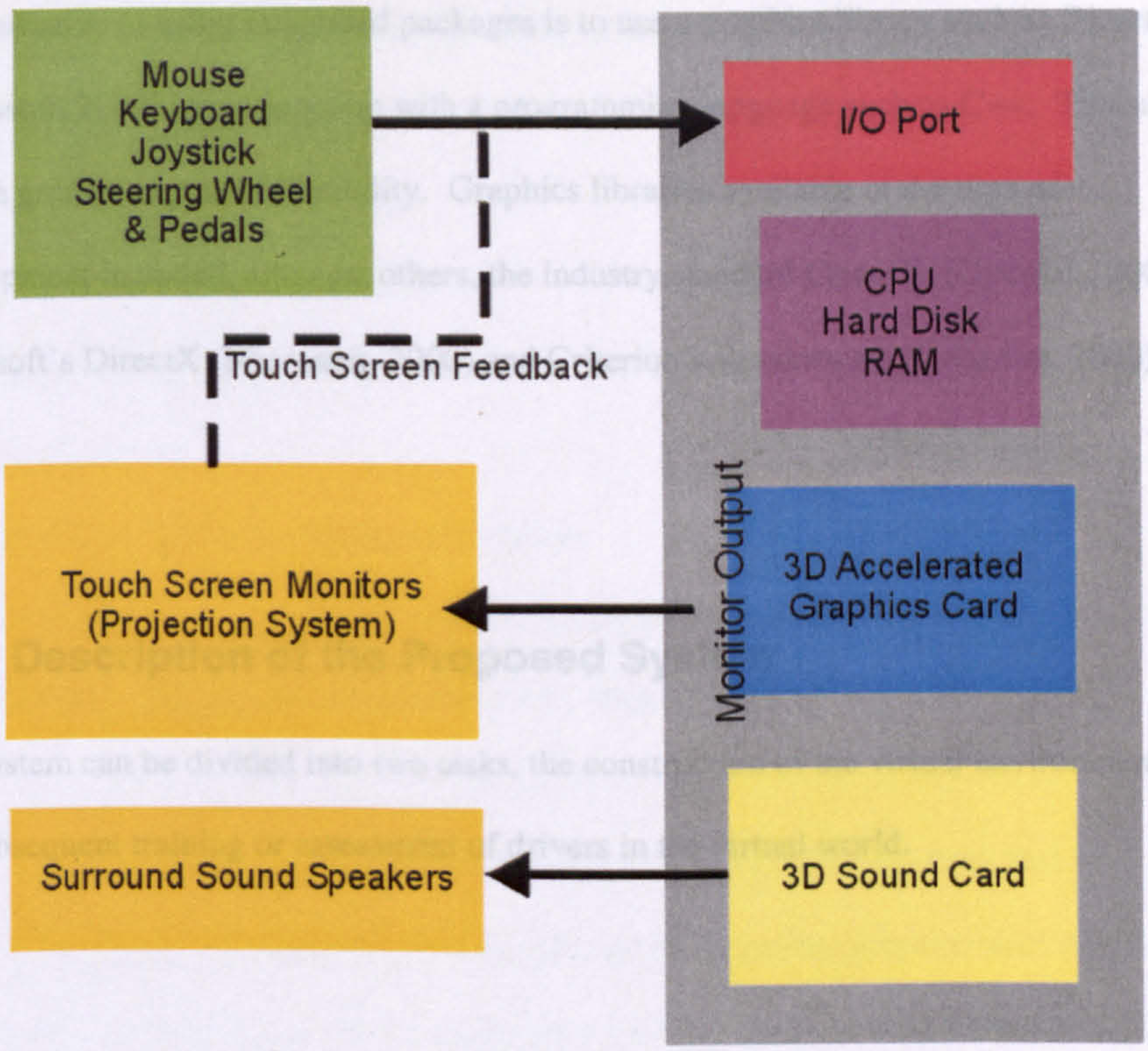

Figure 5.3 Typical hardware components of the proposed system

5.4.2 Software

There are many 'off the shelf' VR packages that are available, two such packages are Superscape VRT (Superscape, 2000) and Realimation (2000), these provide a development environment which allows the construction of VR worlds through a mouse-driven interface. A range of tools is provided by each of these packages aimed at speeding the development and construction of the virtual world. The use of such packages does help to reduce the development time but introduces many constraints.

The constraints imposed by such packages were significant and ultimately meant that many features of the proposed system could not be supported, for example the use of external devices such as steering wheels and multiple screens. In addition the packages introduce a significant performance overhead when compared to compiled languages such as C++.

An alternative to using integrated packages is to use a graphics library such as DirectX (Microsoft, 2000) in conjunction with a programming language such as C++. This allows a much greater degree of flexibility. Graphics libraries available at the time of development included, amongst others, the industry standard OpenGL (OpenGL, 2000), Microsoft's DirectX (Microsoft, 2000) and Criterion's Renderware (Criterion, 2000).

5.5 Description of the Proposed System

The system can be divided into two tasks, the construction of the virtual environment, and the subsequent training or assessment of drivers in the virtual world.

5.5.1 Constructing the Virtual Environment

According to Polis et al (1995), the major steps in virtual world construction are the following:

1. Select and prepare existing digital and hard-copy source material.
2. Generate a bare-earth terrain representation using an existing or augmented digital elevation model.
3. Add the transportation network to the bare earth model.
4. Add models of natural and cultural features. These include natural features such as trees, lakes and agricultural areas; and man-made structures such as buildings, towers and telephone lines.
5. Manually test the virtual world model for errors in feature representation, database content and density resulting in iterative refinement.

Polis et al (1995) note that steps 3-5 require significant skill in interactive editing with the current generation of manual scene modelling tools. For example adding a new road to an existing bare earth model generally requires modifying the underlying terrain's shape.

An objective of the system was to reduce the cost involved in the generation of scenarios. This ultimately requires the incorporation and manipulation of data from a variety of sources, including the following:

1. Digital 3D terrain geometry.
2. Road network.
3. Terrain colour and texturing information.
4. Dynamic object positioning, route information, and behaviour.
5. Positional information of static features, trees, signs, buildings etc.

The nature of a surface mine environment is geometrically different from that of an underground mine. Instead of consisting of a series of overlapping corridors and tunnels, it normally incorporates one continuous, non-overlapping surface that describes the terrain. The surface can therefore be completely viewed in plan and many of the algorithms and functions that work on the surface can be implemented in two dimensions with the third (elevation) dimension being calculated on the surface. For example, the position and direction of objects can be added by the user in two dimensions, the elevation and orientation value can then be automatically generated on the surface of the terrain.

Employees of surface mines are often required to interpret 2D information that is often presented in the form of a map. The creation and manipulation of scenarios in 2D-plan view is a similar concept and one that does not require additional knowledge.

5.5.2 Training and Assessment in the Virtual Environment

The training and assessment module will allow the user to experience a virtual world from the point of view of a haul truck driver. They may take control of the vehicle and drive it through a virtual surface mine as they would in the real world. As they travel through the world the user will be able to identify hazardous situations as they arise and subsequently to indicate any corrective action which needs to be taken.

The view provided onto the virtual world should be as large as possible, it should at least occupy one full screen. Representations of important instruments (speedometer, fuel gauge etc) should be included either in the virtual world or as part of the cab.

The use of sound is important as it can provide many valuable warnings to personnel. This includes sound generated from the driven truck such as engine noise and cab warning alarms, as well as from other equipment, this can be important in identifying the position, velocity and state of each piece of equipment in the mine.

A number of input devices should be used, this allows the system to remain flexible and be used in as many configurations as possible. These devices should include a keyboard, mouse and joystick as well as a steering wheel and pedals. This should provide a natural interface for a haul truck driver.

5.5.2.1 Hazard Identification

The mechanism by which the user identifies hazards is important, it must be simple and consistent in its appearance, whilst supporting a wide variety of hazards. It must allow the trainee to communicate appropriate hazard and risk information and provide a means of evaluating performance.

The hazard spotting mechanism employed by Squelch (1998) requires trainees to explicitly identify hazards and perform the correct safety operation, this is implemented through a point and click interface. In this system hazards are associated with their 3D representations in the virtual world. The classification of a surface mine environment into discrete objects and the association of hazards with these objects would allow a similar mechanism to be adopted. However, there are substantial differences between the type of environment used by Squelch and the system proposed here. This world is a dynamic simulation rather than a static walkthrough, and customisation of scenarios means that a framework capable of more complex hazard types must be developed.

Consideration must be given to the type and scope of hazards that the system is able to represent. The framework developed should be capable of representing a wide variety of those hazards experienced in the real world.

Scope of Hazards Considered

Although there are likely to be regional variations around the globe, the similar equipment and mining techniques mean that there are many common hazards. Some hazards and causes of accidents were identified from MSHA material (1995).

- Normal and irregular positioning of trucks and other equipment.
- Pit entry/crest visibility.
- Edge proximity.
- Poor ground conditions.
- Reversing to dump.
- Adverse camber.
- Spillage.
- Truck start-up.
- Rock fall.
- Slope Failure.

More complex hazard types might include:

- Poor visibility.
- Manoeuvring around an excavator (load point).

- Junctions.
- Brake failure/over-speeding.

It is important that a wide variety of hazards are represented in the virtual environment. Since there are inevitably hazardous situations that are mine specific, there will need to be flexibility in the way hazards defined. Fundamentally surface mining environments consist of a number of different types of objects. These can be grouped as in Table 5.1.

Object Type	**Examples**
Landform	Road network, Pit walls, Sky.
Moving Objects	Trucks, Scrapers, Personnel, Bulldozers.
Stationary Objects	Road Signs, Spillage, Buildings, Parked Vehicles.

Table 5.1 Constituent objects of a surface mine environment

Many of the hazards listed previously can be linked to the constituent objects of a surface mine environment. Some examples of these objects and their associated hazards are shown in Table 5.2.

Object	**Associated Hazards**
Moving objects (Trucks, Scrapers, Bulldozers etc.)	Poor visibility (blind spots). Proximity and location with respect to other equipment. Exceeding performance envelope of vehicle, result of over-speeding, overloading etc. Positioning in hazardous locations around moving equipment. Manoeuvrability problems.
Stationary objects	Poorly positioned (left in close proximity to other equipment). Badly parked (engine left running etc.). Obscured, overcrowded, confusing, out of date or dirty road signs.
Mine landform	Environmental conditions (poor visibility, rain, fog, dust etc.) Obscured vision (blind corners, crest visibility)
Road network	Badly designed road layout. Traffic congestion. Poor road conditions (ice, water, unstable ground, too steep a gradient). Lack of or badly positioned berms or guards.

Table 5.2 Hazard classification table

If the virtual environment is experienced from the point of view of the driver, there is also the possibility for the user driving the truck to exhibit hazardous behaviour. This may take the form of over-speeding, irregular positioning, dangerous/incorrect operation or perhaps a failure to follow the correct route. It is also possible to simulate equipment failure in either the driven or in another vehicle, this might include brake failure, overheating oil temperature, low fuel levels or unresponsive steering.

Hazard Identification Framework

Grayson et al. (Grayson, 2000) have developed a theoretical framework for the processes involved in responding to risk. This framework was used on a number of subjects who were asked to identify hazards whilst being driven on public roads. In this framework Grayson et al. identify the main components to be hazard detection, threat appraisal, action selection and implementation. Although this work is as yet unpublished they claim that the model is able to make reasonable predictions of driver safety, good predictions of driver speed choice, and very good predictions of the subjective assessments of driver performance.

The framework used by this training and assessment system is similar to the system used by Grayson et al. (unpublished), but is also based upon the work by Squelch (1998).

The trainee experiences the environment by either driving through the mine themselves, being driven by another (human) operator, or being driven by the computer. At any point during the simulation the trainee is able to pause the virtual world and enter the hazard identification module. Once the trainee has entered the identification module they are required to identify the object with which the hazard is associated. This is done through a point and click interface. After identifying the object the trainee is required to select the associated hazard, evaluate the level of risk, and indicate any actions they might take. When the procedure is complete the virtual world continues from the point at which it was left.

During the hazard identification procedure, the trainee will communicate with the VR system through a multiple-choice list. It was felt that this provided a simple but also extensible means of interaction.

Under this framework, a complete 'identification' will involve the following steps by the trainee:

1. Pause the simulation.
2. Identify the object with which the hazard is associated by selecting it on-screen.
3. Select the appropriate hazard from a multiple-choice list.
4. Evaluate the level of risk, this could be entered as a choice of low, medium or high risk.
5. Indicate any corrective action that may need to be taken. Again a choice is made from a multiple-choice list.
6. Continue the simulation.

5.5.2.2 Measuring Trainee Performance

The use of a VR system allows the possibility of measuring trainee performance in a wide variety of ways. Entire sessions could be recorded by the computer or could be videotaped allowing subsequent playback and discussion with the trainer. The use of a hazard identification mechanism also allows the safety performance of a trainee to be evaluated.

In previous hazard identification systems Mills et al. (1998) recorded the number of hazards a subject missed as well as the time taken to identify a hazard. Squelch (1998) recorded the number of hazards identified, and also recorded whether the correct safety procedure was followed. Both measurement mechanisms provided details that were ultimately used as a measure of competence. Mills et al. believed that the parameters measured were a good way of evaluating the identification skills of subjects.

The design of appropriate measurement criteria must take into account the scope of the hazards considered and also the nature of the system used. In order to make a measurement of the number of hazards missed, it is necessary to know the total number of hazards in the scenario. These hazards must be specified at some point prior to the training session. The hazards identified by a trainee during a training session can be compared against a list of known hazards to obtain a measurement of the number of hazards identified, or the number of hazards missed. Values could be assigned to hazards on the basis of severity allowing a trainee 'score' to be calculated. Missing a critical hazard would reduce the trainee score significantly whereas missing a trivial hazard might impact the score much less.

Information concerning an employee's performance could be maintained and kept together with their safety record. The combination of the two could provide an insight into potential safety shortfalls of the employee. This may help to identify areas of concern for each individual and subsequently potential training requirements.

5.6 Summary

Surface mines are in operation world-wide, the majority employ large haul trucks for the transfer of material both to the outside world and around the site. The size of these trucks and their operating conditions means there is a high level of risk. Allied to this, the commercial nature of the operation means that down time is extremely costly and driver training expensive. VR simulators have often proved effective in situations similar to this. As a result of the preliminary investigation it was concluded that the use of a virtual haul truck simulator might help to improve the safety of operations within a surface mine.

A surface mine haul truck simulator was investigated for training and assessing personnel with the aim of improving the safety of operations. The simulator considered could be used to enhance rather than replace existing training methods. Similar virtual training systems were identified and their methods analysed, resulting in the choice of a hazard identification mechanism as the primary means of testing and reinforcing knowledge.

Important features of the virtual training system were identified as the following:

- Fast generation of geographically realistic scenarios.

- High quality visuals and realistic audio.
- Natural method of interacting with and navigating through the environment.
- Realistic simulation of vehicle behaviour and performance.
- Flexible configuration which is amenable to ongoing modification.
- Should have a low unit cost and be easy to maintain.
- Provide a means for evaluating trainee performance.

Tasks were identified that would be necessary for the successful development of the system discussed. In particular these focused on the problems of constructing a geographically realistic virtual environment and training using hazard identification methods. Some typical hazards were identified that are present in surface mine environments, the system should be capable of representing these and similar hazards.

Based upon the identified features and methods used the system should provide a full screen 3D view onto the simulated surface mine environment. Users should be able to drive, be driven, or fly freely through the surface mine in which a number of pre-defined hazards are included. Through a process of hazard identification trainees will be asked to identify the hazards that are present, classify them according to their potential to cause harm, and indicate any corrective action that should be taken.

The author chose to develop a prototype system to investigate whether the system discussed could be constructed with the features identified and whether such a system showed potential for use in a commercial environment.

6 Development of the Haulage Training and Assessment Simulator

6.1 Introduction

This chapter details the development of the haulage training and assessment simulator that was discussed in the previous chapter.

6.2 System Architecture

The proposed system, called VTruck, is divided into two, based upon the tasks that need to be accomplished. The two tasks and the general workflow of the system are shown in Figure 6.1.

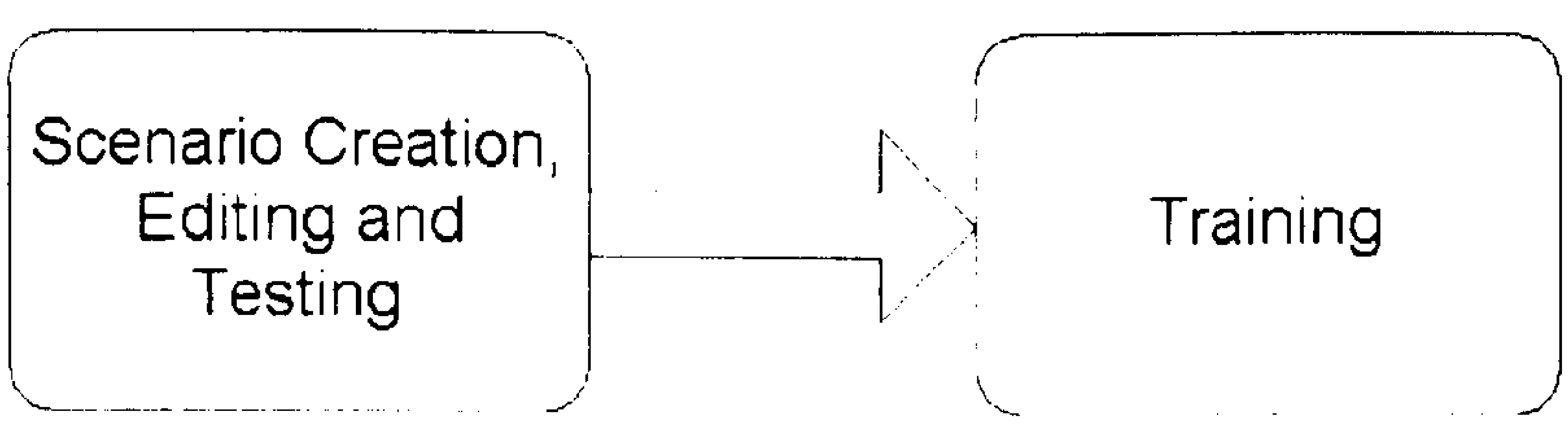

Figure 6.1 Tasks and workflow of proposed system

Each of the two tasks is likely to be undertaken by a different party and has different requirements. The 3D training simulator obviously requires a 3D virtual reality based interface, this is not necessarily the best interface for creating, editing and testing the scenario. The system is split into two modules to accommodate these different requirements. However, at a lower level, common data structures, objects, and functions are shared between the two modules.

6.3 Scenario Generation

Constructing a virtual surface mine environment requires the integration of information from a variety of sources. Information must be provided for each distinct object that exists in the surface mine environment. This includes the following:

- Digital 3D terrain geometry.
- Road network.
- Terrain colour and texturing information.
- Dynamic object (trucks, excavators) positioning, route information, and behaviour.
- Positional information of static features, trees, signs, buildings etc.

The methodology used to integrate this information is similar to that used by Polis et al (1995), however modifications have been made to his methodology to address the specific problems faced. The general process of scenario generation is shown in Figure 6.2.

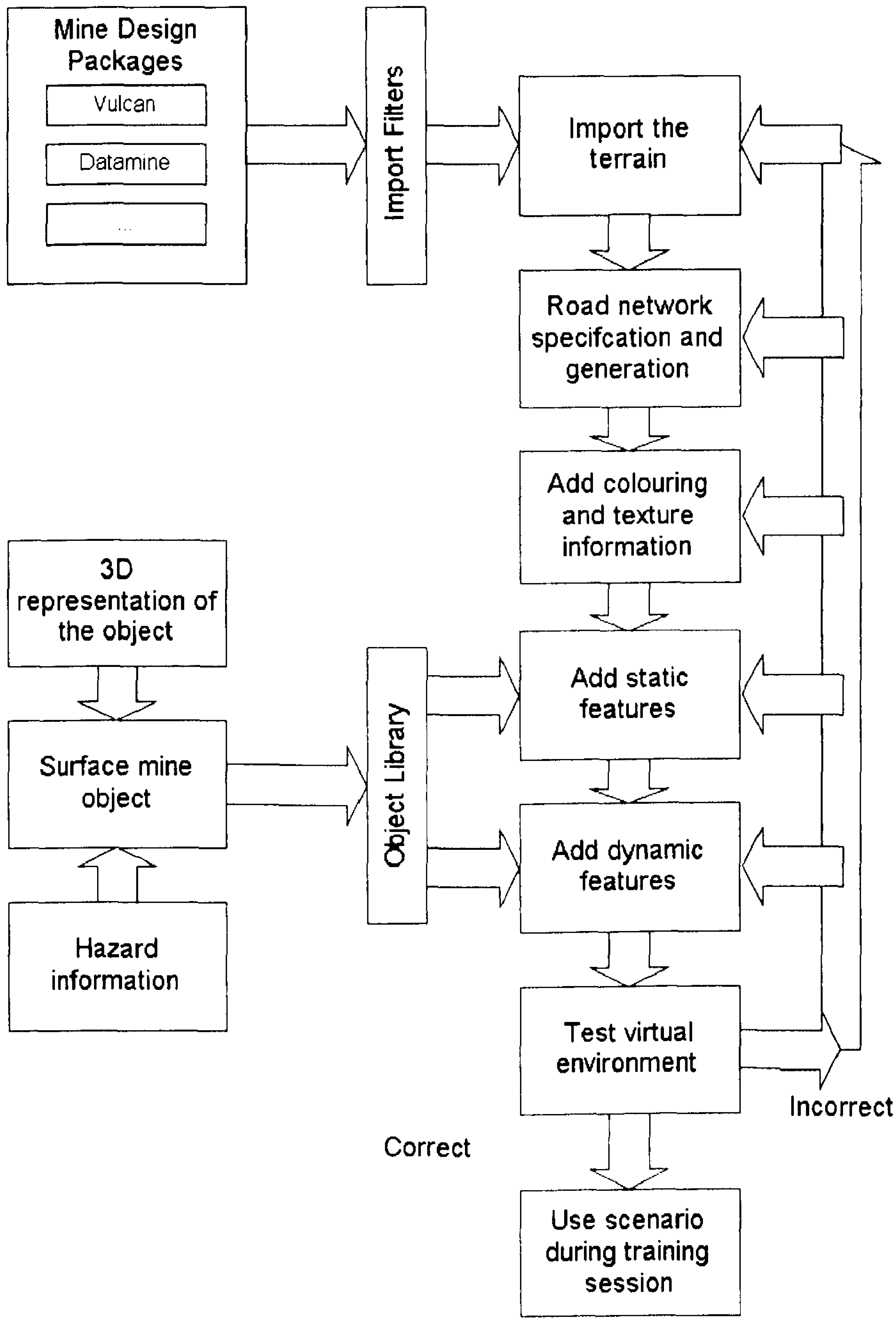

Figure 6.2 Scenario generation architecture

6.3.1 Importing the Landform

One of the most important factors when creating the model of the terrain is the requirement for real-time rendering. The number of faces and vertices in the terrain model is an important factor in determining rendering speed. A good frame-rate is essential for training as it helps to ensure that the system is responsive and interactive.

To achieve geographically accurate scenarios mine specific data describing the geometry of the landform is required. Terrain models of surface mines are maintained by mine operators at each distinct operating phase. The information in these packages is used for a variety of tasks including:

- Mine design and planning.
- Geological modelling.
- Scheduling and survey.
- Geo-statistics.
- Exploration.

Terrain models for surface mines can be generated in a number of possible ways, normally by providing parameters such as bench height, pit wall gradient, road width and gradient. The mine design package will generate a model based upon these parameters, which is normally visualised on screen. Terrain models can also be generated from survey data. A typical output from a mine design package is shown in Figure 6.3.

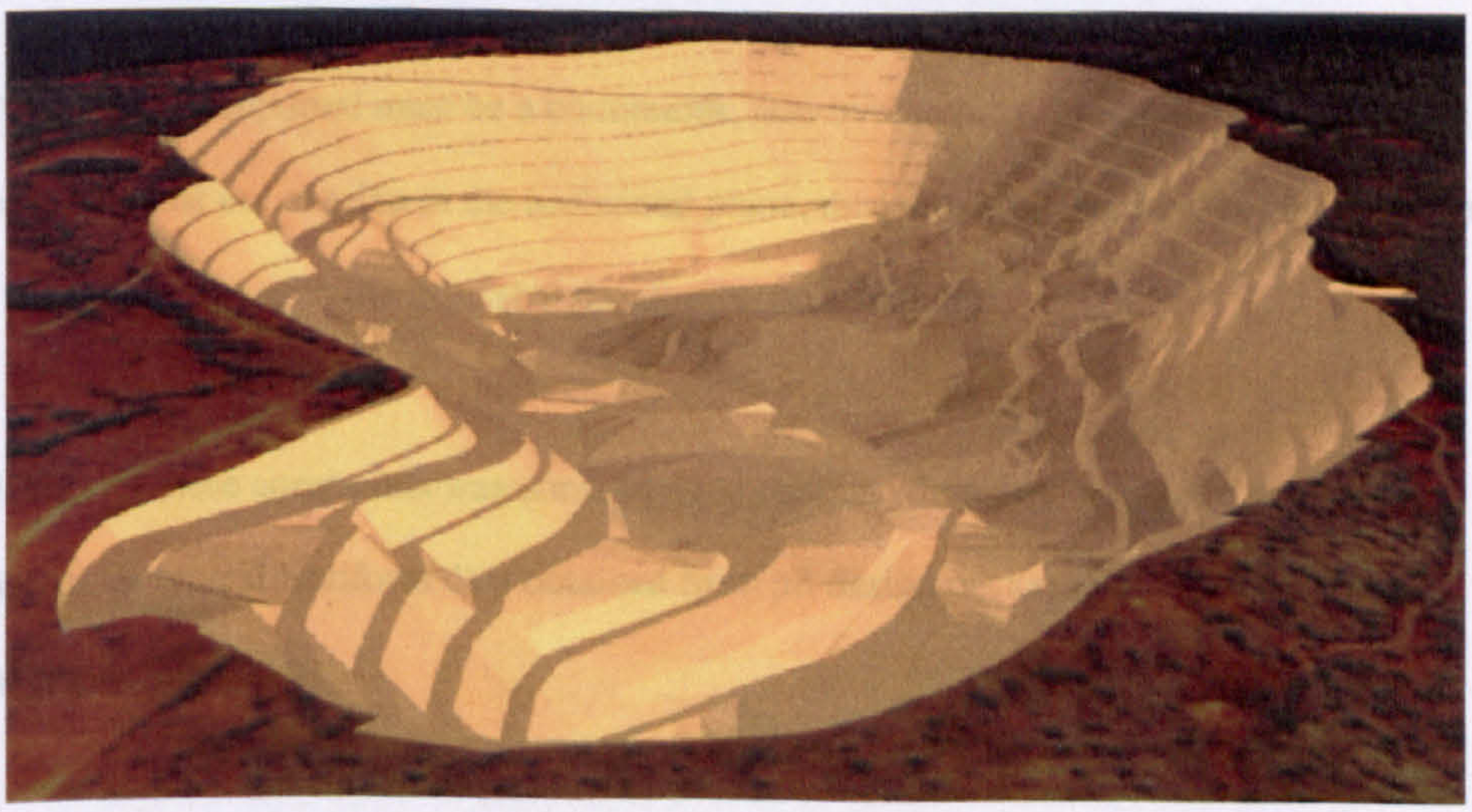

Figure 6.3 Surface mine modelled in Vulcan

The number of faces in each mine model is dependent upon the size of the mine and the resolution at which it is modelled. A pit modelled to a high resolution will contain many more faces and vertices than one modelled to a low resolution. However, the problem of terrain data at too high or too low a resolution can normally be overcome by altering the generation parameters from within the initial design package. Experience has shown that the terrain is normally modelled at a resolution that allows it to be used in a virtual world. Examples shown in this thesis contain approximately 2000 vertices and 4000 faces, though larger mines have been successfully used. Visualisation is a necessary part of the initial modelling process, the package in which this is achieved will typically have similar limits in terms of rendering power as the system that has been developed.

Constraints were imposed on the type of geometry that can be imported into the system. This has implications for many of the algorithms used in both the real-time training system and the scenario editor.

The complexity of the landform model must be such that it can be rendered in real-time. Violating this constraint will result in poor performance of the training system in terms of frame-rate, loss of responsiveness and interactivity and ultimately the usability of the training system.

The landform imported must be a continuous, non-overlapping, triangulated surface. Surfaces must not overlap in the horizontal plane, this allows the landform to be treated as a 2D flat surface with the third (height) dimension computed.

Neither of these constraints was considered to seriously impair the effectiveness of the system, as typical landform data obtained from pit design packages conforms to both of the above constraints.

6.3.2 *Road Network Generation*

An important feature of the mine is the road network. Accurate representation of this feature is essential to meet the objectives defined. Movements of equipment and personnel within a surface mine are normally restricted to the haul road. Furthermore equipment movements are normally defined by mine operators who provide specific routes for drivers to follow.

Mesh data obtained from the mine design package sometimes includes the haul road, however in the majority of cases this is not of sufficient quality to be used in a driving simulator. A typical view of a haul road taken from a mine design package is shown in Figure 6.4.

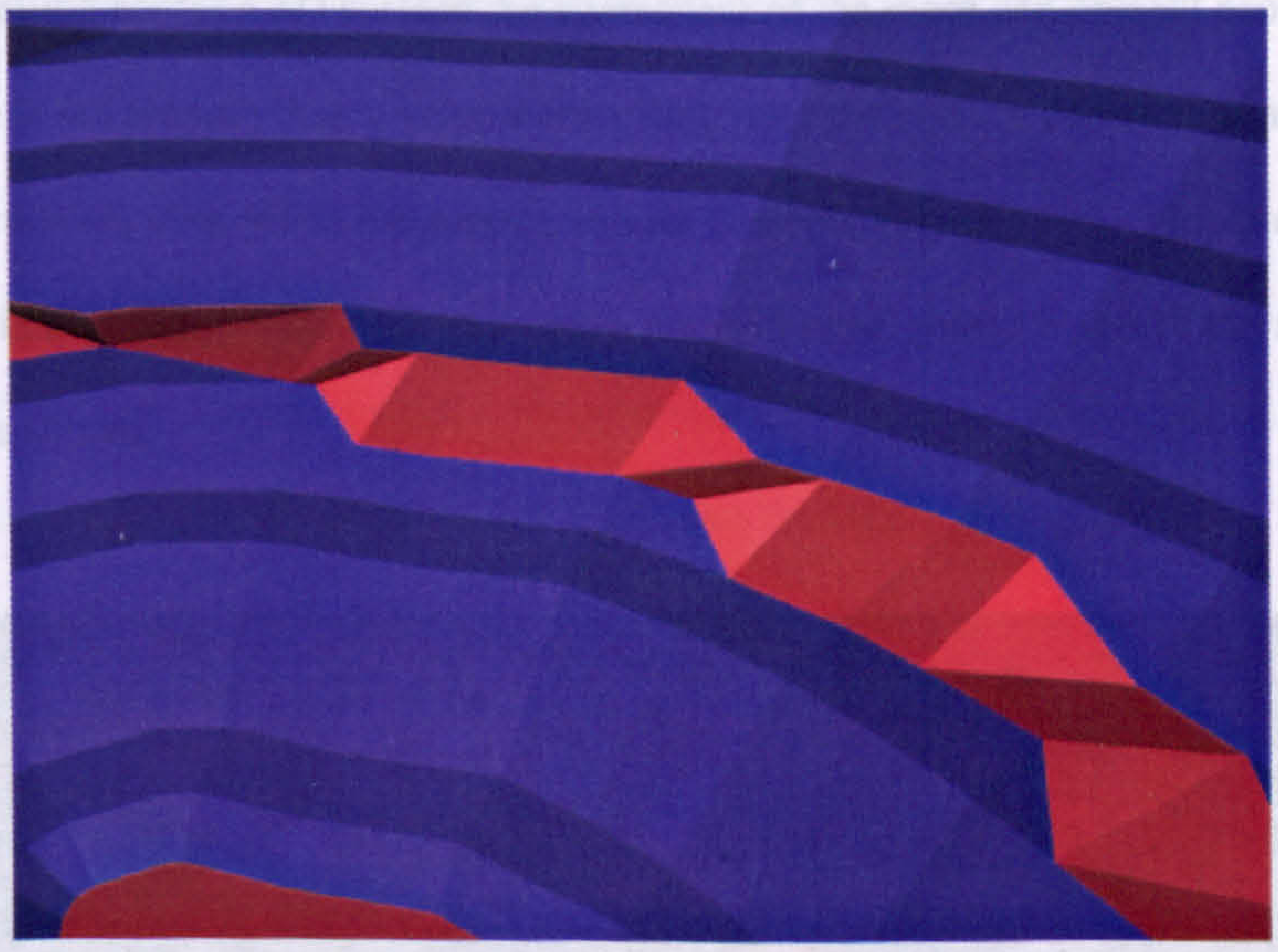

Figure 6.4 Haul road mesh (in red) from pit design package

The main problems with using the haul roads directly exported from mine design packages are as follows:

- The haul road is often not distinct from the pit mesh, it is therefore difficult to identify where the road ends and the sides of the pit begin.
- The road surface is unrealistic. It is coarsely defined which often means that it is

extremely 'bumpy' and not straight.

Output from a mine design package will normally consist only of the terrain mesh. There is typically no information concerning the location and dimensions of the haul road. Furthermore, there is normally no mechanism that allows the haul road to be identified. In Figure 6.4 the haul road (highlighted in red) has been identified manually following export from the mine design package. It is essential that information is available that details the location and dimensions of the haul road so that computer controlled equipment can be routed through the virtual world. Additionally, to provide a realistic simulation of the movement of trucks and to monitor the position of a manually driven truck it is essential to know the geometry of the road.

When travelling across a 3D surface the coarseness of the mesh can present problems, if the surface is not smooth then a vehicle travelling over the surface can experience a wide range of gradients even when the surface should be approximately flat. This problem is illustrated in Figure 6.5 where the yaw, pitch and roll experienced by a vehicle at three locations is shown.

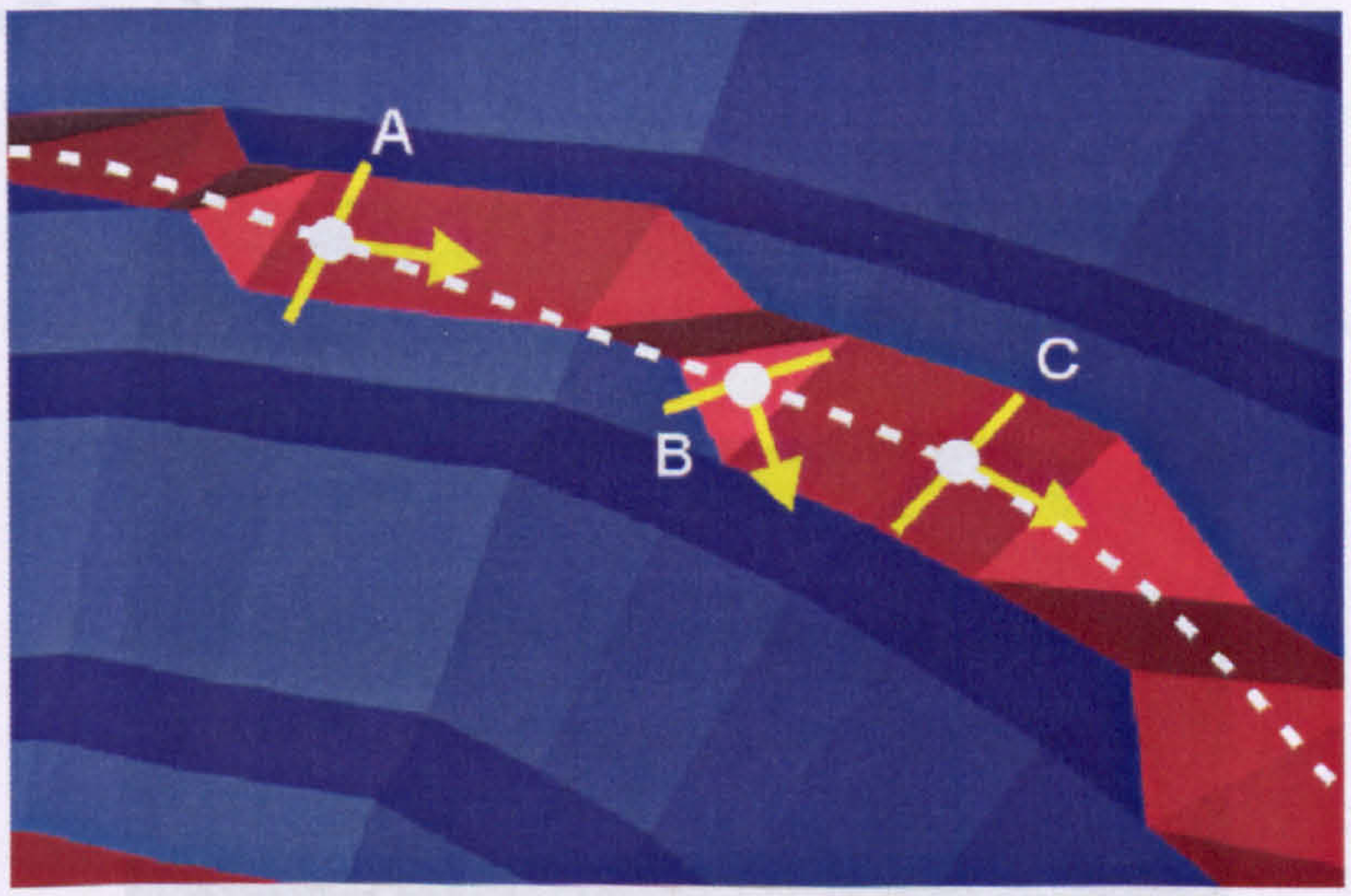

Figure 6.5 Gradients experienced by a vehicle travelling over an uneven haul road

According to Polis et al (1995) there are two basic ways to integrate roads into a 3D terrain. One approach graphically pastes road polygons directly onto the terrain skin without modifying the terrain underneath, this approach works well when the terrain is flat. However, when the terrain is not flat the results can be unrealistic as shown in Figure 6.6.

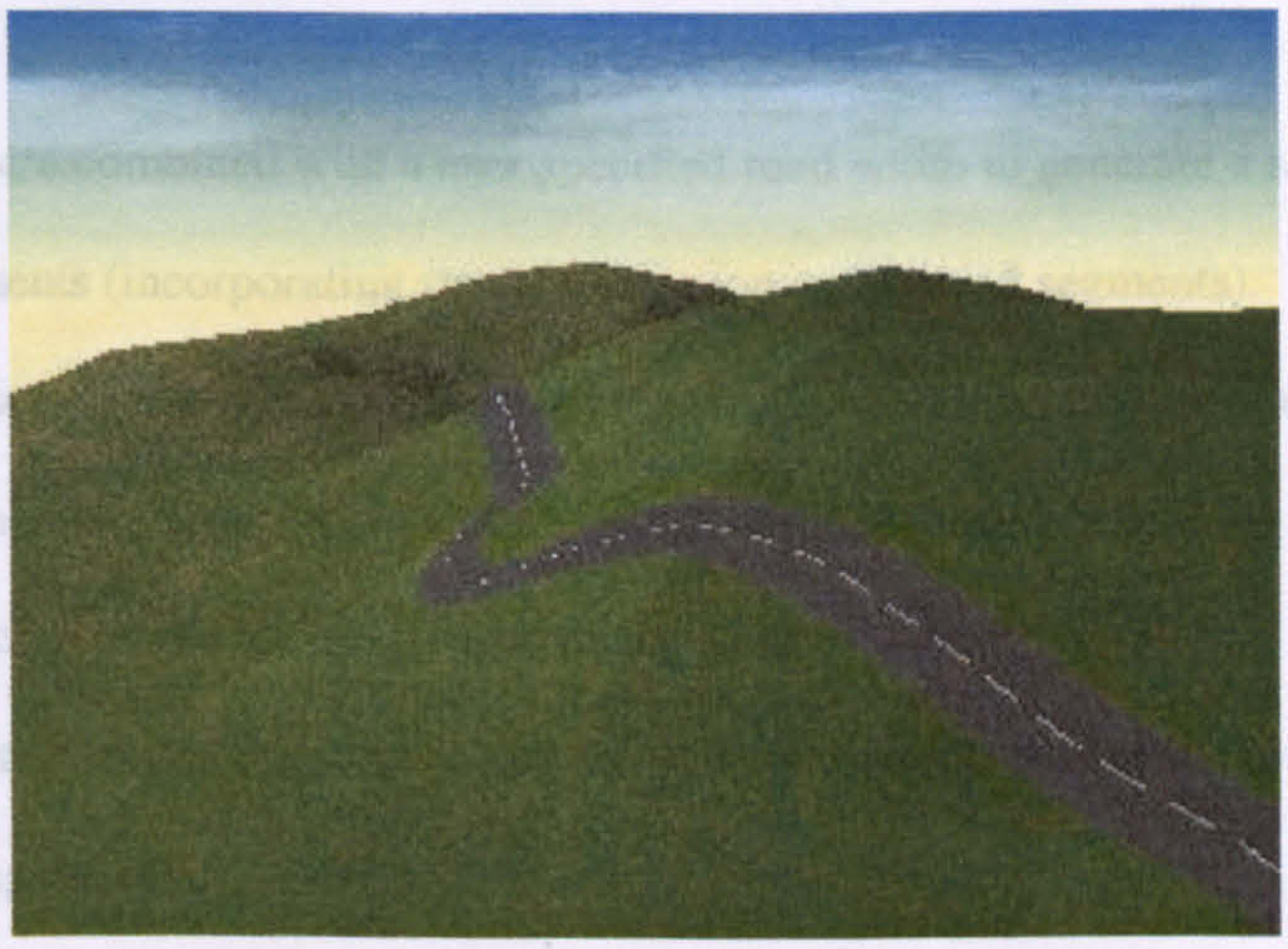

Figure 6.6 Road is pasted directly onto the terrain

The second method involves modifying the terrain geometry itself. This produces more visually pleasing and geometrically realistic results than the previous method. This is shown in Figure 6.7.

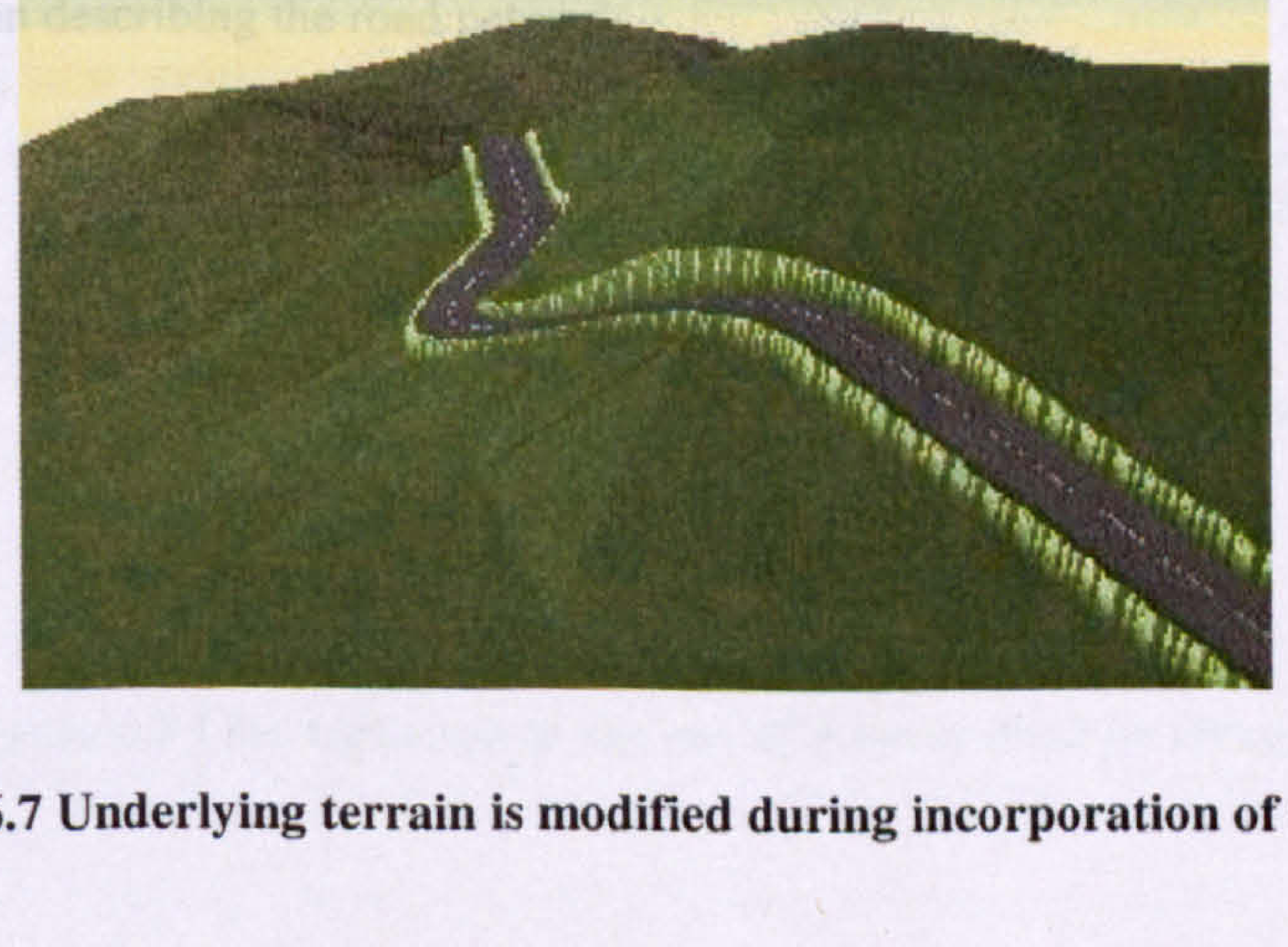

Figure 6.7 Underlying terrain is modified during incorporation of the road

The second method was chosen given the importance of providing a realistic haul road. The following procedure was defined for combining the road network into the imported 3D terrain:

1. Road network is first described as a series of 2D straight and curved lines. These define the centre of the haul road.
2. The lines are combined with a user specified road width to generate a series of 2D road segments (incorporating straight, junction and curved segments).
3. For each segment of the road, any triangles from the 3D terrain that overlap with the road segment are removed. Faces to represent the haul road are added and this is re-triangulated with the terrain to remove any holes.
4. The elevation of the haul road is calculated based upon the original elevation at each point along the road.

This procedure is described in more detail below.

6.3.2.1 Description of the 2D Road Network

The road network is first described as a set of nodes and interconnecting line segments that may be either straight or curved (see Figure 6.8). These are digitised into the system by hand using a set of simple drawing tools. This has shown to provide a large degree of flexibility when describing the road network.

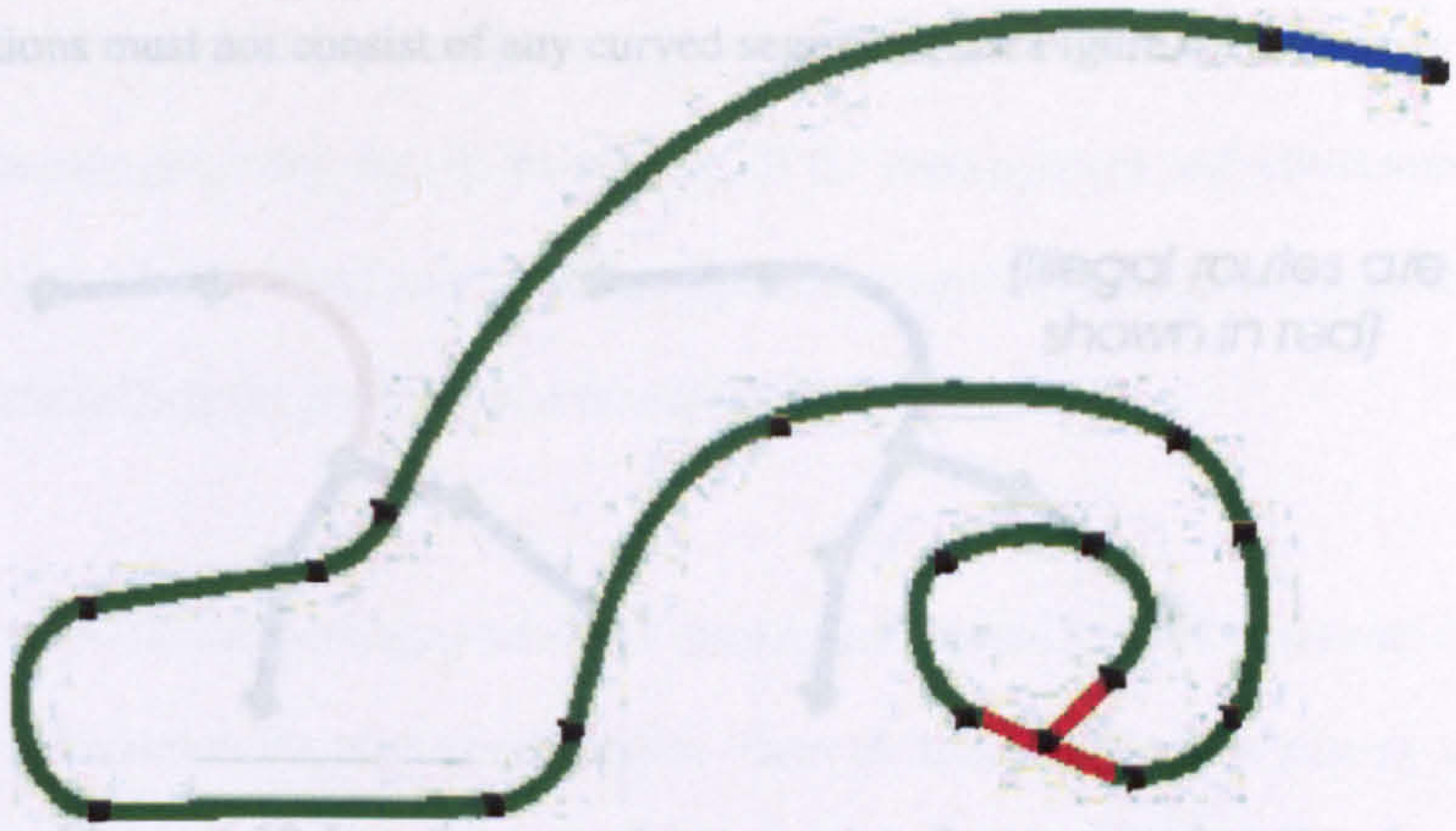

Figure 6.8 Haul road network is first described as a series of nodes and line segments

Many current mine design packages support the generation of what are termed 'strings'. These are a sequence of connected lines with a beginning and an end. It was anticipated that the similarity in the description of the road system and the string data structures used in these packages would allow the road network to be imported at the same time as the 3D terrain. This would remove the process of digitising a road network by hand. Any combination of straight and curved routes can be used as long as the following conditions are met.

1. Each line segment that is at the end of the route must be straight, and not connected to a junction node, see Figure 6.9.

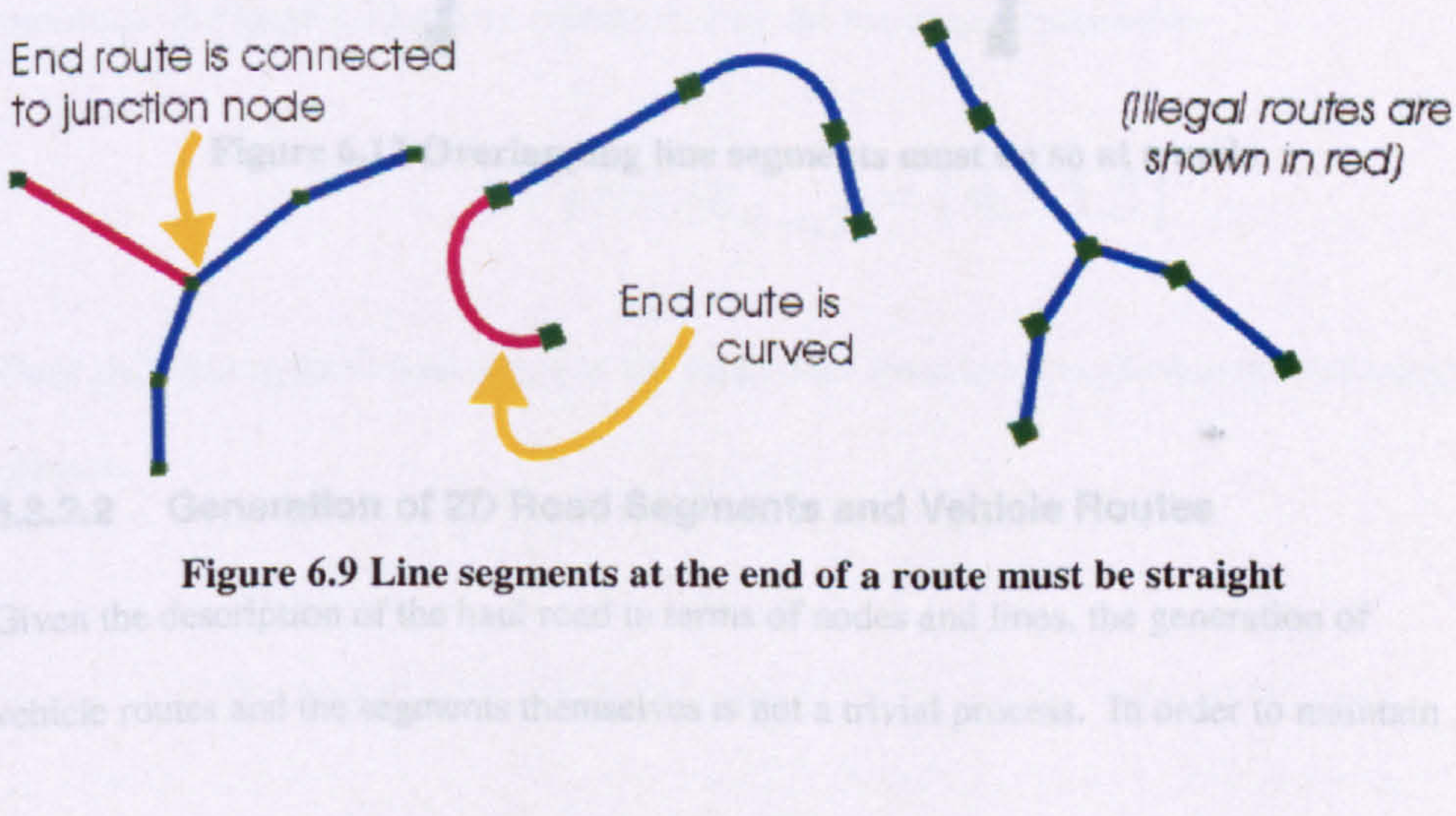

Figure 6.9 Line segments at the end of a route must be straight

2. Junctions must not consist of any curved segments, see Figure 6.10.

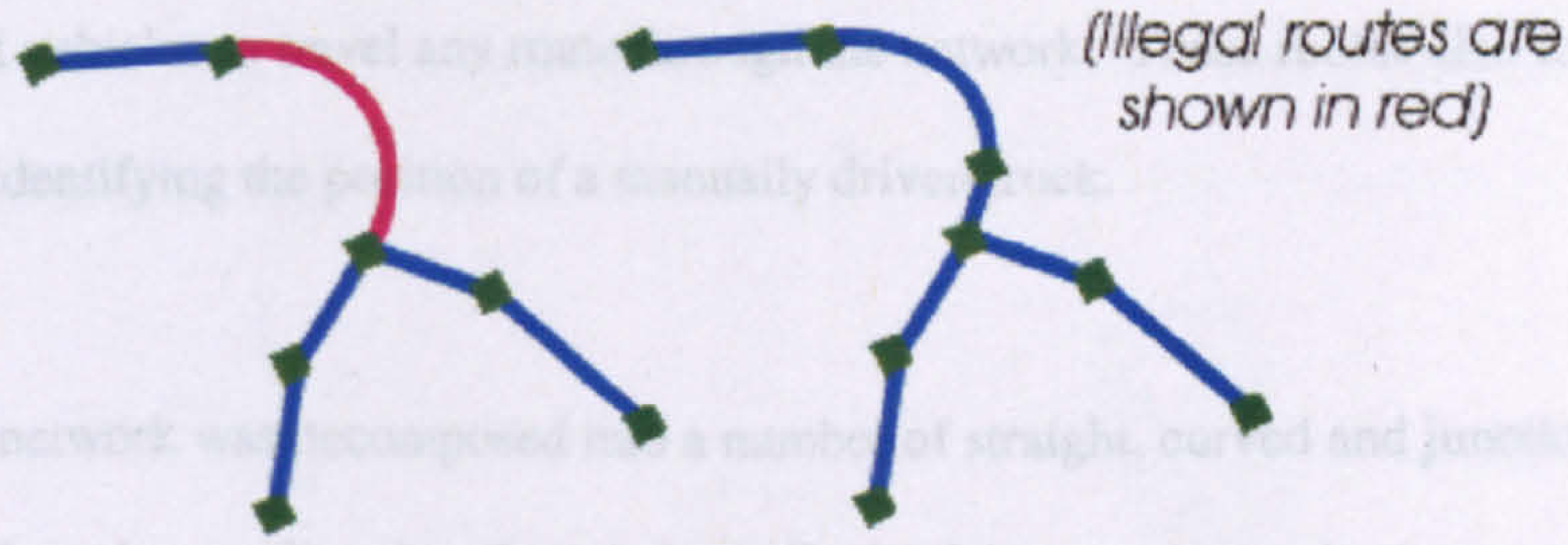

Figure 6.10 Junctions must not consist of any curved segments

3. Only one line segment may exist between any two nodes, see Figure 6.11.

Figure 6.11 Only one connection between any two nodes

4. Lines that overlap must do so at a node, see Figure 6.12.

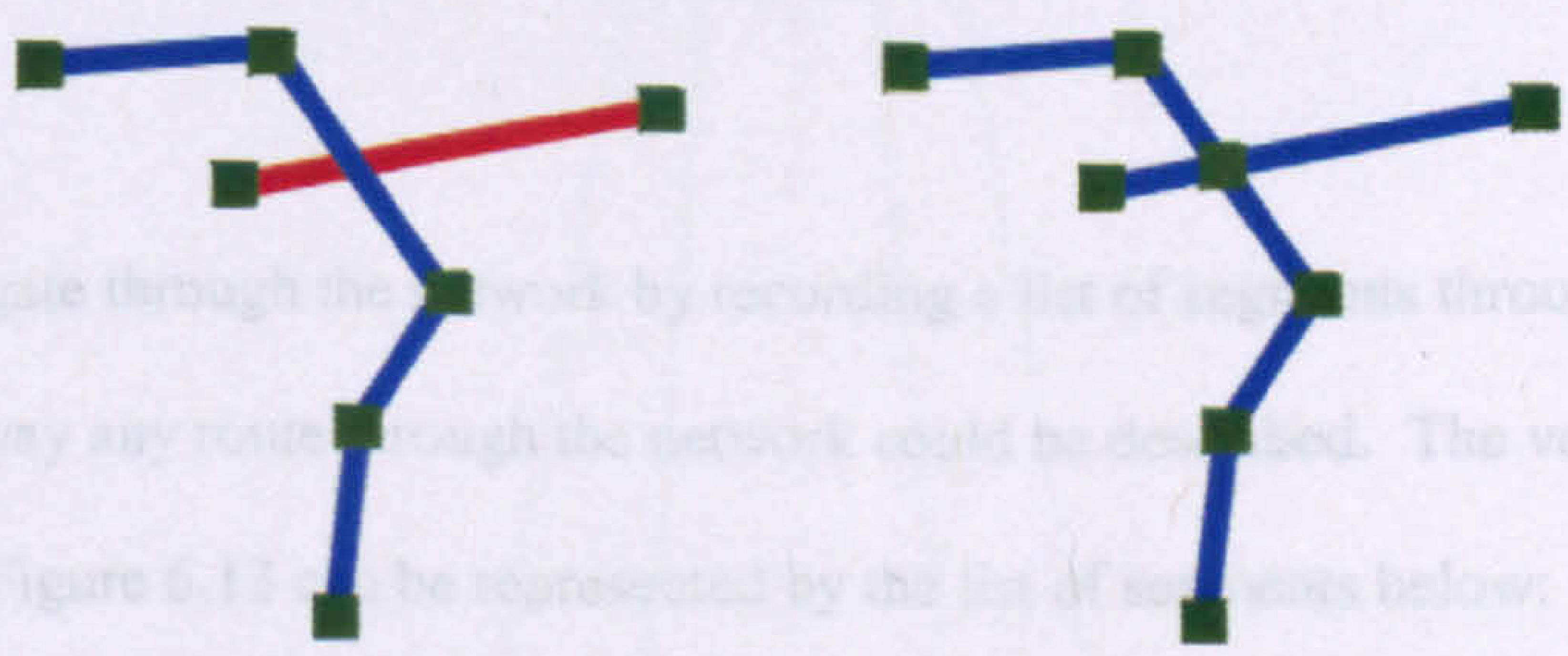

Figure 6.12 Overlapping line segments must do so at a node

6.3.2.2 Generation of 2D Road Segments and Vehicle Routes

Given the description of the haul road in terms of nodes and lines, the generation of vehicle routes and the segments themselves is not a trivial process. In order to maintain the speed of the real-time system pre-computed vehicle paths are used wherever possible. These paths are generated during the creation of the road network and allow computer-controlled vehicles to travel any route through the network. These routes also form the basis for identifying the position of a manually driven truck.

The road network was decomposed into a number of straight, curved and junction segments based upon the rules given below. Each of these segments is given a unique ID value, they also maintain a list of connecting segments and a description of all possible routes. These describe how to get from one connecting segment to another. Examples of this are given in Figure 6.13.

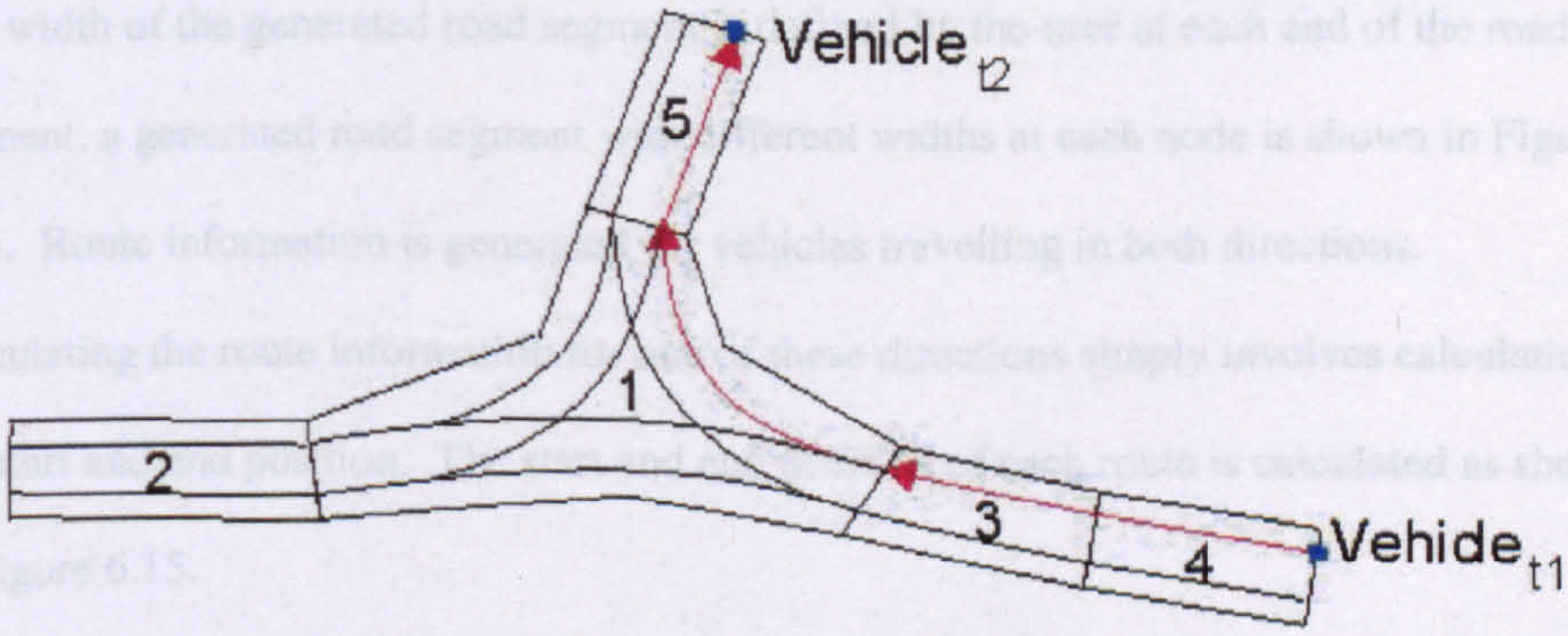

Figure 6.13 Segment ID's and routes

Vehicles navigate through the network by recording a list of segments through which they pass. In this way any route through the network could be described. The vehicle movement in Figure 6.13 can be represented by the list of segments below:

$$Vehicle_{t1\rightarrow t2} = \{4,3,1,5\}$$

Three different types of road segment are supported; these are described in the following sections.

Straight Segment

This is generated when the nodes at each end of the line segment have no more than one additional connecting segment and the line connecting the two nodes is straight. An example is given in Figure 6.14.

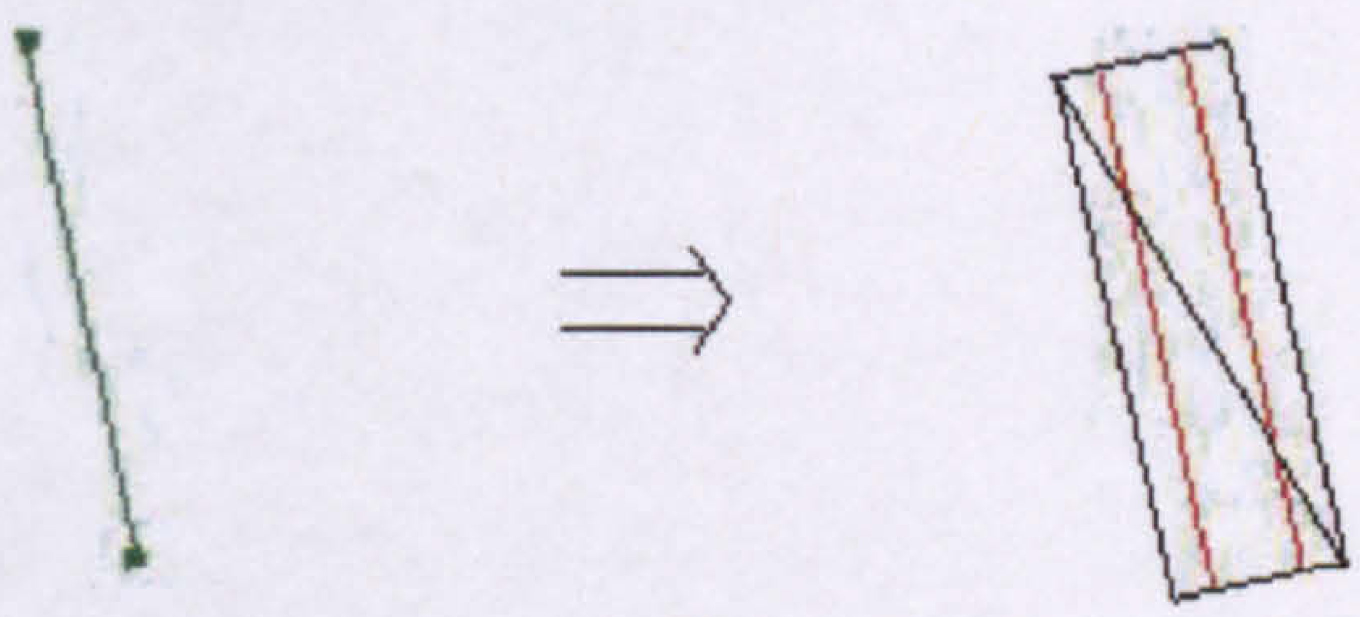

Figure 6.14 Straight segment road generation

The width of the generated road segment is defined by the user at each end of the road segment, a generated road segment with different widths at each node is shown in Figure 6.15. Route information is generated for vehicles travelling in both directions. Calculating the route information for one of these directions simply involves calculating the start and end position. The start and end position of each route is calculated as shown in Figure 6.15.

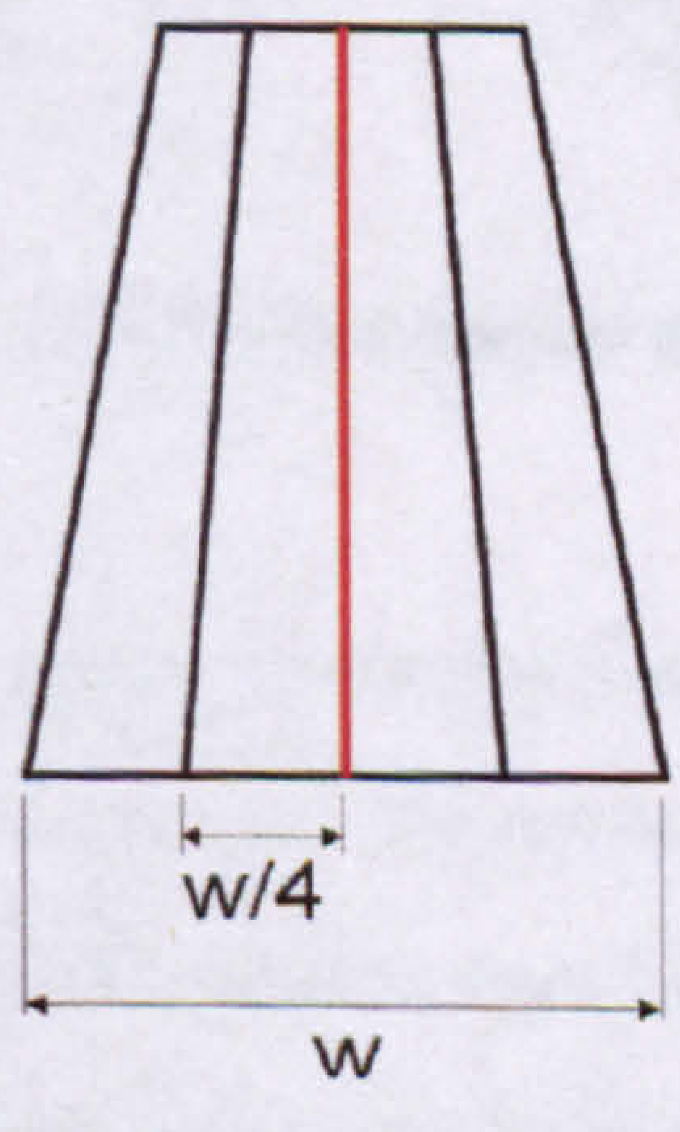

Figure 6.15 Variable width straight road segment showing calculation of route position

Since the segment varies linearly in height from one end to the other it is possible to compute the position of a vehicle on this segment given the route, and a distance along that route. Care must be taken to ensure that the direction of each route is consistent with the vehicle travelling on the right hand side of the road. The two routes are generated in opposite directions, a check is then performed to ensure that they 'appear' clockwise when viewed from above. If they appear counter clockwise the routes are simply reversed.

Curved Segment

A curved segment is generated when the nodes at each end of the line segment have no more than one additional connecting segment and the line connecting the two nodes is curved. The segment has a uniform curvature throughout. An example is shown in Figure 6.16.

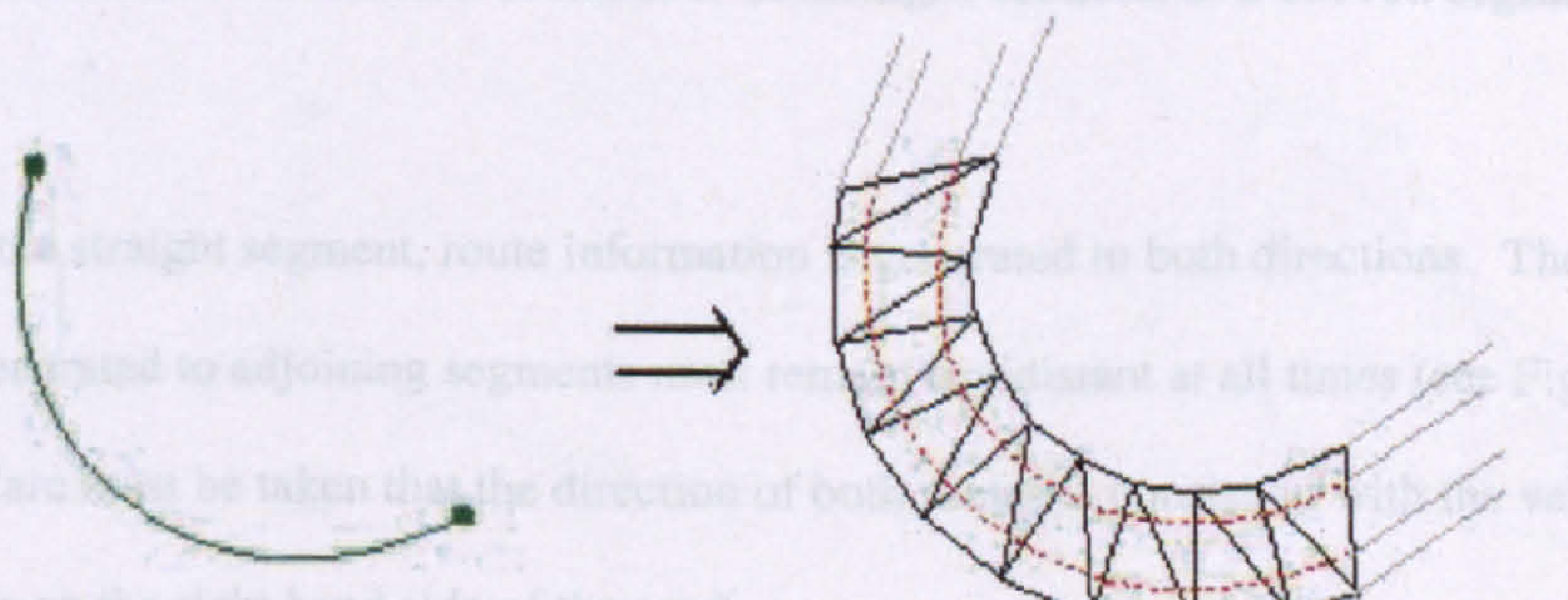

Figure 6.16 Curved segment generation

The road segment itself is decomposed into smaller straight segments to maintain a low face count whilst retaining the curved look. The number of straight segments into which the curve is decomposed is dependent upon the angle through which the curve passes. The number of segments is calculated as shown in Figure 6.17 and Equation 6.1. Dividing by a value of $\pi/10$ means that a full circle is decomposed into exactly 20 segments, this value has shown to provide a good balance between providing a curved look and maintaining a low face count. The width of the road can be defined by the user but must be the same along the entire length of the curve.

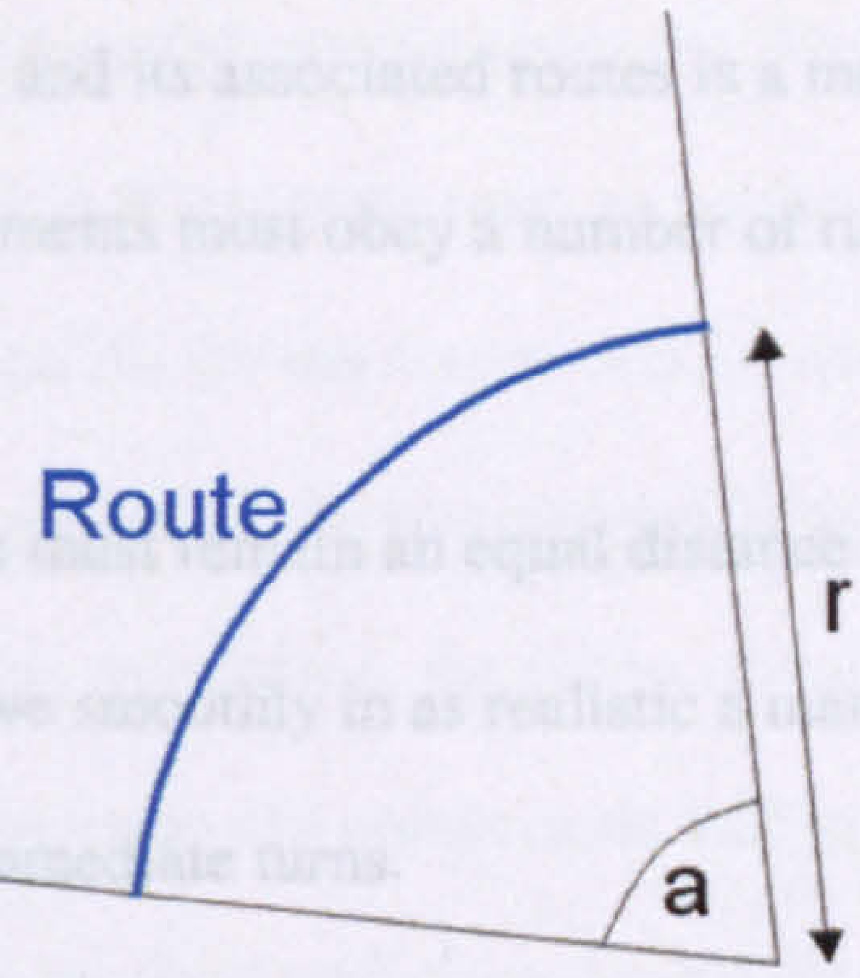

Figure 6.17 Curved route line segment

$$\text{Number of straight segments} = \frac{\text{Angle (a) in radians}}{\frac{\pi}{10}}$$

Equation 6.1 Calculation of number of straight sections in a curved segment

As with the straight segment, route information is generated in both directions. The routes generated to adjoining segments must remain equidistant at all times (see Figure 6.18). Care must be taken that the direction of both routes is consistent with the vehicle travelling on the right hand side of the road.

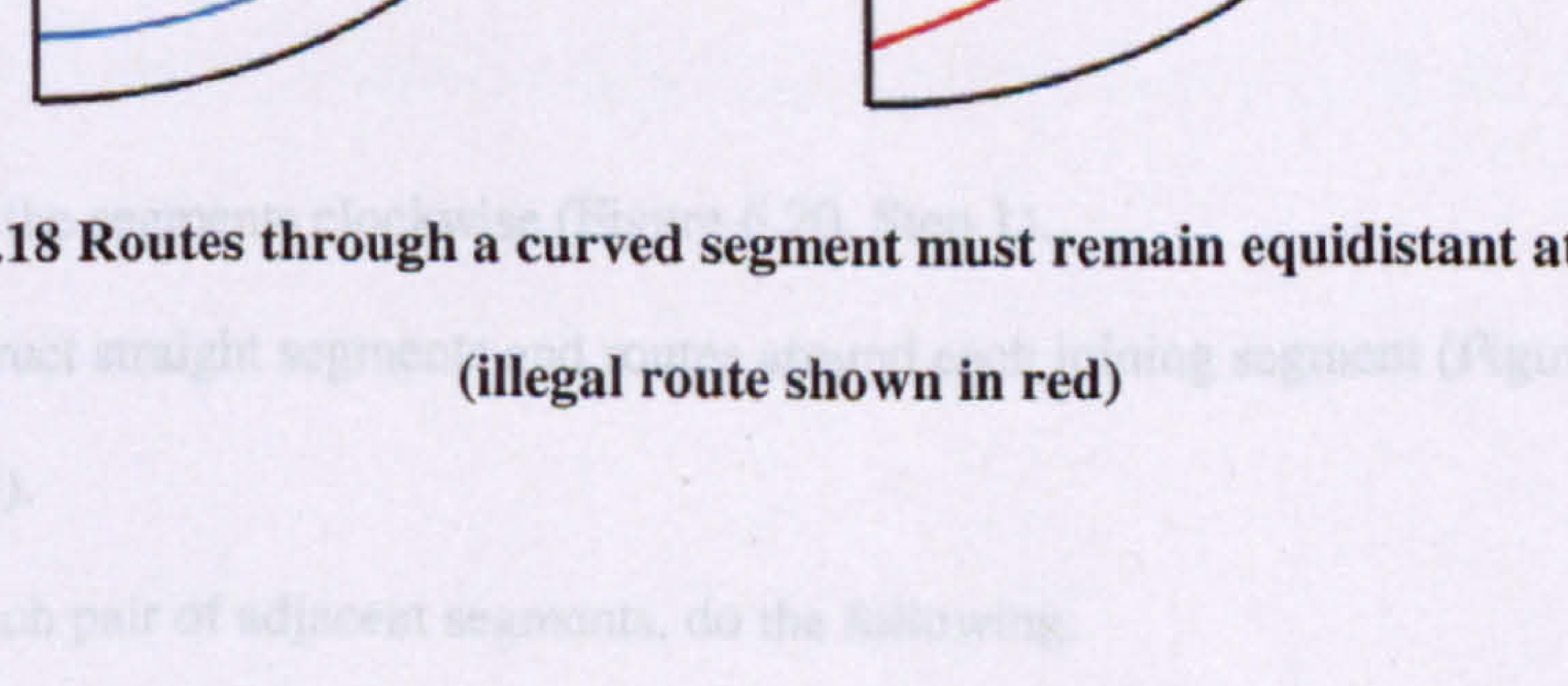

Figure 6.18 Routes through a curved segment must remain equidistant at all times (illegal route shown in red)

Junction Segment

Generation of a junction segment and its associated routes is a more complicated process. Routes to and from adjoining segments must obey a number of rules:

- Routes in opposite directions must remain an equal distance apart at all times.
- Vehicles must be able to move smoothly in as realistic a manner as possible. There must not be any sudden or immediate turns.
- Junctions may involve more than three intersecting routes.
- Roads must be able to intersect at any angle.

An algorithm for constructing junction segments when three or more straight segments join at any given node was developed. The result of applying this algorithm is shown in Figure 6.19.

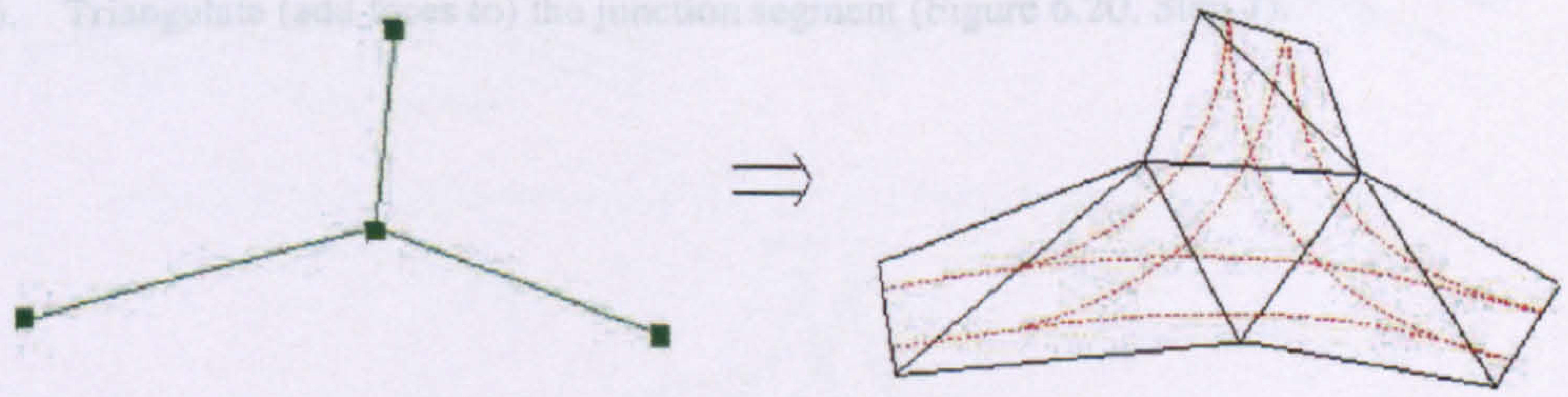

Figure 6.19 Junction segment generation

Each route within the junction segment will consist of a curved section and up to two straight sections. This is necessary to ensure that routes in opposite directions remain equidistant at all times and that they join perfectly with the routes in adjacent segments. The construction algorithm is as follows:

1. Order the segments clockwise (Figure 6.20, Step 1).
2. Construct straight segments and routes around each joining segment (Figure 6.20, Step 2).
3. For each pair of adjacent segments, do the following:

a. Construct a line that passes through the centre of the junction and the intersection of the two associated straight segments (Figure 6.20, Step 3). The centre of the curved section of the route must lie on this line.

b. Calculate the maximum radius for the curved section of the inner route such that the resulting circle is tangential to the two associated straight routes (Figure 6.20, Step 4). As a result of this calculation, the centre of the circle that is used for the curved section of both the inner and outer routes will be known. The centre of the circles used to define the inner and outer curved sections are the same, this ensures that the routes in opposite directions remain equidistant at all times.

c. Calculate the inner and outer routes for these two segments (Figure 6.20, Step 5). This will include the curved and straight sections of each route.

d. Calculate the position of the associated inner vertex for these two adjoining segments (Figure 6.20, Step 5).

5. Order the resulting vertices of the junction segment (Figure 6.20, Step 6).
6. Triangulate (add faces to) the junction segment (Figure 6.20, Step 7).

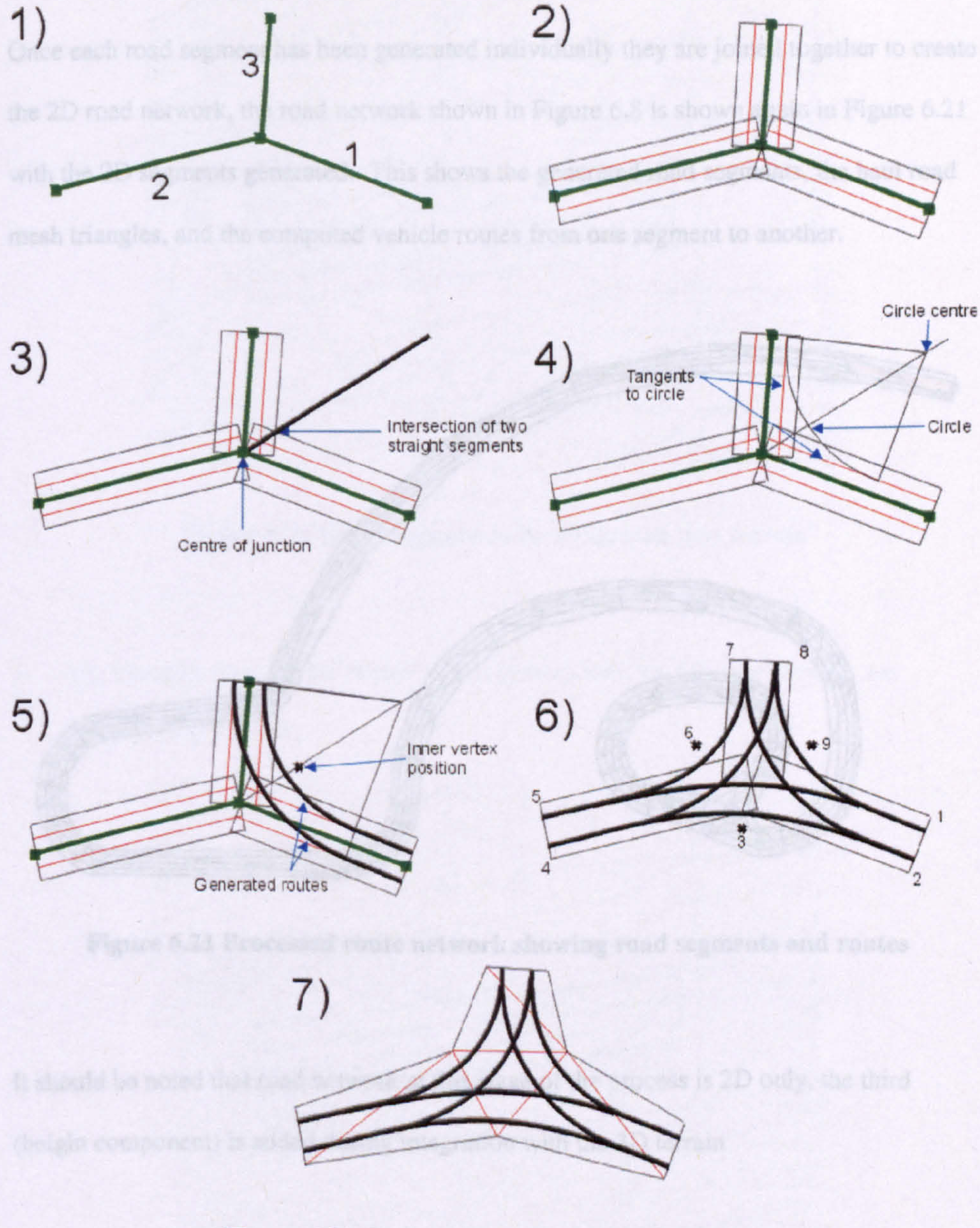

Figure 6.20 Construction of a junction segment

The curved sections of the routes within the junction segment are calculated using the same procedure as the routes in the curved segment. As with the curved segment, the width of the road must be equal along the entire lengths of each segment that comprises the junction.

Integrating the Segments into a 2D Road Network

Once each road segment has been generated individually they are joined together to create the 2D road network, the road network shown in Figure 6.8 is shown again in Figure 6.21 with the 2D segments generated. This shows the generated road segments, the haul road mesh triangles, and the computed vehicle routes from one segment to another.

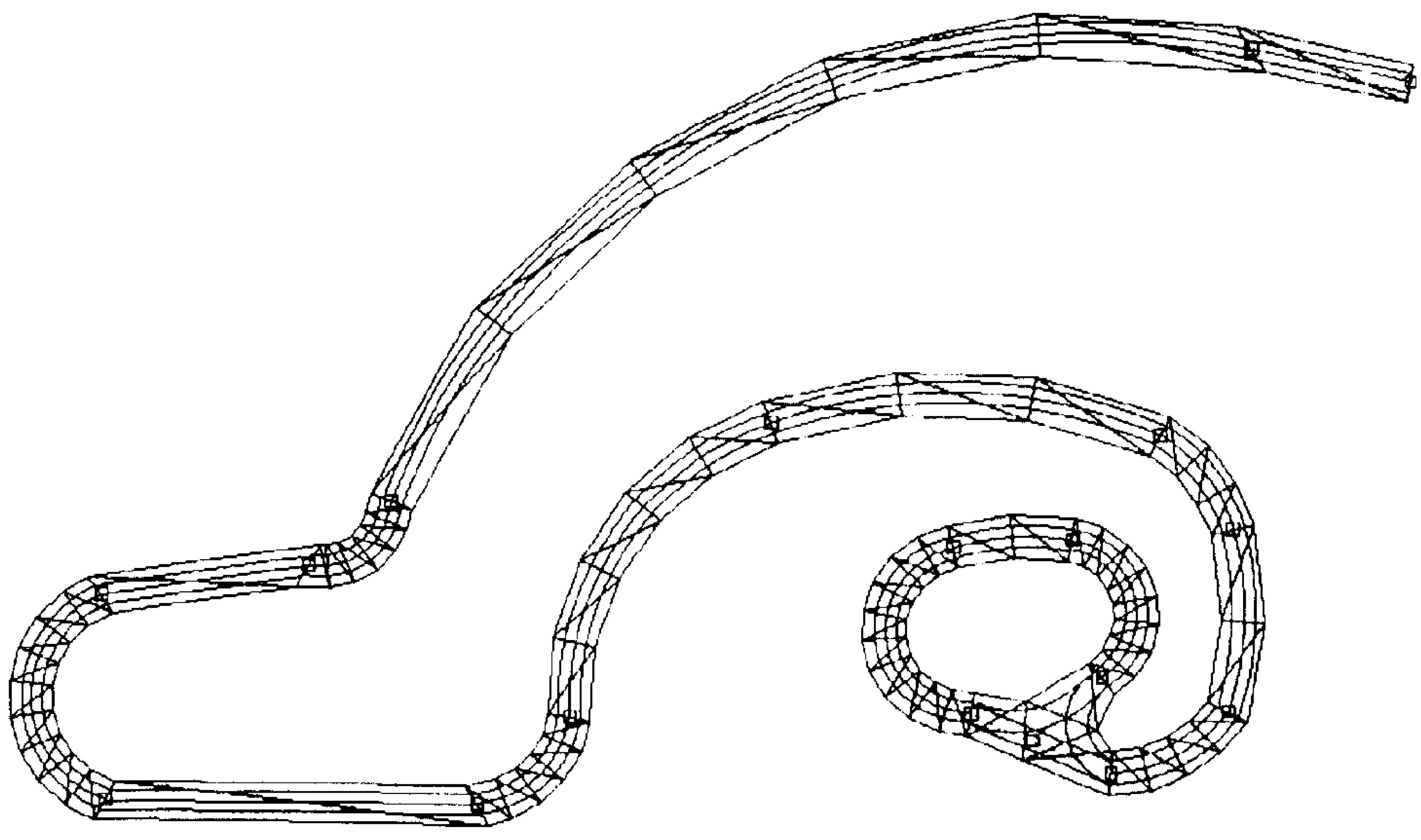

Figure 6.21 Processed route network showing road segments and routes

It should be noted that road network at this stage of the process is 2D only, the third (height component) is added during integration with the 3D terrain

6.3.2.3 Integration of 2D Road Segments into 3D Terrain

The 2D road network is superimposed over the imported 3D terrain as shown in Figure 6.22. Each of the individual 2D road segments is then integrated into the 3D terrain using a three-step process.

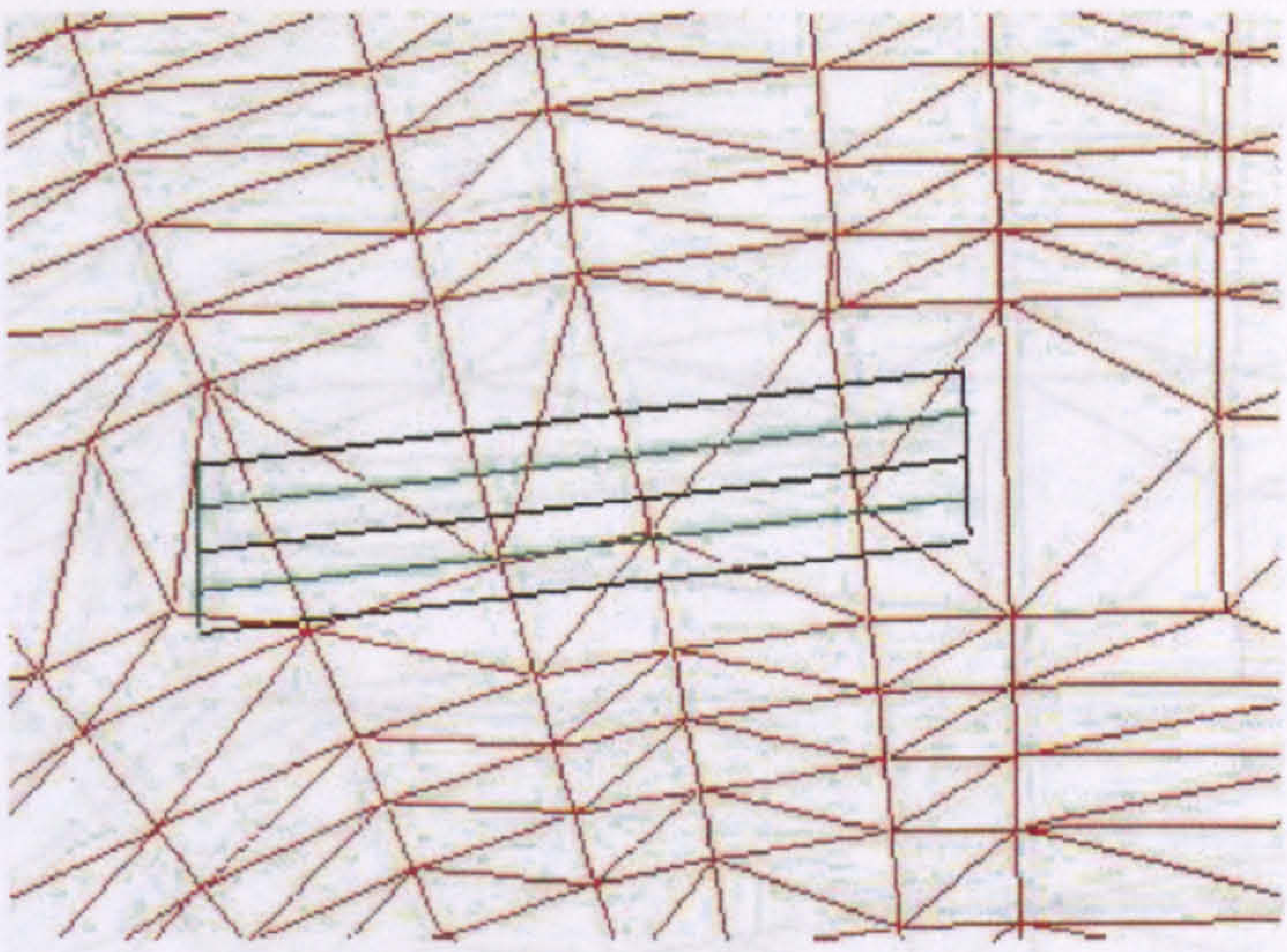

Figure 6.22 Road segment to be integrated into terrain

1. Any triangles from the 3D terrain which overlap with the 2D road network are removed (Figure 6.23).

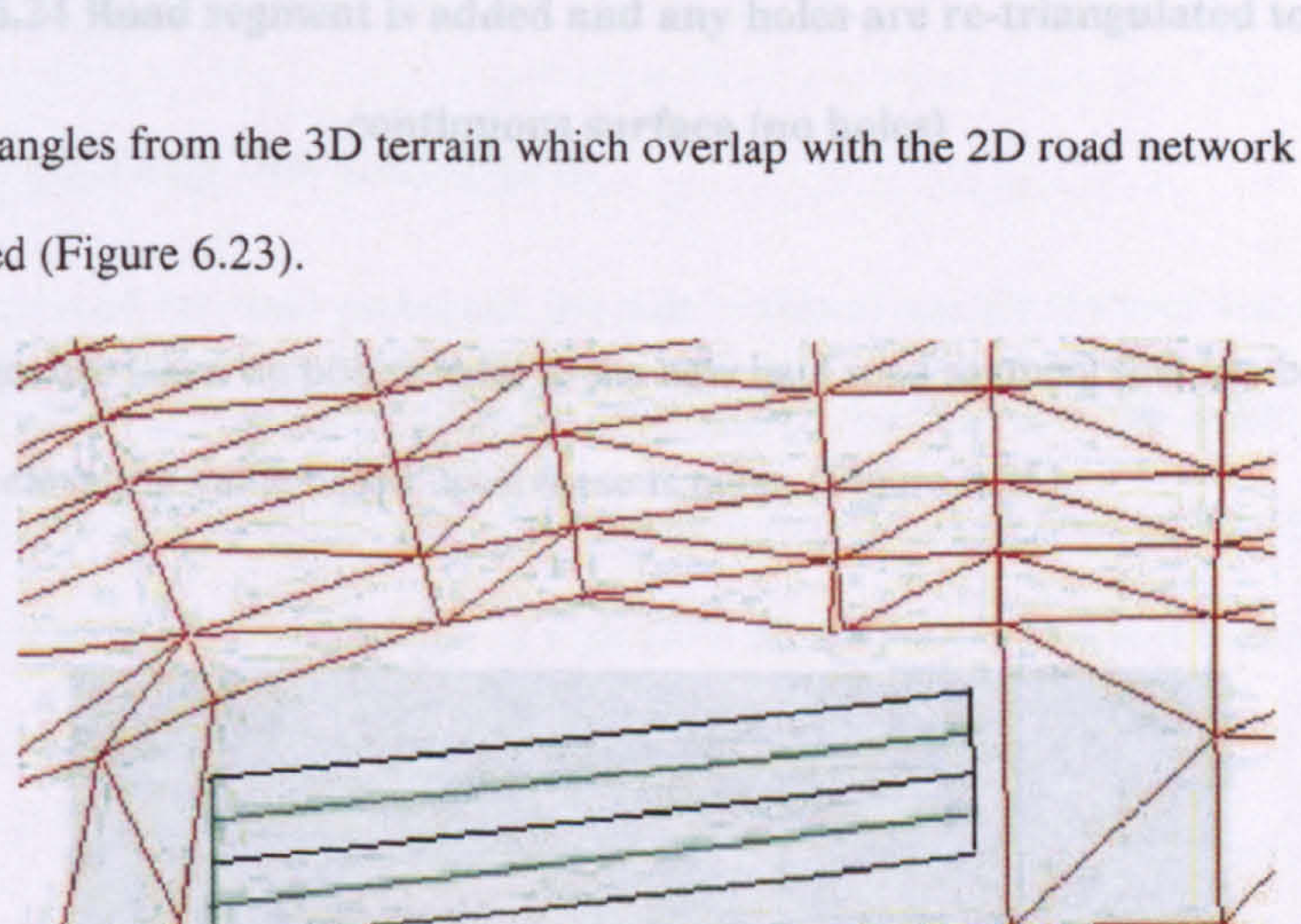

Figure 6.23 Faces from the terrain are removed

2. The triangles that make up the road segment are added into the 3D terrain. Any holes which remain in the terrain are re-triangulated (Figure 6.24).

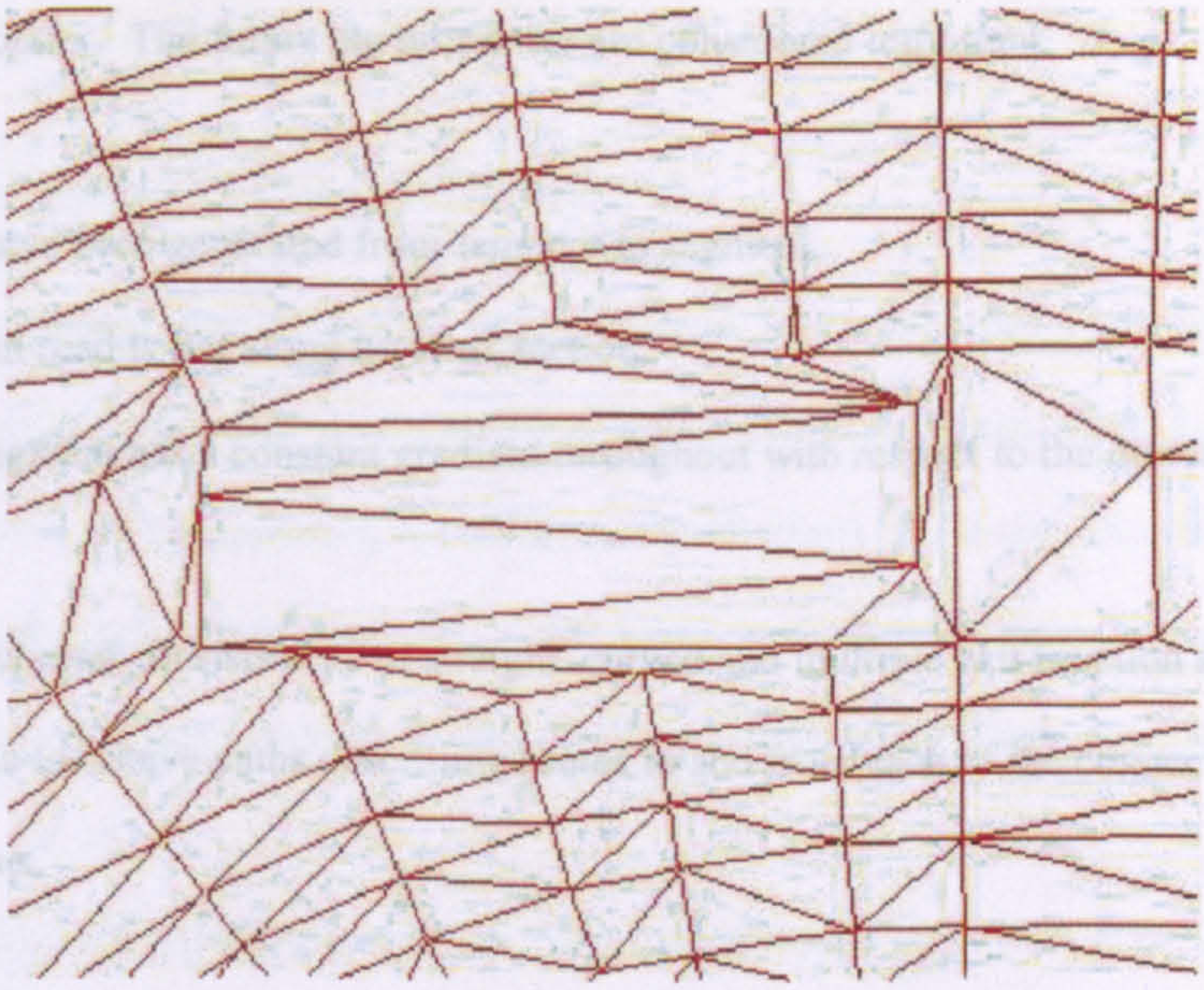

Figure 6.24 Road segment is added and any holes are re-triangulated to form a continuous surface (no holes)

3. Averages are taken on points local to the new haul road segment that has been added and an elevation value based upon these is taken (Figure 6.25).

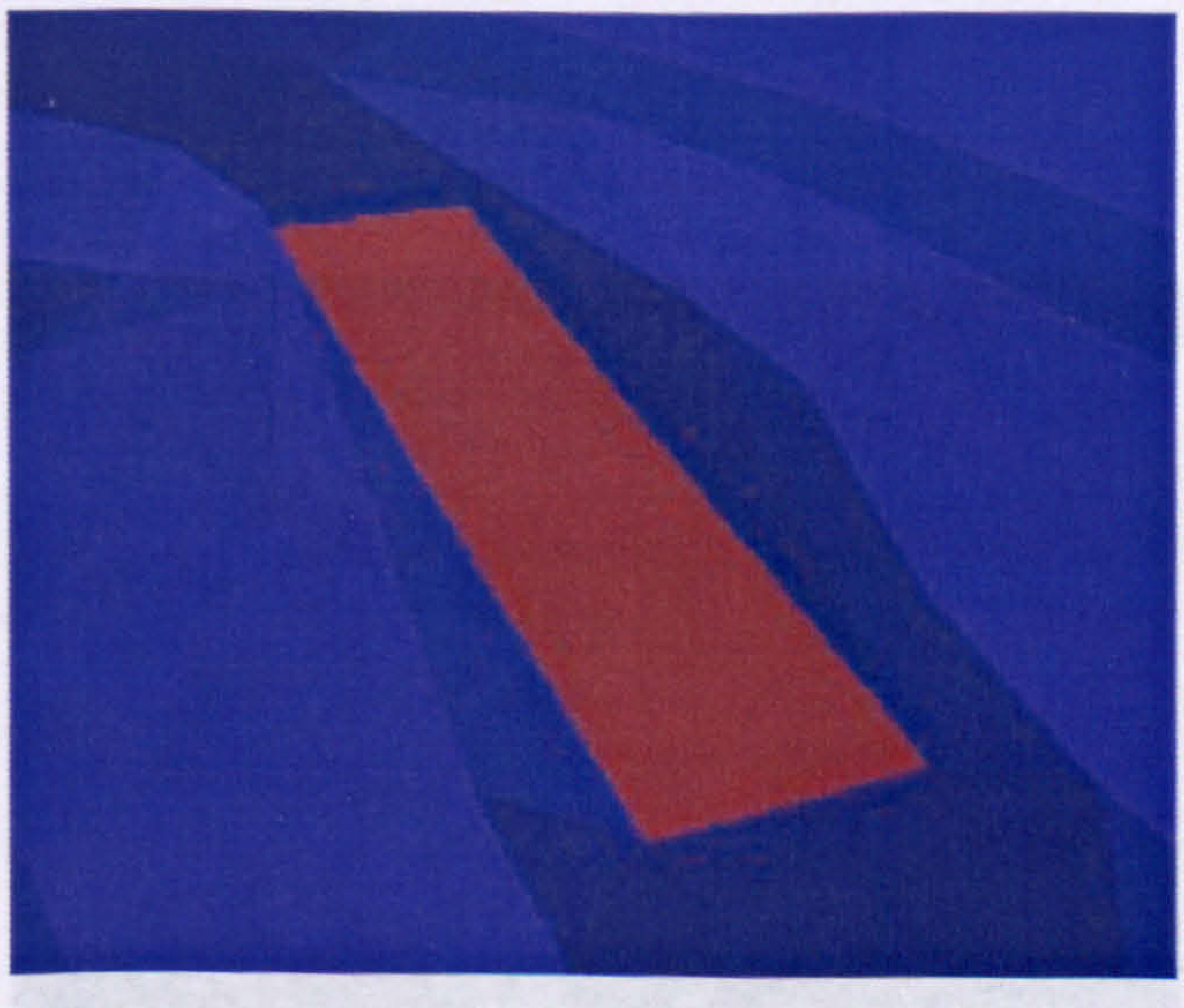

Figure 6.25 Elevation values are computed

The geometrical representation of the generated haul road is aesthetically correct. Generating the haul road in this way allows us to ensure that it is suitable for use in the driving simulator. The following properties are considered important.

1. Paths have been generated from segment to segment.
2. The haul road is flat along its cross section.
3. Each segment has a constant gradient throughout with respect to the direction of travel.
4. The haul road consists only of straight, curved and multiple exit junction segments. These in turn have paths describing routes to and from each of the connecting segments.

6.3.3 Texturing the Landform

Once the haul road has been generated, the user is able to specify textures that are subsequently applied to the pit wall and haul road objects. The user can either provide a texture in the form of a bitmap, perhaps a photo of the rock surface in the mine, or use one of those provided. An example of a textured haul road segment and terrain is shown in Figure 6.26.

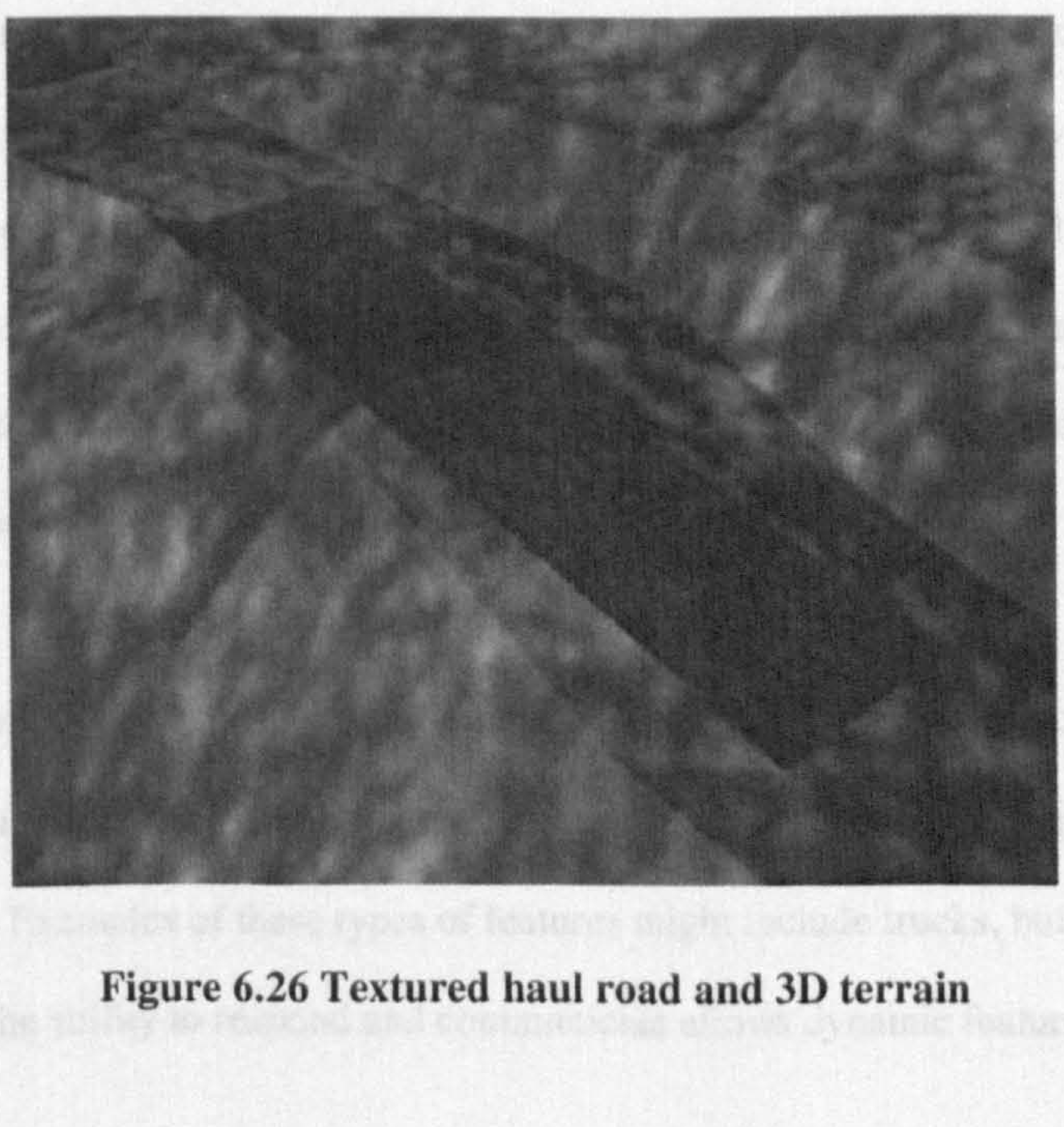

Figure 6.26 Textured haul road and 3D terrain

6.3.4 Populating the Environment

Once the terrain and road system has been generated, the environment must be populated with other features, for example, equipment, personnel and buildings. Each feature will have a different set of properties, for example a truck might be moving around a site and would typically require a different set of data than a stationary building. The properties of each feature will be dependent on the nature of the real world object that it represents.

Vince (1995) notes that objects within a virtual environment can typically be divided into two groups, static and dynamic. Consider an architectural interior, Vince identifies the static objects as those which cannot be moved (floors, ceilings and stairs) and the dynamic as those which are able to move (doors, windows and drawers).

The approach used here is similar to that described by Vince, it was hoped that classifying objects into static and dynamic types helps to ensure that the system remains flexible, customisable and extensible.

Within the VTruck framework three types of objects were defined. The landform objects comprise the underlying terrain, these include the pit walls and the haul road objects. Static features are defined as objects within the virtual environment that never move and are not required to communicate with any other features in the virtual world. Examples of static features might include buildings, road signs, trees or spillage on the side of the road. During the creation and editing of a scenario, the user is only required to specify the position and possibly orientation of the static feature.

Dynamic features require more processing than static, not only may they move through the environment, but they must also respond to and communicate with other objects in the virtual world. Examples of these types of features might include trucks, bulldozers and excavators. The ability to respond and communicate allows dynamic features to modify their and other features behaviour based upon the state of the surrounding environment. The specification of dynamic features during scenario creation will obviously be more involved. As with static features initial position and orientation must be specified. Additional information might also be required, including a vehicle's route information, its performance, and how it should behave under certain conditions.

A library of features is provided, though additional features may be subsequently defined and used by the scenario editor. For each feature that is defined, data must be provided describing such things as its dimensions, performance or behaviour. Typical properties might include:

- A 3D model used to represent the feature
- Size of the feature, used to test for collisions within the 3D world.
- Hazard information, used during the hazard-spotting phase of the training simulator.
- Information concerning a vehicles performance.
- Details regarding the features behaviour under specific conditions or at specific times.

Well populated scenarios can be built from the features provided in the standard library, however, the ability to define further features or to modify existing ones allows a wide range of scenarios to be modelled.

6.3.5 Hazard Information

Each object in the virtual environment may have attached hazard information. This information defines the choices that can be made during the hazard identification phase of the training simulation, and also contains the necessary information for evaluating performance. It describes the hazards associated with each type of object, the available risk levels of a hazard, and the possible corrective actions that may be taken.

The structure of the information is in the form object-hazard, hazard-risk level and hazard-action. Each of these relationships is one to many (any number of hazards can be defined for a given object, similarly any number of risk levels and actions can be defined for a given hazard). Each of the relationships has an associated score that is used when evaluating trainee performance.

Additional relationships within this structure may be defined or existing ones edited through the VEdit application. Additional descriptions of the variables recorded to measure the performance of the trainee are given in later sections.

6.3.5.1 Object-Hazard

The hazard score is an indication of the severity of incorrectly identifying the hazard, the larger the associated hazard score the greater the impact on the trainee score if the hazard is missed. The values used are relative and have no scale, suitable judgements must be made by the trainer when assigning these values. Table 6.1 shows example hazards for a parked land rover.

Object	Hazard	Hazard Score
Parked land rover	Irregular positioning	40
	No lights on	30
	Vehicle unattended	40

Table 6.1 Example hazards and scores with a parked land rover

6.3.5.2 Hazard-Risk Level

The risk level score is a relative measure of the risk assigned to the hazard, this is only considered if the hazard has been correctly identified by the trainee. If the risk level is incorrectly specified then the difference between the correct level and the trainee specified risk level is added to a cumulative risk level score maintained for the trainee. If the trainee is consistently overestimating or underestimating the level of risk then the cumulative risk level score should indicate this. The values assigned have no scale and should be chosen based upon the judgement of the trainer. The number of correct and incorrect risk level identifications is also recorded.

For the hazard 'Irregular positioning' the risk levels, actions and their associated scores can be defined as in Table 6.2 and Table 6.3. Similar tables exist for the other hazards associated with the Land Rover.

Hazard	Risk Level	Risk Level Score
Irregular positioning	Low	30
	Medium	60
	High	90

Table 6.2 Example risk levels and their associated scores for the irregular positioning of a Land Rover

6.3.5.3 Hazard-Action

The action score is a measure of the severity of choosing an incorrect action, this is only considered if the hazard has been successfully identified by the trainee. The larger the value chosen the more impact it will have on trainee score if they fail to select it. The values assigned have no scale and should be chosen based upon the judgement of the trainer. For the hazard 'Irregular positioning' the actions and their associated scores could be defined as in Table 6.3. Similar tables exist for other hazards associated with the land rover.

Hazard	Action	Action Score
Irregular positioning	Stop and tell driver to move	10
	Flash the driver.	20
	Radio control	40
	Ignore	10

Table 6.3 Example corrective actions and their associated scores for the irregular positioning of a land rover

6.3.6 Testing the Scenario

The scenario created must be verified to ensure that the generated virtual environment is a realistic representation of the real world and that the features within the environment behave in a lifelike manner. Testing can occur at each stage in the scenario generation process outlined in Figure 6.2. Testing is undertaken to ensure the validity of the landform, the road network, and the positioning and behaviour of static and dynamic features.

Dynamic features have the ability to modify their and other feature's behaviour based upon the state of the surrounding environment. If a manually driven vehicle is used in the scenario then the output from the simulation in terms of the positioning of dynamic features will be unknown. Only the input to the simulation can be specified during scenario creation, even if these initial parameters are acceptable, the output from the simulation may produce undesirable results. Extensive testing and subsequent modification of the scenario will help to ensure that the scenario created is as realistic as possible. A number of different types of testing are supported within the system, these include:

1. Quick preview of the movements of equipment in the 2D editor.
2. Inspection of the scenario in 3D.

3. Experiencing the scenario as a trainee (effectively the running in training mode).

6.3.6.1 Previewing the Scenario in 2D

The application that was written to allow the creation and editing of a scenario in 2D provides a plan view of the environment. The view shows the landform and the location of all the added features in 2D, an example is shown in Figure 6.27. In Figure 6.27 the small green squares represent the user defined static or dynamic features.

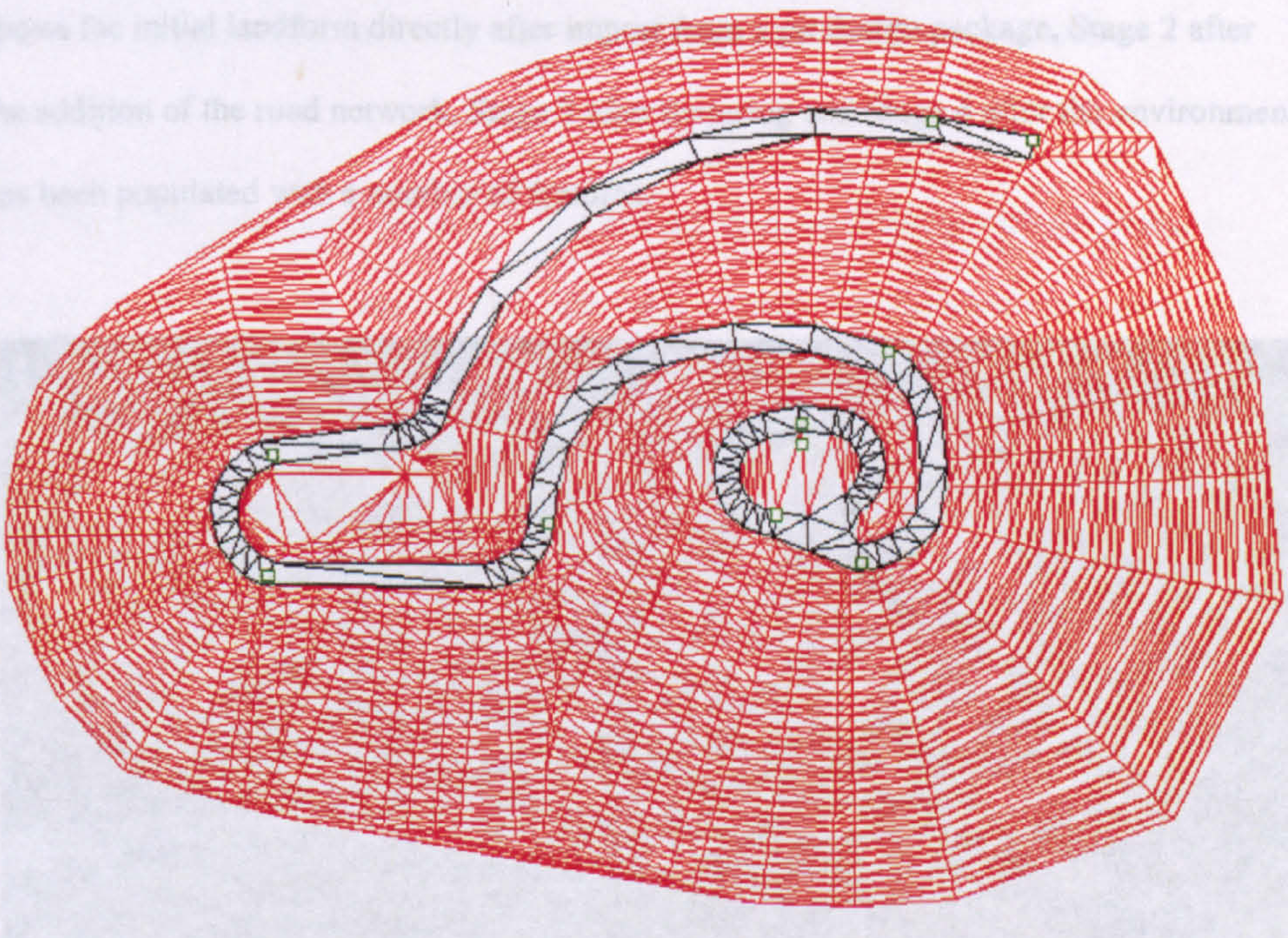

Figure 6.27 2D preview of scenario

The 2D editor also provides access to the simulation component of the system, this allows the movements of dynamic features to be evaluated. This provides a quick and easy method for identifying vehicle routes and potential problems with the specified initial parameters. The 2D nature of the view allows editing to be performed within a simple interface, this is important given that the target users will have little or no experience of editing within a 3D environment. However, this approach has limitations, inconsistencies can arise that lead to unrealistic positioning of the road network and features, these are not instantly recognisable from a 2D view.

6.3.6.2 Inspecting the Scenario in 3D (Fly-by mode)

At any point after the initial import of the terrain, the current state of the scenario can be inspected. The virtual environment can be loaded into the training system in 'fly-by' mode. In this mode the user is free to move anywhere in the environment, this allows a full inspection of the generated environment to be undertaken. Figure 6.28 shows an environment being inspected at various stages of construction. Stage 1 (Figure 6.28) shows the initial landform directly after import from a pit design package, Stage 2 after the addition of the road network, Stage 3 after texturing and Stage 4 after the environment has been populated with a number of features.

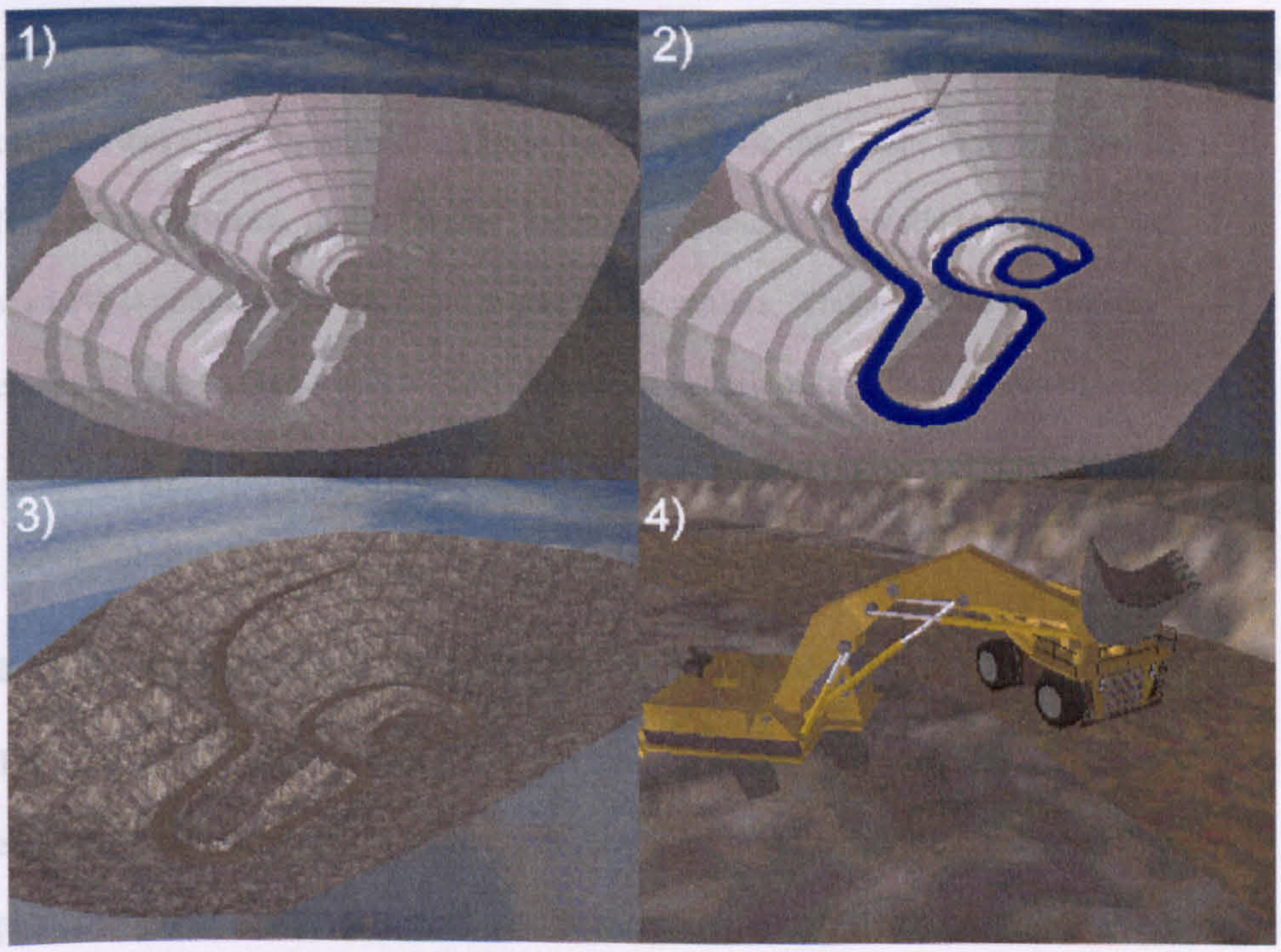

Figure 6.28 Inspection of a scenario at various stages of construction

Inspecting the environment in this manner allows inconsistencies in the landform, the road-network or in the positioning of objects to be identified that is not always possible from within the 2D editor. An example shown in Figure 6.29, step 1 shows the haul road incorrectly positioned, in step 2 the position has been corrected.

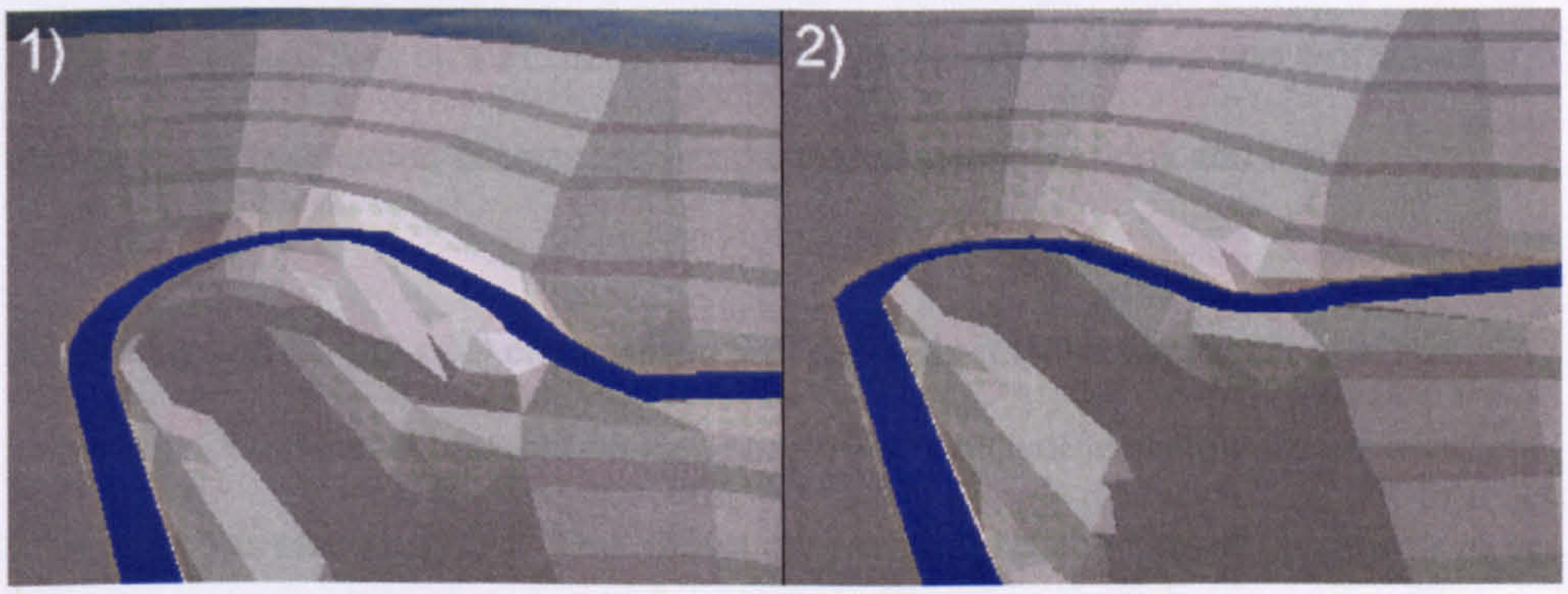

Figure 6.29 Inconsistency in the position of the haul road in 3D

Loading a fully processed scenario with static and dynamic features into the trainer in 'fly-by' mode allows the position and movement of static and dynamic movements to be examined. The full simulation of vehicle movements is used, this together with additional controls that allow the simulation to be paused provide the means to investigate all features movements. In this 'fly-by' mode, any manually controlled vehicle in the scenario is converted to a computer-controlled vehicle. This provides the person evaluating the scenario with a likely behaviour pattern of objects in the environment.

6.3.6.3 Experiencing the Scenario (Training mode)

The generated scenario can be run in full training mode. This provides a similar experience to that which the trainee will receive. The scenario is experienced from the point of view of the driver and allows the user to take control of a haul truck and navigate through the generated scenario.

6.3.7 VEdit – The Application

The author wrote a windows based application that allows scenarios to be generated following the procedural description in the previous section. The application was written in Visual C++ and runs on a PC under Windows 95/98. The interface was written using the Microsoft Foundation Classes and has the typical windows 'look and feel'.

Positioning and editing a 3D environment will normally involve significant skill and knowledge. Constraints imposed on the geometry of the landform allow the environment to be treated as essentially 2D. This allows the position and direction of the objects to be defined using a 2D-plan view.

The application forces the user to follow the necessary elements of the scenario creation procedure as outlined previously in Figure 6.2. To fulfil the requirements for the haulage trainer the user must follow steps one through four in sequence, steps five and six are optional.

1. Import the terrain from a mine design package.
2. Specify the road network as a series of straight and curved road segments using mouse driven drawing tools.
3. Generate the 2D-haul road network.
4. Integrate the 2D-haul road network into the 3D terrain.
5. Define the static and dynamic features in the environment and any colouring and texturing information for the terrain and haul road.
6. Test the environment.

At any of the stages the scenario can be saved to file and subsequently restored to the VEdit application. This allows many different scenarios to be built using the same underlying data with little extra work. Additionally, once stored, the scenario can be loaded into the 3D training module so that the environment can be visualised in 3D.

6.3.7.1 Importing the Landform

The author wrote three filters to allow mine data to be imported from VULCAN, SURPAC and Direct3D (Retained Mode). Each of these filters reads the ASCII version of the file format. Each of the filters is accessed through the load command from the file menu. In all of these cases VEdit will extract the geometrical data and compose the structures and additional information required such that the landform can subsequently be used in a VR world. This allows any landform, or some other geometrical object to be imported into the VEdit program from VULCAN, SURPAC or Direct3D. The data imported must describe a continuous non-overlapping surface as described in previous sections.

Once loaded, the faces of the landform are displayed to the user in plan view. Each face from the mesh is represented by a red triangle and is displayed in plan view. An example mesh is shown in Figure 6.30.

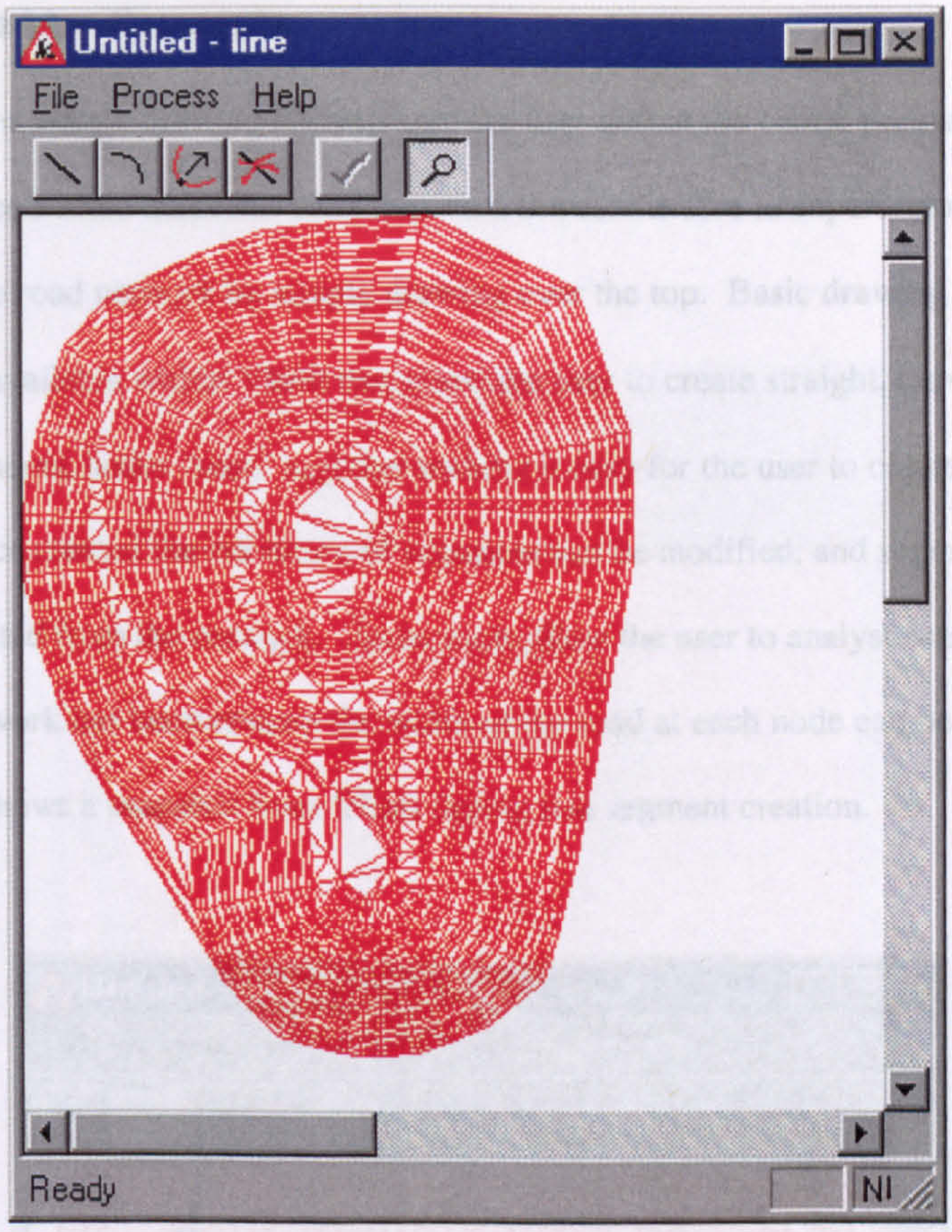

Figure 6.30 Imported landform in VEdit

6.3.7.2 Road Network Generation

There are three steps to road network generation:

1. Creation of the line segments.
2. Generation of the 2D haul road network.
3. Integration into the 3D terrain.

VEdit forces the user to complete the above three steps in order.

Creating the Line Segments

VEdit provides simple drawing tools to help the user define the centre points of the road network. Once a mine mesh has been imported the user is able to superimpose the lines that define the road network by simply drawing over the top. Basic drawing and editing facilities are available within VEdit that allow the user to create straight, curved and junction segments, nodes 'snap' together making it easy for the user to create a joined network. Once created the curvature of segments can be modified, and segments can be added or deleted from the network. Zoom tools allow the user to analyse areas in detail. Once the network has been created the width of the road at each node can be modified. Figure 6.31 shows a snapshot from VEdit during line segment creation.

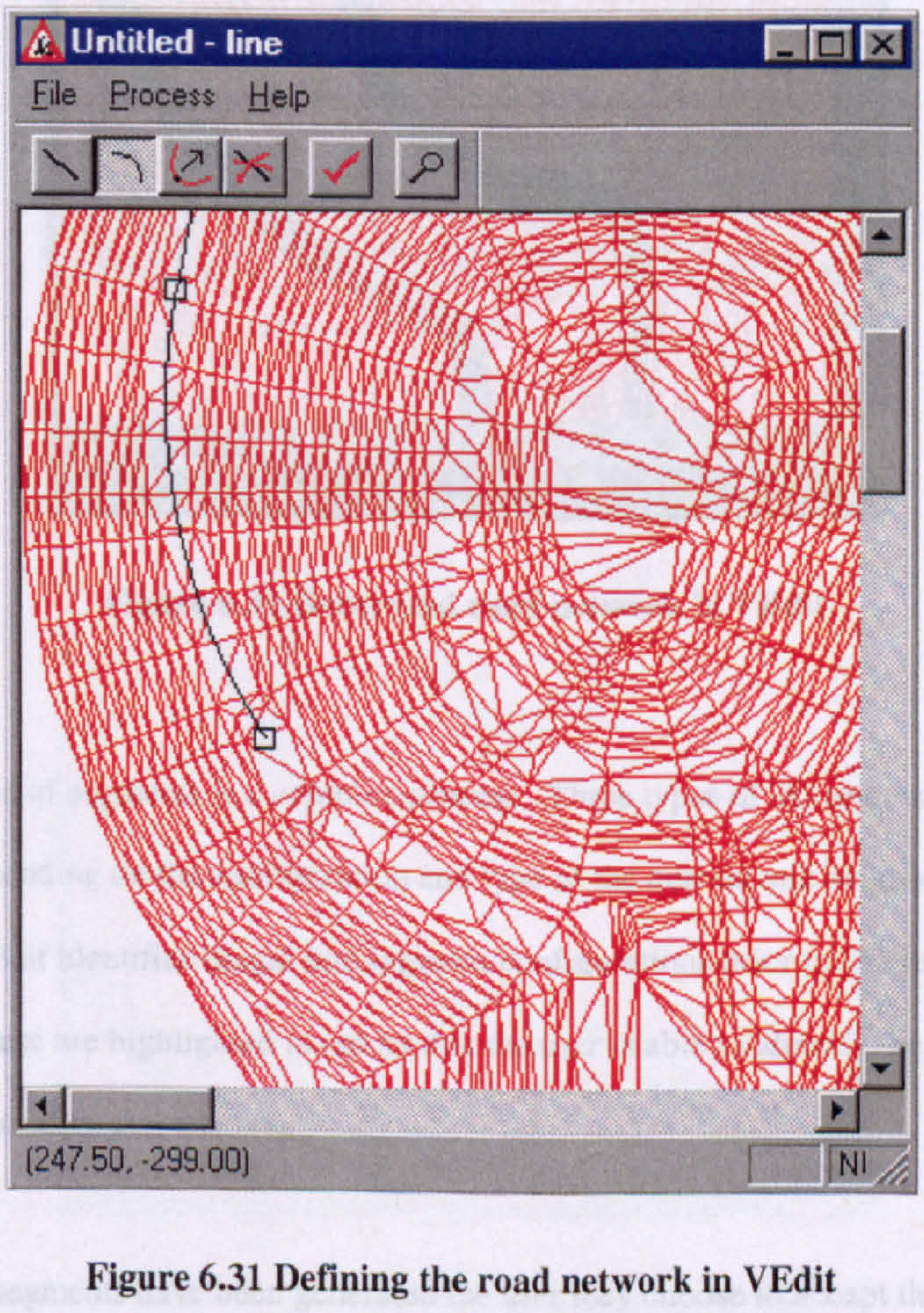

Figure 6.31 Defining the road network in VEdit

Generating the 2D Haul Road Network

VEdit automatically generates the 2D road segments from the line segments defined by the user. A generated road network is shown in Figure 6.32.

Figure 6.32 Generated road network in VEdit

The generation of segments is a complex process. Three types of 2D segment are generated depending on the configuration and type of the current and neighbouring line segments. VEdit identifies illegal line segment configurations prior to 2D segment generation, these are highlighted in red so that the user is able to identify the problem and subsequently modify the network.

Once the 2D segments have been generated the user may choose to accept the generated network and proceed to the next stage, integration with the 3D terrain. However, if the user is unhappy with the generated haul road they are able to modify the underlying line network before regenerating the 2D haul road, this can be repeated as many times as necessary until a satisfactory result is achieved.

Integrating the 2D Road Network into the 3D Terrain

Once a satisfactory 2D-haul road network has been generated, it can be integrated into the 3D terrain by selecting the 'merge road' command from the menu. This causes the algorithm described in section 6.3.2.3 to be initiated. VEdit automatically stores the state of the program prior to integration so that the user can return to the previous state. The display is updated after each individual road segment is integrated (see Figure 6.33). This provides the user with visual feedback on the current state of the process as well as providing a means of understanding how the resulting landform has been generated.

Figure 6.33 VEdit during road integration

After the entire haul road has been completely processed, the toolbar and menu of the VEdit application are changed to reflect the commands that are now available to the user.

These commands allow the user to define static or dynamic features, to colour the landform and the haul road, to preview the object's movements in 2D and to export the scenario to the 3D training module.

6.3.7.3 Define Static and Dynamic Features

VEdit and VTruck provide a library of features that can be added to scenarios. As described in previous sections two types of objects other than the landform were defined. Static features are defined as objects within the environment that never move. Dynamic features may move through the environment and communicate with other dynamic features.

The function of the VEdit program during the definition of static and dynamic features is to define the initial parameters used for the simulation. The number of parameters that the user is required to define will depend on the type and nature of the feature. For example, a haul truck might require a start position and list of segments defining its route, a tree will only require a position.

Given that the landform must be a non-overlapping continuous surface, the environment can essentially be treated as 2D with the third dimension (height) computed. This means that when specifying the position of a feature only the XY location need be defined.

Static Features

Static features are defined by selecting the 'Add Static Features' button on the toolbar, then clicking the desired position on the main model. The direction that the static feature faces is defined by a second click anywhere on the model. VEdit will display both the position of the static feature and its direction by a small red box and an arrow respectively. Once the position and direction have been defined VEdit will present you with a choice of possible static features from the currently available library.

Route Following Features

VEdit requires the user to specify the type of equipment as well as the route. Selecting the 'Add Dynamic Feature' button on the toolbar allows the user to click on the road segment from where the feature will begin its movement.

Once the first road segment has been selected VEdit will highlight in green all the segments that are valid routes. In the case of a junction all segments just beyond are highlighted to indicate a choice of direction. Clicking on any green segment will add any routes between the current segment (highlighted in red) and the selected segment to the vehicles route list. It will also cause VEdit to recalculate the possible destinations and present the user with an updated list of green segments from which they may pick again (see Figure 6.34).

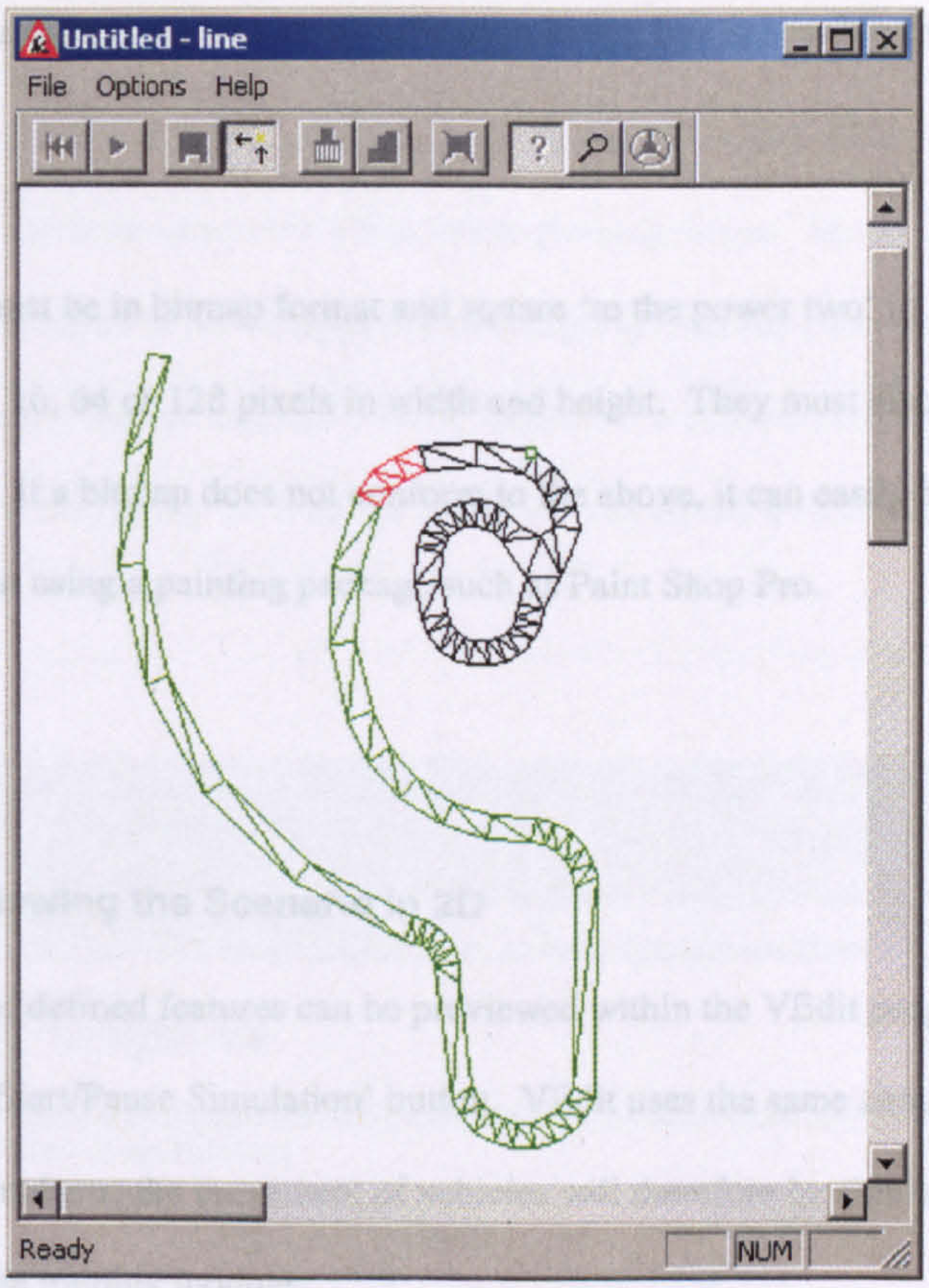

Figure 6.34 Defining the route of dynamic features

Special Behaviours

A number of special behaviours are included at this time, these can be specified through dialog boxes accessible from the main menu. These allow vehicles to be specified that between a given period in the simulation they will begin to tailgate or speed.

The manually driven vehicle is specified by selecting the 'Set Manual Truck' command on the toolbar then clicking on any route following feature defined in the model.

6.3.7.4 Texturing the Landform

Textures for the pit walls and the haul road are specified by typing the location and name of the file to be used into the texture specification dialog box accessible from the main menu.

These textures must be in bitmap format and square 'to the power two' in size, ie. they must be either 8, 16, 64 or 128 pixels in width and height. They must also have a colour depth of 16 bits. If a bitmap does not conform to the above, it can easily be modified to the correct format using a painting package such as Paint Shop Pro.

6.3.7.5 Previewing the Scenario in 2D

The movement of defined features can be previewed within the VEdit program by clicking on the 'Start/Pause Simulation' button. VEdit uses the same simulation engine as the driving simulator; the movement of vehicles will therefore be similar to that experienced in the training module.

This map view has shown to provide a good way of quickly identifying unrealistic behaviour of dynamic features. This quick identification method helps to reduce scenario construction time.

6.3.7.6 Saving the Scenario

The scenario can be stored through the Save command on the File menu. The files generated can either be used to restore the data in VEdit, or to load into the full screen VTruck training system. VEdit creates a sub-directory in which all the files required for a scenario are stored.

6.3.7.7 Help Files

A complete set of help files is provided with the VEdit system, these are HTML based and can be accessed from within the VEdit (from the help menu). Movie clips take the user through the creation of an example scenario highlighting key processes such as line segment creation and feature addition. These clips can be accessed directly from within the browser that is displaying the help files. Figure 6.35 shows a screenshot from the help system.

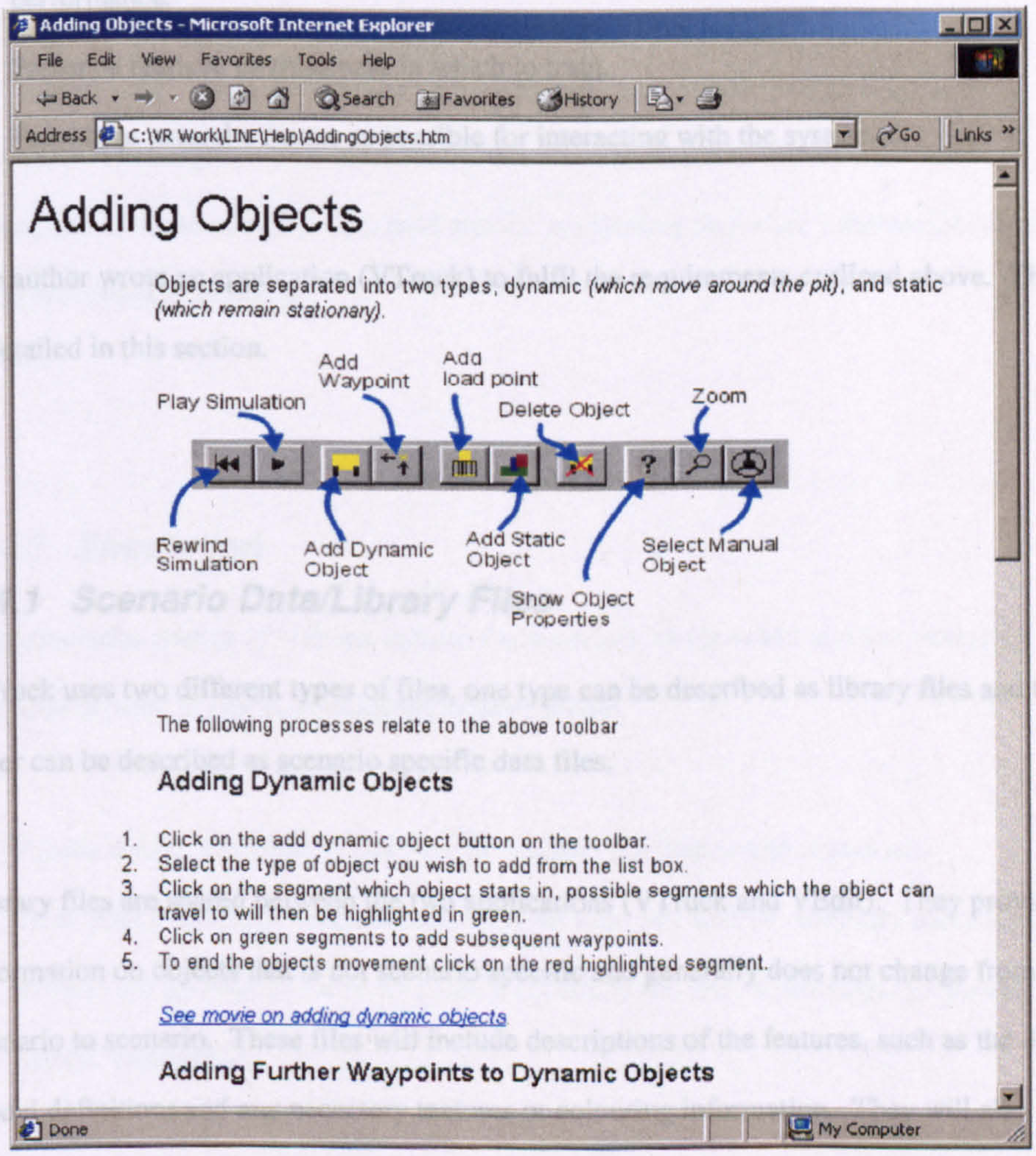

Figure 6.35 Screenshot of VEdit help system

6.4 Training System

The training system must support the following:

1. Read surface mine environment data generated from the VEdit application.
2. Execute a simulation based on the data provided.
3. Support a number of different modes of operation.
4. Support hazard identification and provide a means of recording and assessing trainee performance.
5. Present a realistic environment in which to train.
6. Provide as natural a means as possible for interacting with the system.

The author wrote an application (VTruck) to fulfil the requirements outlined above. This is detailed in this section.

6.4.1 Scenario Data/Library Files

VTruck uses two different types of files, one type can be described as library files and the other can be described as scenario specific data files.

Library files are shared between the two applications (VTruck and VEdit). They provide information on objects that is not scenario specific and generally does not change from scenario to scenario. These files will include descriptions of the features, such as the 3D model definitions and any necessary textures or colouring information. They will also specify the parameters used during the simulation and hazard spotting phase, this includes details such as engine performance, weight, dimensions of the object and payload capacity.

Maintaining the library files as a number of structured ASCII files held outside the binary executable allows objects to be added, removed or modified independent of the executable. Mine operators can add new features, or tailor existing ones to their specific needs without the need to recompile the application. For example a mine operator could create a new type of truck, it might use the same basic truck model provided, but have a damaged engine and brakes, and it might be a different colour. The existing truck feature might be copied and modified so that the performance of its engine and brakes was reduced, a different texture might be provided to cover its body, and a new set of hazards might be specified. These are just some of the attributes that can be modified through the VTruck library files.

The scenario data files describe the scenario specific data created within the VEdit package and subsequently loaded into the VTruck application. This includes the description of the terrain, the haul road and the positioning and route information of all static and dynamic features.

6.4.2 Simulation

The simulation engine of VTruck defines the dynamics of the world and the interaction between objects. It can be considered in three phases.

1. Initialisation. The objects and their parameters are loaded and initialised.
2. Main execution loop. Input is read from the user, any user or computer controlled objects are updated in the simulation, feedback to the user is provided (graphical, sound, haptic etc.).
3. Post processing, clean up and exit. Application performs final processing of any generated data, writes any stored information, restores any resources used, and exits.

A complete execution of the application will typically include one haulage cycle, one cycle is typically the time taken for a haul truck to complete its entire route. This route is typically repeated a number of times in a workers shift. Given that this is a reasonably small period of time many potentially dynamic features can be considered static. Some examples of static and dynamic objects are shown in Table 6.4.

Static Objects	Dynamic Objects
Parked vehicles	Haul trucks
Spillage	Bulldozers
Buildings	Scrapers
Signposts	Excavators

Table 6.4 Examples of static and dynamic objects

Although the two types of feature are different they share some common attributes including:

1. Collision box, this is used during collision tests.
2. Hazard information, this is used during the hazard spotting phase of the training module.

Static features are objects within the virtual environment that never move and do not communicate with any other features in the virtual world. The amount of processing time required during a training session is limited to the following:

1. Initial positioning of the feature in the environment.
2. Rendering the feature.
3. Processing of any collision box or hazard spotting information.

6.4.2.1 Simulating Dynamic Features

Dynamic features require more processing than static objects, not only do they move through the environment, but they also respond to and communicate with other objects in the virtual world. Their ability to respond and communicate allows dynamic features to modify their own and other features behaviour based upon their internal state and their surrounding environment. Examples of dynamic features include trucks, bulldozers or excavators.

Dynamic features are typically situated on the surface of the landscape, they are further subdivided into moving and stationary features. Moving features attempt to follow a pre-defined route through the mine, this is defined by a list of segments through which the vehicle passes. Stationary features do not move but retain the ability to communicate with and respond to other features in the virtual world.

In the case where the position and orientation are fixed, features are often required to communicate within the virtual environment. An excavator can be considered to move infrequently during a workers shift, for the purposes of simulation it's position can therefore be taken as fixed. It must however respond to other dynamic features within the mine, for example it must load a truck when it stops to be loaded and cease loading once the truck is full and before it has moved away.

Other dynamic features follow a route through the environment, this defines their position and orientation. They attempt to follow pre-calculated paths that are defined by the generated road segments and their pre-assigned routes. They are able to communicate with other dynamic features and analyse their local environment before updating their position, orientation and speed. The performance of each piece of equipment is based upon industry standard rimpull and retarder curves that are modelled within VTruck based upon specifications available from the equipment's manufacturer.

An object-oriented simulation was developed to model the behaviour of dynamic features. A number of simulation 'objects' were designed and implemented that model different behaviour patterns. A simulation object is used to model the behaviour of vehicles and equipment inside the virtual environment. The object in the simulation controls the position, orientation and appearance of the features representation in the virtual world.

Different simulation objects are used depending on the nature of the real world object being simulated.

The author wrote classes for different types of simulation objects, these contain the logic that dictates the behaviour of each feature. All of the classes written for the simulation objects are inherited from a basic simulation object. This object defines the functionality that is available, though the implementation of this functionality is different depending on the behaviour that is required.

All of the simulation objects in the virtual world follow the routes that were pre-calculated when the road network was created. Simulation objects must always reside on a path in a defined haul road segment. This constraint applies to both the moving and stationary dynamic features. This constraint greatly simplifies the simulation and allows it to execute in real time.

This constraint was not considered to impair the systems intended use too greatly. It is anticipated that the use of the system will concentrate on the haul road and on the vehicles operating on the haul road.

Whilst the simulation must provide a reasonable simulation of features behaviour it is important that some degree of control is maintained. Using completely autonomous features capable of deciding speed, direction and destination independently, would provide little means of controlling vehicle movement. In a system designed to provide a means for authoring and subsequently experiencing hazardous situations it is desirable that a reasonable degree of control is maintained.

Vehicles in VTruck are only able to control their speed within the current version of the simulation. The scenario author using the VEdit application dictates both the destination and position of the vehicle. This has shown to allow a degree of control, whilst providing a good behaviour pattern for features in the virtual world.

Vehicle Movement

This system concentrates on simulation of individual vehicle behaviours, this includes performance modelling, simulation and behaviour. Many vehicle simulations take into account a huge number of variables. Whilst this helps to provide a highly realistic simulation it requires a large amount of processing power. Restrictions of the system will limit the number of variables that can realistically be considered.

Vehicle performance is calculated based upon industry standard performance curves that are provided by manufacturers. These are available for all types of equipment and are in most cases supplied in a standard form. **Figure 6.36** shows typical the rimpull and retarder curves for a Euclid R-120M haul truck.

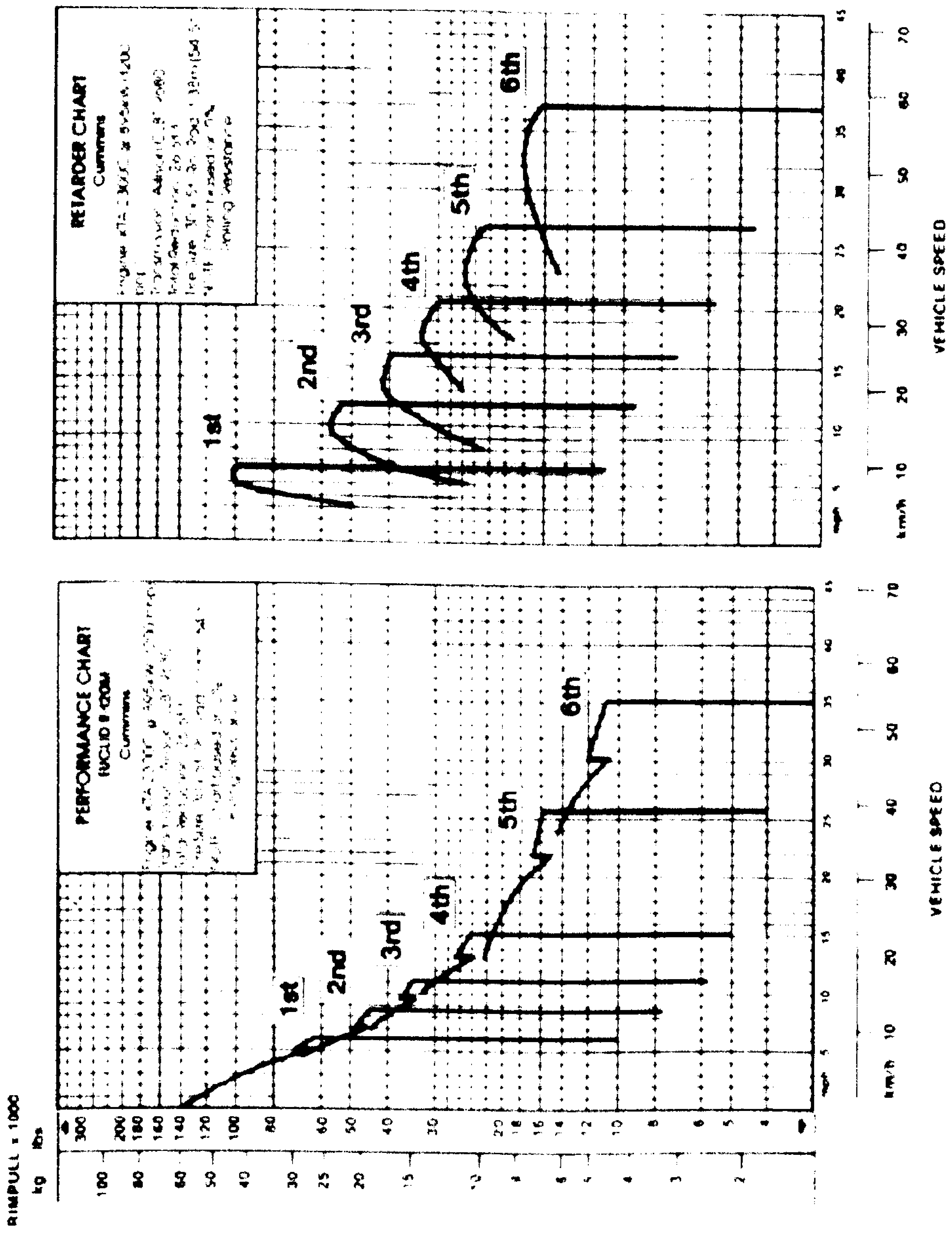

Figure 6.36 Performance curves for a Euclid R-120M haul truck

Only a small number of variables are considered when modelling the performance of the vehicle. This was found to be sufficient for the purposes of the current training simulator. Once the available performance of the vehicle is known a decision must be made concerning the route and speed of the vehicle.

When making this decision a number of factors are considered, including the following:

1. Current speed and position of the vehicle on the road.
2. Current speed and position of any local vehicles on the road.
3. Destination of the vehicle. This may include decisions as to whether it needs to start slowing down to stop at a load point.
4. Current maximum available acceleration and deceleration of the vehicle.
5. Suggestions or directives from other vehicles.
6. User defined special behaviour modifiers.

As a result of considering these and other factors, the vehicle decides whether and by how much it is braking or accelerating. The calculations and logic behind this decision is detailed in the following sections.

Vehicle Performance Calculation

The available performance of a vehicle is dependent on a number of factors. VTruck takes into consideration similar factors that mine operators use when estimating the output from a surface mine. It is expected that these must produce reasonable estimations of vehicle performance. The performance calculations are repeated for each vehicle in the virtual environment at each discrete time step. The initial aim is to calculate the maximum available acceleration and the maximum available deceleration. This is subsequently used to calculate the position of the haul truck in the next time step.

Each equipment manufacturer provides detailed information on vehicle performance. The information provided is sufficiently detailed to allow their performance to be modelled. Some terms used in the calculation of performance are described in Table 6.5.

Rimpull	The force (in kg, lb or kN) available between the tyre and the ground to propel the vehicle (this is limited by traction).
Weight	This is the gross vehicle weight (kg or lb) and is equal to the total vehicle weight plus the payload.
Retarding Force	The force (in kg, lb or kN) available between the tyre and the ground to slow the vehicle (this is limited by traction).
Grade Resistance (Assistance)	The force that must be overcome to move a machine over unfavourable grades (uphill). Grade Assistance is a measure of the force that assists machine movement on favourable grades (downhill). This is normally measured or estimated.
Rolling Resistance	The force that must be overcome to roll or pull a wheel over the ground. It is affected by ground conditions and the vehicle's weight. This is normally estimated
Total Resistance	= Grade resistance + Rolling resistance

Table 6.5 Terms used in vehicle performance calculations

Rolling resistance is used during the performance calculations in VTruck. It is currently assumed to be constant at 3%. The value for rolling resistance in combination with rimpull and retarder information allows the calculation of the available acceleration and deceleration at any given time. Examples (Euclid Hauler Handbook, ed.15) of the rimpull and retarding curves for the Euclid R-120M are given in **Figure 6.36**.

An example calculation based upon this data is given in Table 6.6 for a vehicle with a gross mass of 190 000Kg, climbing a hill with an inclination of 2°, and travelling at 10 kph (see Figure 6.37).

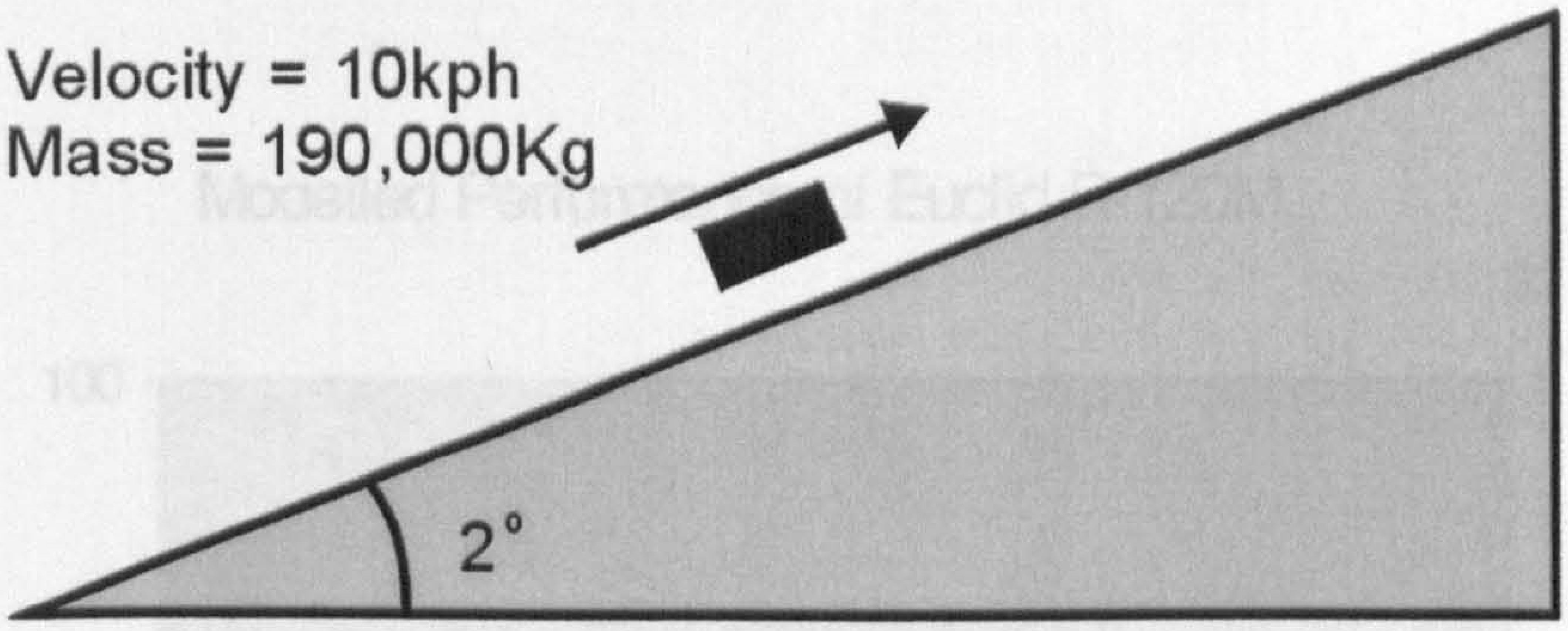

Figure 6.37 Vehicle on a two degree gradient

Resistance:	
Rolling Resistance =	0.03 * 190,000
=	5,700 N
Grade Resistance =	sin(2°) * 190,000
=	6,631 N
Total Resistance =	12,331 N
For acceleration:	
Rimpull curve @10kph rimpull =	32,000 N
Maximum acceleration (force / mass) =	(32,000 – 12,331) / 190,000
=	0.104 m/s^2
For deceleration:	
Total Resistance =	12,331 N
Retarding curve @10kph retarding force =	44,000 N
Maximum deceleration (force / mass) =	(44,000 + 12,331) / 190, 000
=	0.296 m/s^2

Table 6.6 Example calculation of acceleration and deceleration for a haul truck

Representations of the rimpull and retarding curves are incorporated into the simulation. The curves are described in the simulation as a series of linear sections for each appropriate range of speed. The performance curves used in VTruck to represent the Euclid R-120M are shown in Figure 6.38.

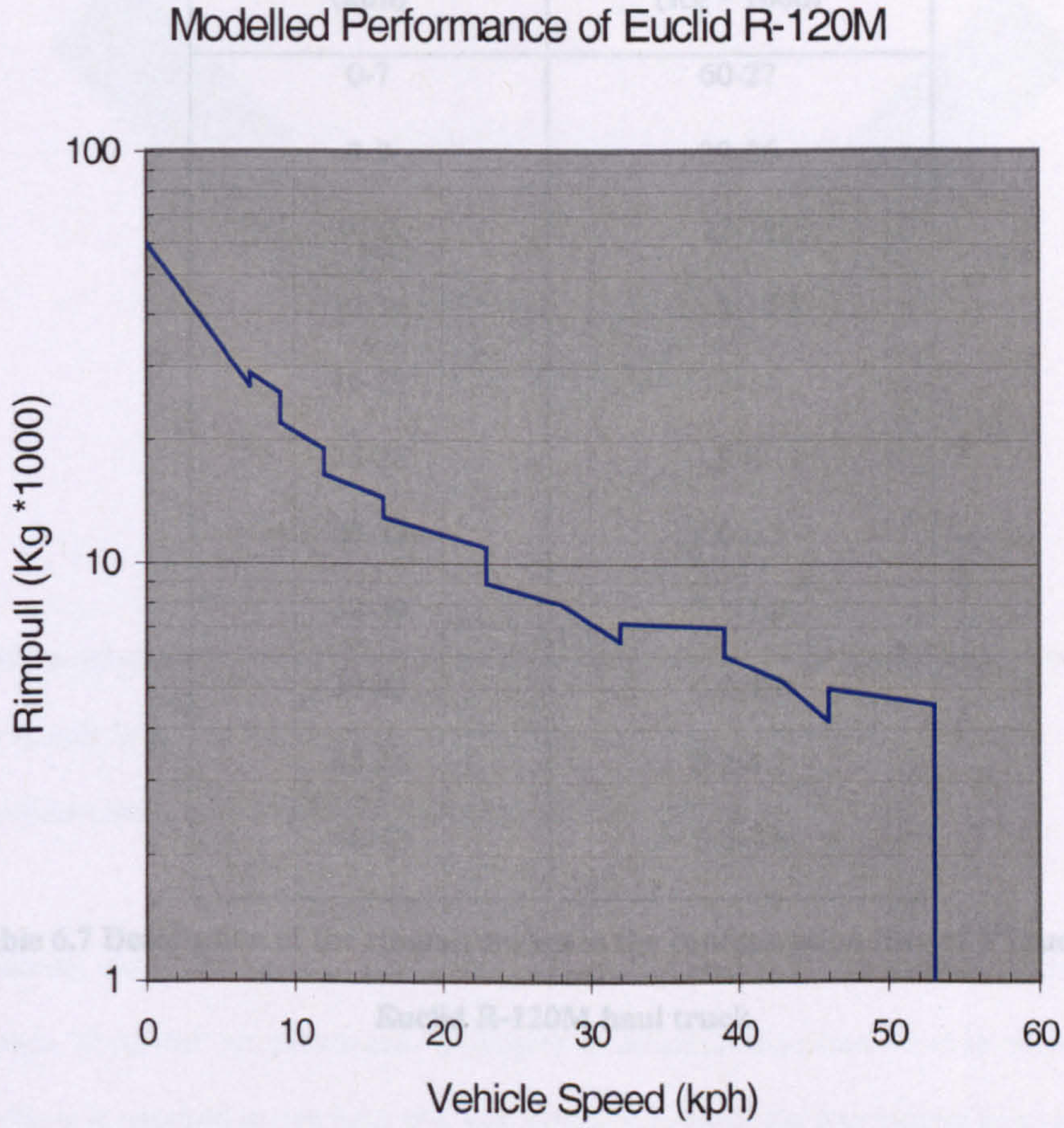

Figure 6.38 Modelling of rimpull for a Euclid R-120M haul truck

This modelled rimpull curve is described in the object description file along with other information such as vehicle mass and it's dimensions. The description of the above curves is shown in Table 6.7.

Change in Speed (kph)	Change in Rimpull (Kg * 1000)
0-7	60-27
7-9	29-26
9-12	22-19
12-16	16.5-15.5
16-23	13-11
23-28	9-8
28-32	8.0-6.5
32-39	7.2-7.0
39-43	6.0-5.2
43-46	5.2-4.2
46-53	5.0-4.6

Table 6.7 Description of the rimpull curves in the configuration files of VTruck for a Euclid R-120M haul truck

Behaviour and Positioning

The vehicles in the surface mine are treated as individual objects that react to the physical road network as well as to suggestions or directives from other simulation objects. The primary requirement for the system is that it must perform updates in real-time, this places a heavy constraint on the simulation especially given the already high cost of producing real-time images of the 3D environment.

Vehicle movements in a surface mine are normally restricted to the haul road, they are rarely required to operate outside the normal lanes of these roads. They spend the majority of their time travelling in these lanes, which are dictated by the location of the haul road and their direction of travel. Pre-computed paths are generated during the construction of the scenario that describe the lanes for each segment in each direction. These are shown in Figure 6.39.

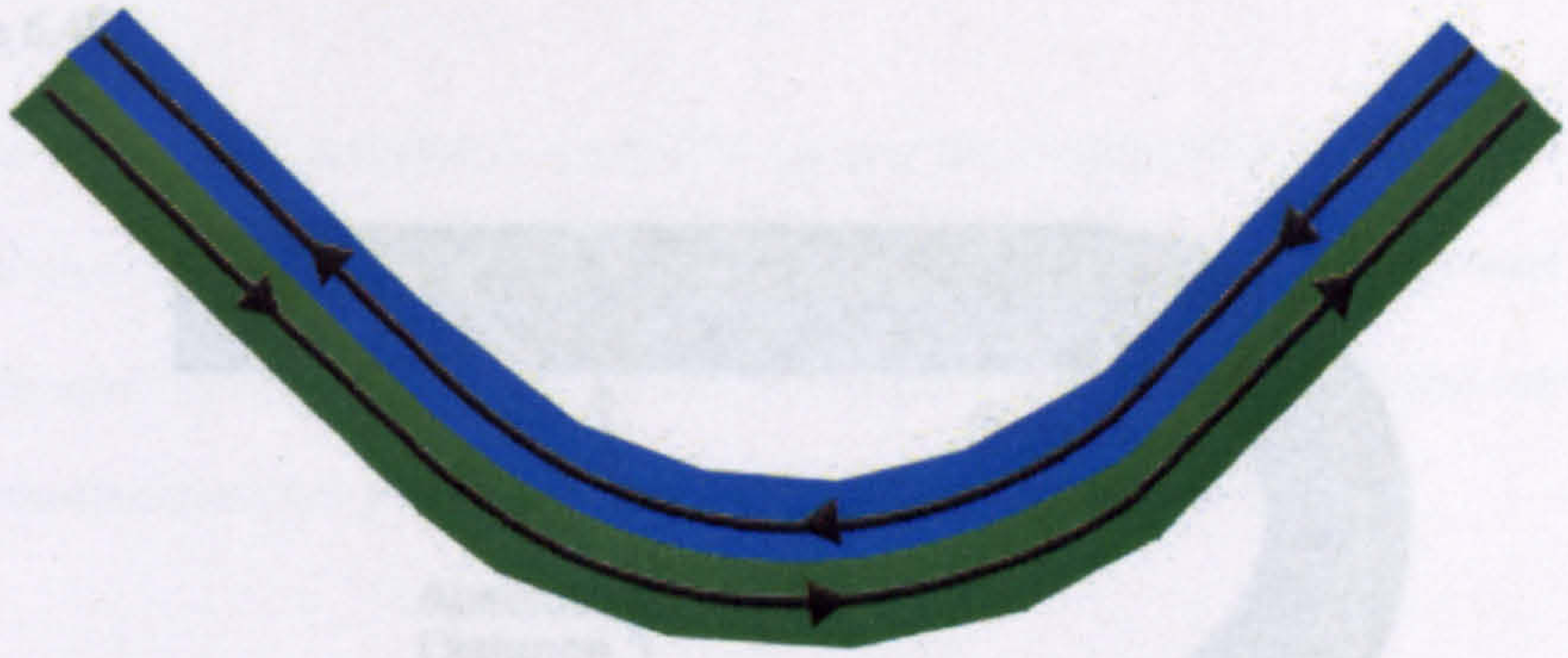

Figure 6.39 Lanes within haul road segments.

Vehicle movements are restricted to the paths within these lanes. Under these conditions the vehicle is merely incrementing the distance they have travelled along this pre-calculated path and interpolating between two known locations.

However, as the simulation was required to be extensible, provision has been made to include 'abnormal' circumstances. Examples of abnormal situations could be seen when a vehicle is required to overtake, this will require it to leave the pre-defined lanes for a time.

A discussion of some of the issues considered whilst determining the objects future position follows.

Proximity to Other Features

Calculating the proximity to other features in the mine is of fundamental importance. The proximity to other features can be measured in a number of ways. The use of lanes provides a means for identifying the proximity and the nature of that proximity.

Vehicles ahead and behind can be identified, it is also possible to distinguish the relative direction, or speed (whether it is travelling in the same or opposite direction) and to calculate the distance to intercept from a given location. These distances are illustrated in Figure 6.40.

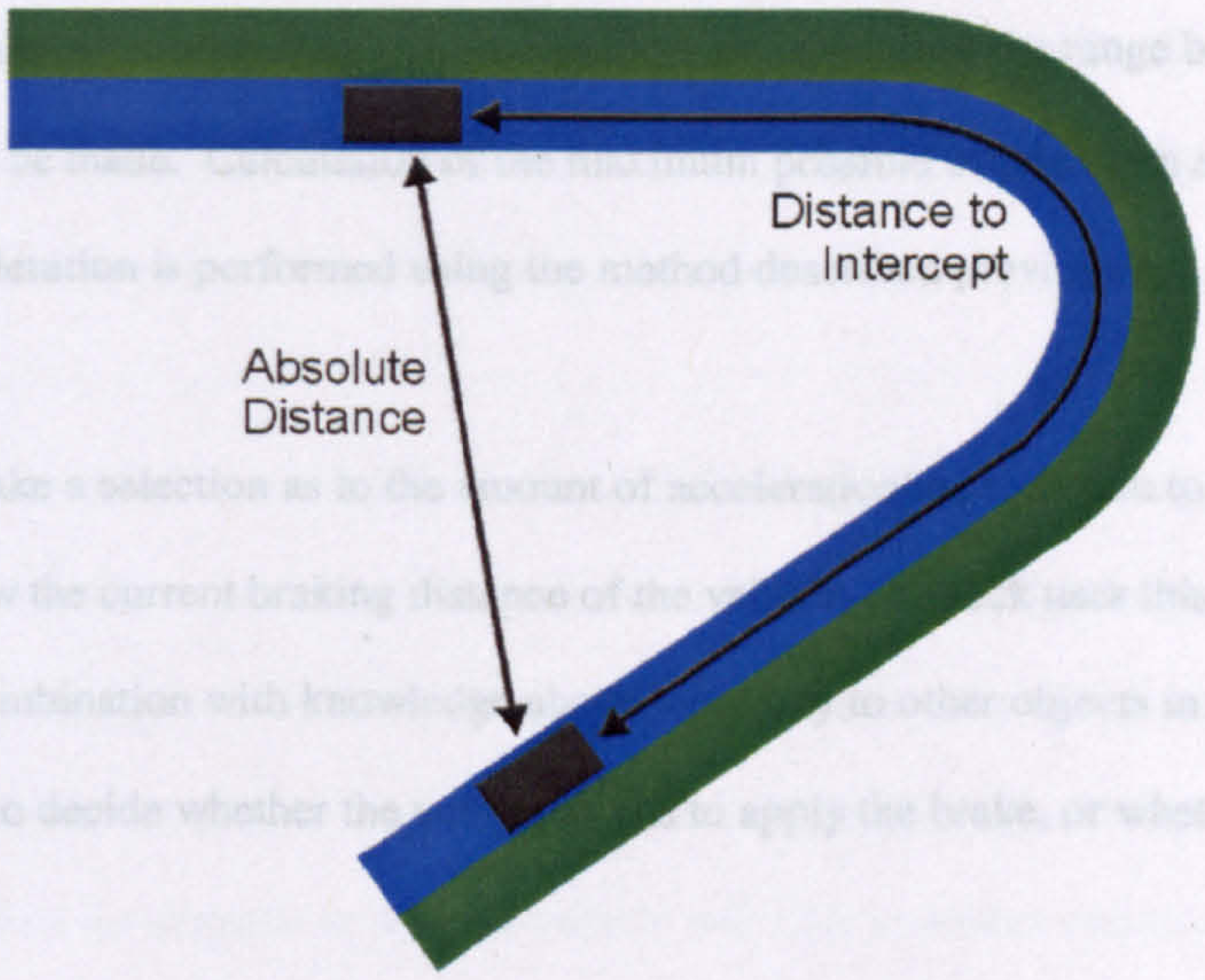

Figure 6.40 Calculated vehicle distances in VTruck

Speed Adjustment

The speed at which a vehicle travels is a fundamental issue. Consideration must be given to the safe speed at which a vehicle is able to travel. The general assumption is made that vehicles will always attempt to travel as fast as possible within safety guidelines. It is not believed that this is an unrealistic assumption due to the financial pressures that are present in a surface mine operation.

A number of factors were taken into consideration when evaluating the safe speed at which a vehicle could travel along a particular section of the road, these included:

- Speed of the vehicle.
- Approximate distance that could be seen ahead.
- Situation the vehicle was facing (in terms of traffic ahead, and road layout).
- Weight of the vehicle.

- Gradient over which the vehicle is travelling.

The selection and adjustment of speed first requires the calculation of the current maximum available acceleration and deceleration, this describes the range between which a choice must be made. Calculation of the maximum possible acceleration and maximum possible deceleration is performed using the method described previously.

In order to make a selection as to the amount of acceleration/deceleration to apply, it is useful to know the current braking distance of the vehicle. VTruck uses this braking distance in combination with knowledge about proximity to other objects in the environment to decide whether the vehicle needs to apply the brake, or whether it is safe to accelerate.

The maximum deceleration of a vehicle at any given time is dependent on the maximum available retarding force, the mass of the vehicle and on the gradient of the terrain. Since it is difficult to estimate the gradient of the terrain over the entire braking distance of the vehicle and the maximum available retarding force varies with speed, evaluating the actual braking distance for a vehicle is not a trivial task.

An estimation of the braking distance based upon the calculated maximum available deceleration is insufficient, as there is a tendency for the retarding force to increase with the speed of the vehicle. This will result in an estimated braking distance that is smaller than the actual distance, though factors such as gradient may work against this.

If a vehicle makes an estimate of braking distance that is smaller than the actual distance, this may lead to problems as it will choose not to brake until absolutely necessary, by which time it may be too late. If the vehicle estimates the distance to be greater than the actual distance then it will choose to brake too soon. If the vehicle chooses to brake too soon, then it is likely that on the next evaluation of safe speed it will consider that it is safe to accelerate. This can lead to an unstable simulation as vehicles continually switch from braking to accelerating and back again.

This is not an effective modelling of a vehicle's accelerating/braking behaviour. Early versions of the simulator required that vehicles be in one of two states, either accelerating or braking as hard as possible. A new method was developed that allowed this behaviour to be modelled more realistically, this is described below.

Two distances are used to decide the accelerating/braking behaviour for a given vehicle. The first is the minimum estimated stopping distance, this calculation is based upon the currently available maximum deceleration. The second is an estimate of a 'safe' distance. This distance is always greater than the minimum stopping distance and is an approximation of the distance at which a vehicle will start to reduce accelerating. This distance is currently set as six times the minimum estimated stopping distance, this value provides a good modelling of vehicle behaviour. These distances are shown in Figure 6.41.

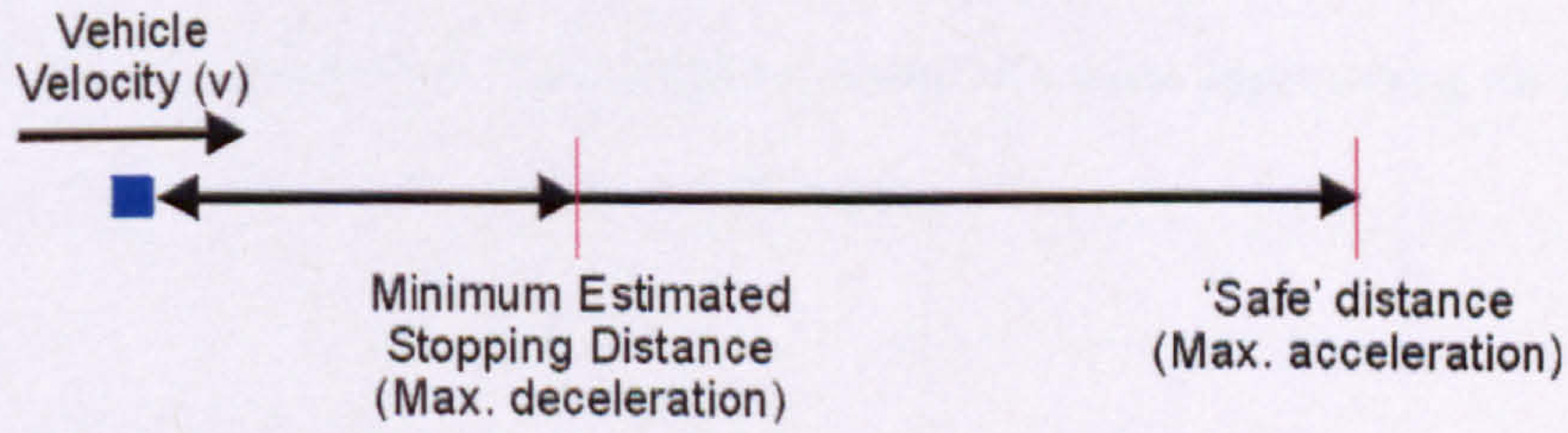

Figure 6.41 Minimum and 'safe' distances

Once a vehicle has evaluated these two distances, and it's proximity to other factors it can determine whether it should be accelerating or braking and by how much it should be doing so. By mapping the choice of maximum acceleration and maximum deceleration to these two distances, and analysing the vehicle's proximity to other objects in the environment it is possible to obtain a decision. The maximum available deceleration is mapped to the minimum estimated braking distance, and the maximum available acceleration is mapped to the estimated 'safe' distance. A linear model is implemented inside VTruck for mapping proximity from an object to a decision on amount of acceleration or deceleration to apply. As distance from the factor decreases, the vehicle chooses to apply less acceleration and eventually to brake.

Consider a situation where a vehicle is approaching the end of the road. In the vehicle's initial state, the end of the road is beyond the calculated safe distance of the vehicle. As a result the vehicle chooses to accelerate as hard as possible (see Situation 1 in Figure 6.42). The vehicle's distance to the end of the road will decrease and eventually becomes less than the calculated safe distance. Once it becomes less than the safe distance the vehicle chooses to apply less acceleration (situation 2) and eventually the brake (situation 3). As the vehicle decelerates, its minimum estimated braking distance and the calculated safe distance also decrease. Ultimately this results in the vehicle coming to a stop when the distance is equal to zero.

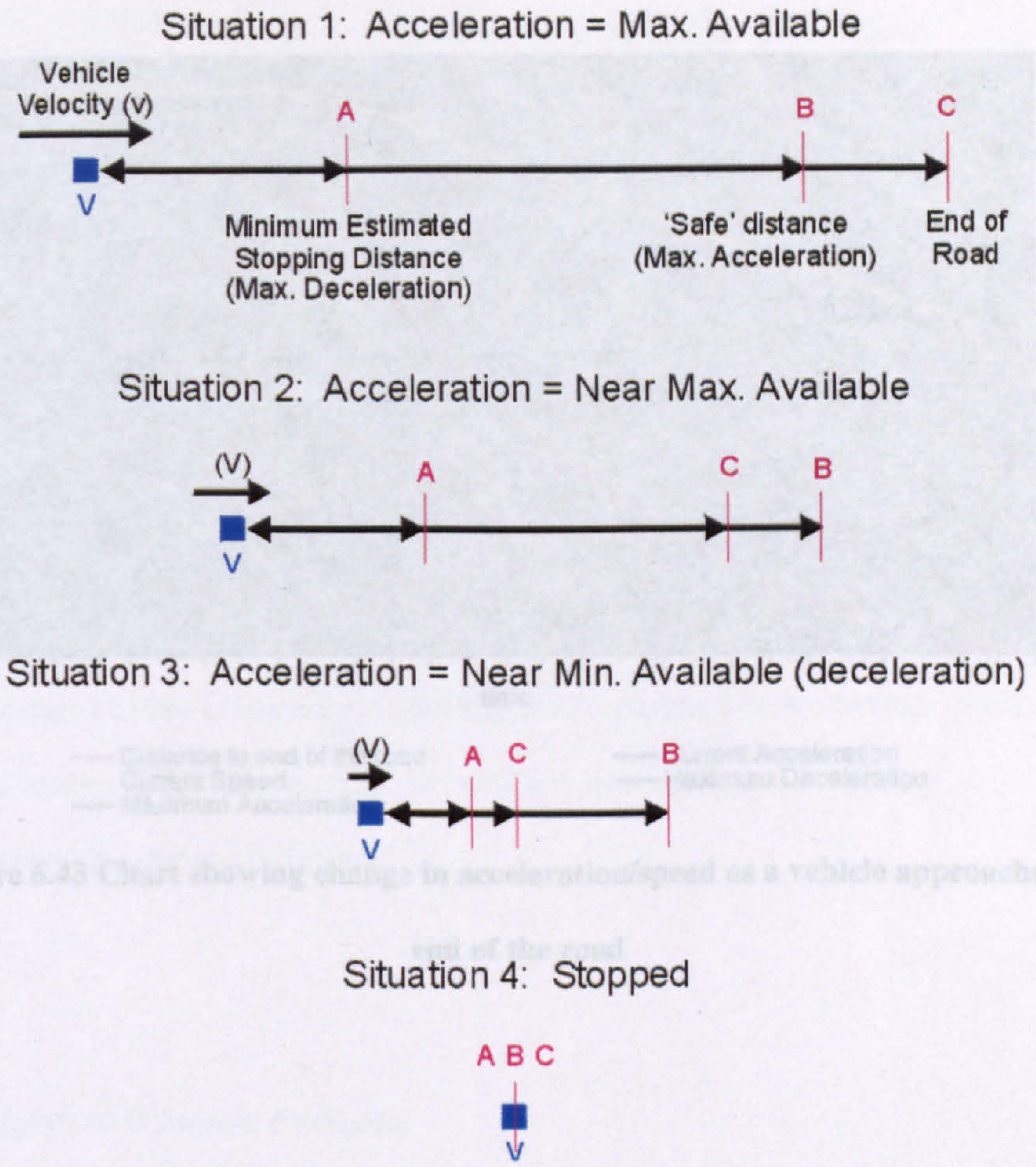

Figure 6.42 Acceleration/deceleration behaviour of vehicle approaching the end of the road

The change in acceleration, speed, and distance to the end of the road is shown in Figure 6.43.

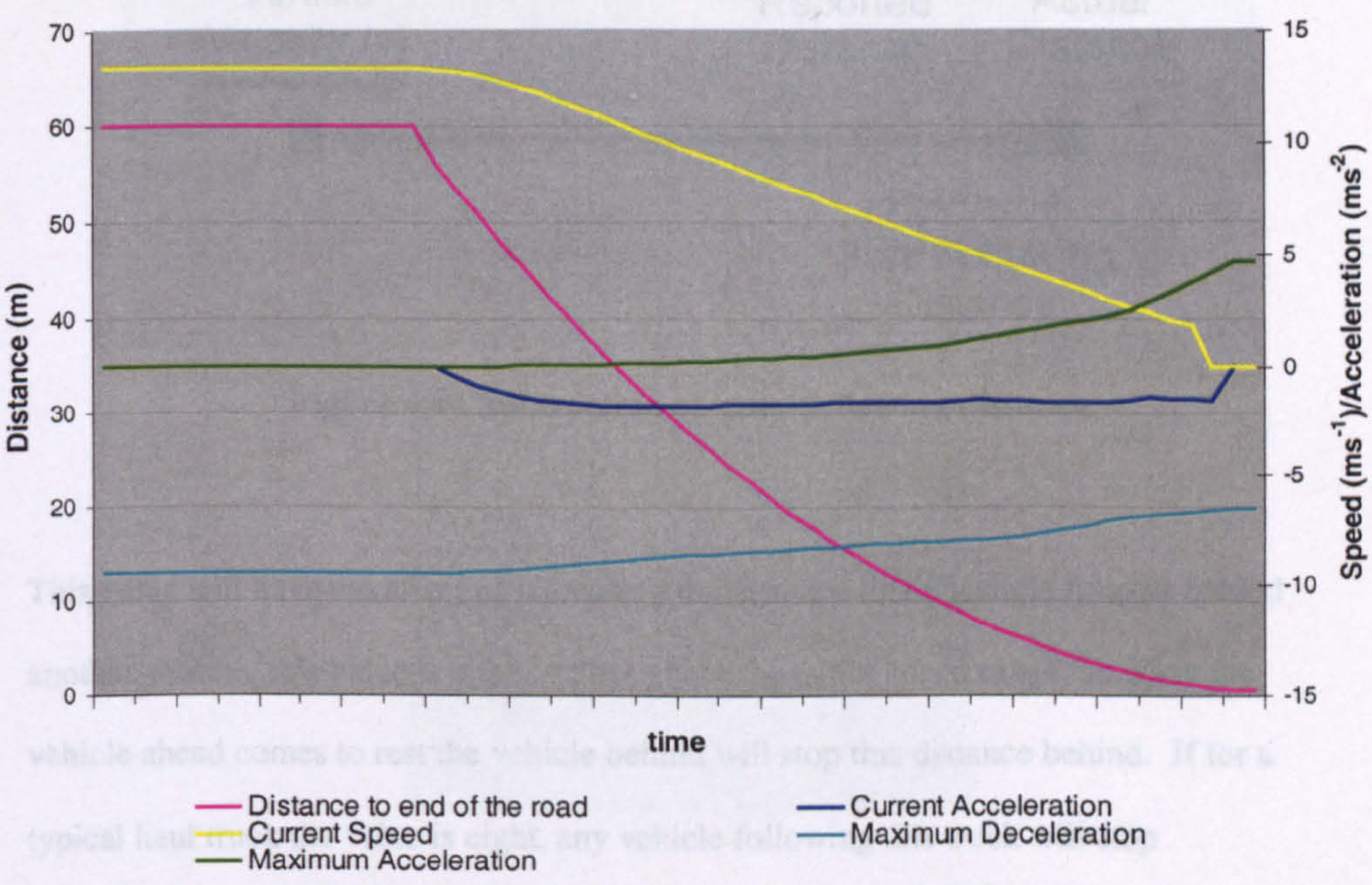

Figure 6.43 Chart showing change in acceleration/speed as a vehicle approaches the end of the road

This method produces reasonable results for the 'end of the road' case, but it must also be viable for a number of other scenarios. Consider one moving vehicle following a second moving vehicle. The only additional parameter that is included is a number that describes the 'safe' following distance. This value is specified by the vehicle ahead and describes the additional distance that the vehicle behind may safely approach when the vehicle ahead is stationary. This value is effectively subtracted from the distance that a vehicle thinks it is from a factor (see Figure 6.44). For the end of the road, this value is zero, whilst for a typical haul truck it will be approximately eight.

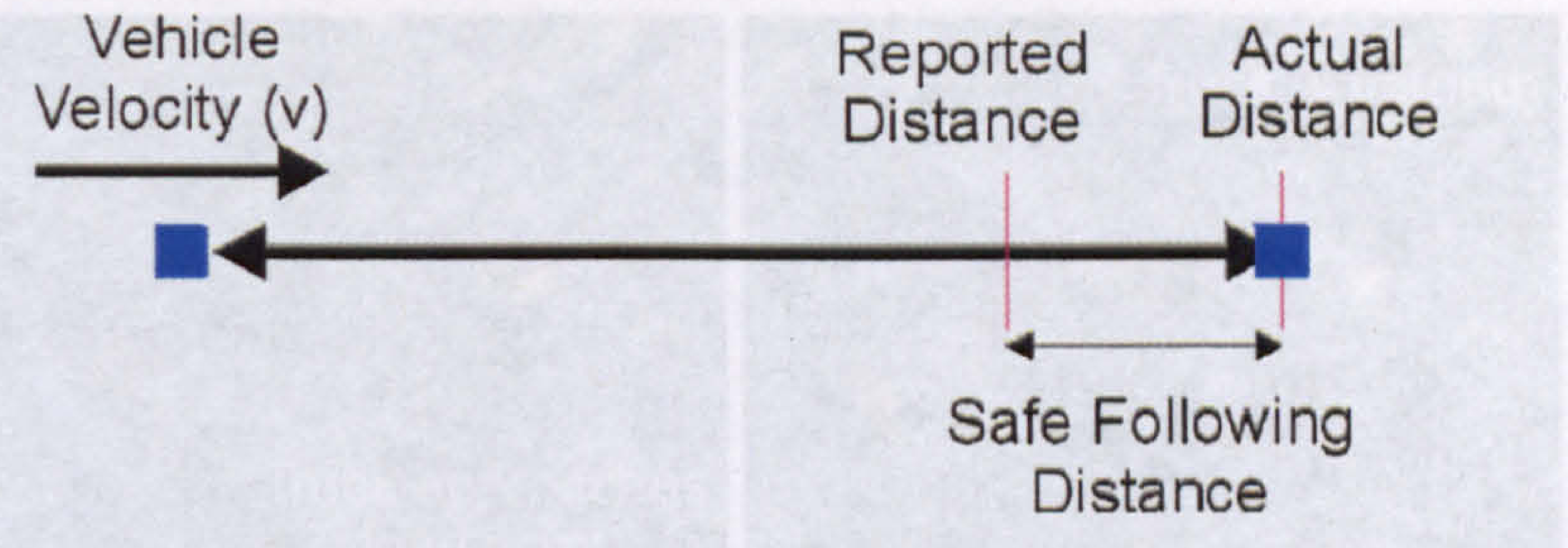

Figure 6.44 Subtraction of 'safe' following distance

This value will have the effect of increasing the distance that a vehicle follows behind another vehicle, this value is applied throughout the entire speed range, so when the vehicle ahead comes to rest the vehicle behind will stop this distance behind. If for a typical haul truck the value is eight, any vehicle following this truck will stop approximately eight metres behind.

Examples of Dynamic Features

Load Points

There are a number of possible configurations of load points in surface mines. VTruck currently supports the 'drive-by' loading method. Haul trucks arrive from one direction, slow to a stop, are loaded by the excavator, and leave in the opposite direction. This is shown in Figure 6.45.

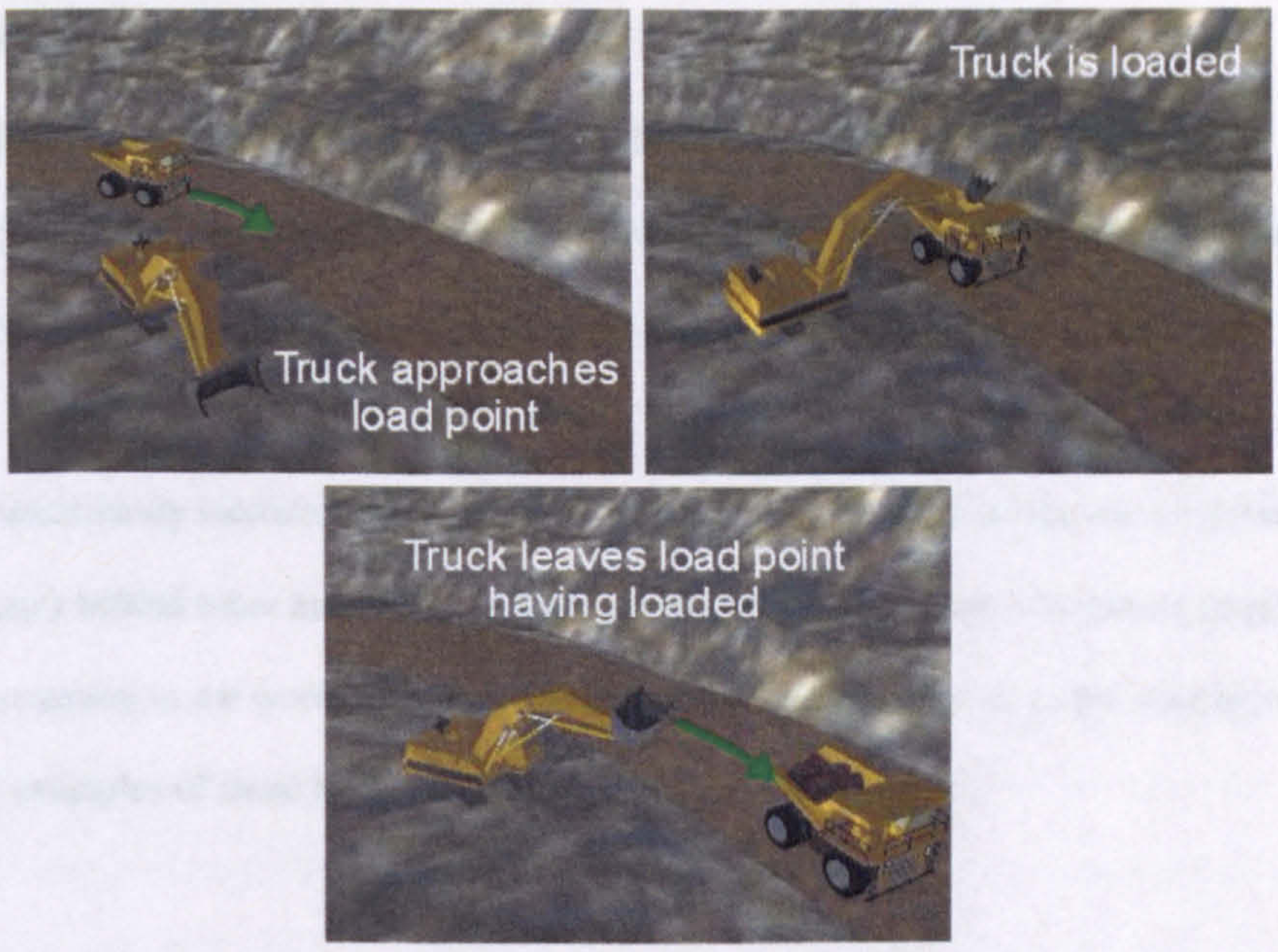

Figure 6.45 Drive-by loading method in VTruck

An excavator is represented within the simulation as a static dynamic feature. Within the simulation the excavator's position is considered on the haul road. However, the graphical representation of the excavator is offset from the haul road, the amount of the offset is calculated so that excavator appears to load the stopped haul trucks.

As vehicles approach the excavator, they decide whether they should stop at the load point to be loaded. This is currently determined by whether they are currently loaded, if they are loaded they will not stop, however, if they are not loaded they will stop and wait to be loaded by the excavator. If they stop, they will slow to a stop and wait for the excavator to load them. Once the vehicle has stopped at the location of the load point, it sends a message to the excavator to start loading.

Once the excavator has received the 'start-loading' message, it will complete a pre-set number of load cycles. Once it has completed loading it will send a message back to the vehicle indicating that loading is complete. After the vehicle has received this message it will continue along the pre-defined route after recording it's new weight.

Moving Dynamic Features

These are computer-simulated vehicles capable of following a predefined route as specified by the scenario editor in VEdit. They include the modelling of performance and the behaviour and positioning detailed in previous sections.

The functionality included allows them to stop and load at dump points and to queue if necessary behind other automatic or manual vehicle objects. They will have a graphical representation in the world that is positioned at the same location as in the simulation. Some examples of these types of objects are given in Figure 6.46.

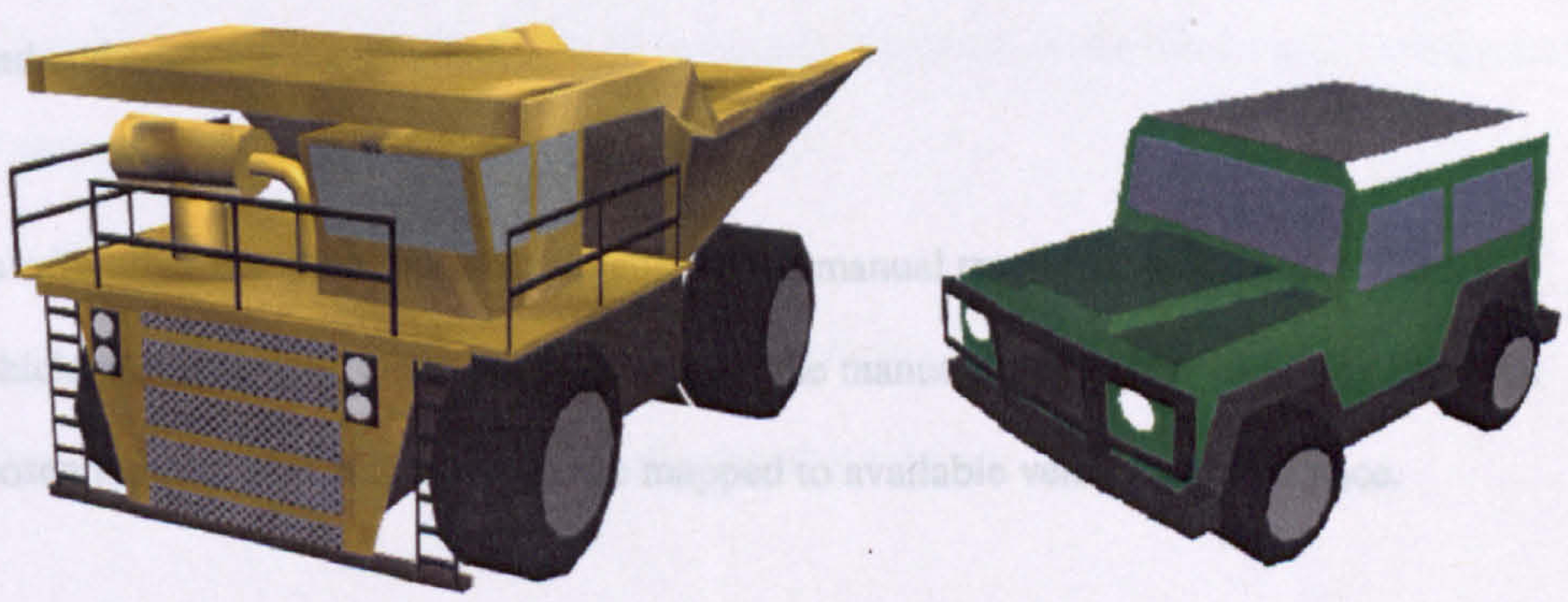

Figure 6.46 Examples of dynamic features

Manual Vehicle

The manual vehicle uses much the same information as the moving dynamic vehicle. The principal difference being the method of control. The manual vehicle includes all the modelling of vehicle performance and the specification of a route.

The manual vehicle is also able to send and receive messages with other objects in the simulation. Other objects in the simulation communicate in much the same way as they would with a moving dynamic feature. They are able to identify its position and state and adjust their behaviour accordingly.

The position of the manual truck in the mine is recorded in two ways. The first is the absolute position, this is the position of associated graphical object. The second is its route position, this is a measure of distance along the pre-defined route. This measure allows VTruck to track progress down the haul road and to identify the vehicle's position within the segment.

A manual vehicle's movement within the virtual world is restricted to the haul road. If the user strays from the haul road then the simulation will be paused, a message will be displayed, and after an acknowledgement VTruck will reposition the vehicle on the haul road and continue the simulation.

As with other computer controlled vehicles the manual truck first calculates available vehicle performance. Once this is complete, the manual truck will read values from the chosen input device and these will be mapped to available vehicle performance.

Any of the examples given for moving dynamic vehicles could be used as a manual vehicle.

6.4.2.2 Collision Detection

Collision detection is only enabled when the system is in 'driver training' mode. Collision tests are performed between the manually driven vehicle and other objects (both static and dynamic) in the virtual environment. Under normal conditions it will be unlikely that computer controlled vehicles will collide, it is therefore unnecessary to perform collision tests between these objects. This reduces the computation performed each discrete time-step and improves the performance of the simulation.

The collision box used during the test is specified in the object description file as a series of four points. These describe the size and position of the object in local co-ordinates. Additional collision tests are performed to ensure that the manual vehicle never leaves the haul road.

Collision tests are performed in 2D as the restrictions on the environment, introduced during the creation of the world, remove the need to test in 3D.

6.4.3 Modes of Operation

A number of potential uses for the system have been established and this subsequently led to the identification of three modes of operation. For each of the three modes the method of presentation of the virtual world is different.

In each of the three modes the full hazard identification framework is supported. This allows the user to identify hazards as described previously.

6.4.3.1 Driver Training (manual mode)

The user is presented with a view from the cab of the vehicle that can be driven anywhere on the haul road. As with computer controlled vehicles, its performance is simulated in real-time. The vehicle can be driven using a variety of input devices. These include a mouse, keyboard, joystick or a steering wheel. Each of these input devices provides a means to accelerate, brake and turn to the left or right. The full hazard identification framework is available at any time.

The driven vehicle has a pre-defined route that the trainee is asked but not required to follow, progress along this route is monitored by the simulation. If the trainee drives off the haul road at any point or crashes into any other feature in the surface mine then a collision results. Once a collision has occurred the simulation is paused and a collision notification is given. Acknowledging this message will result in the vehicle being placed back on the haul road close to where the collision occurred.

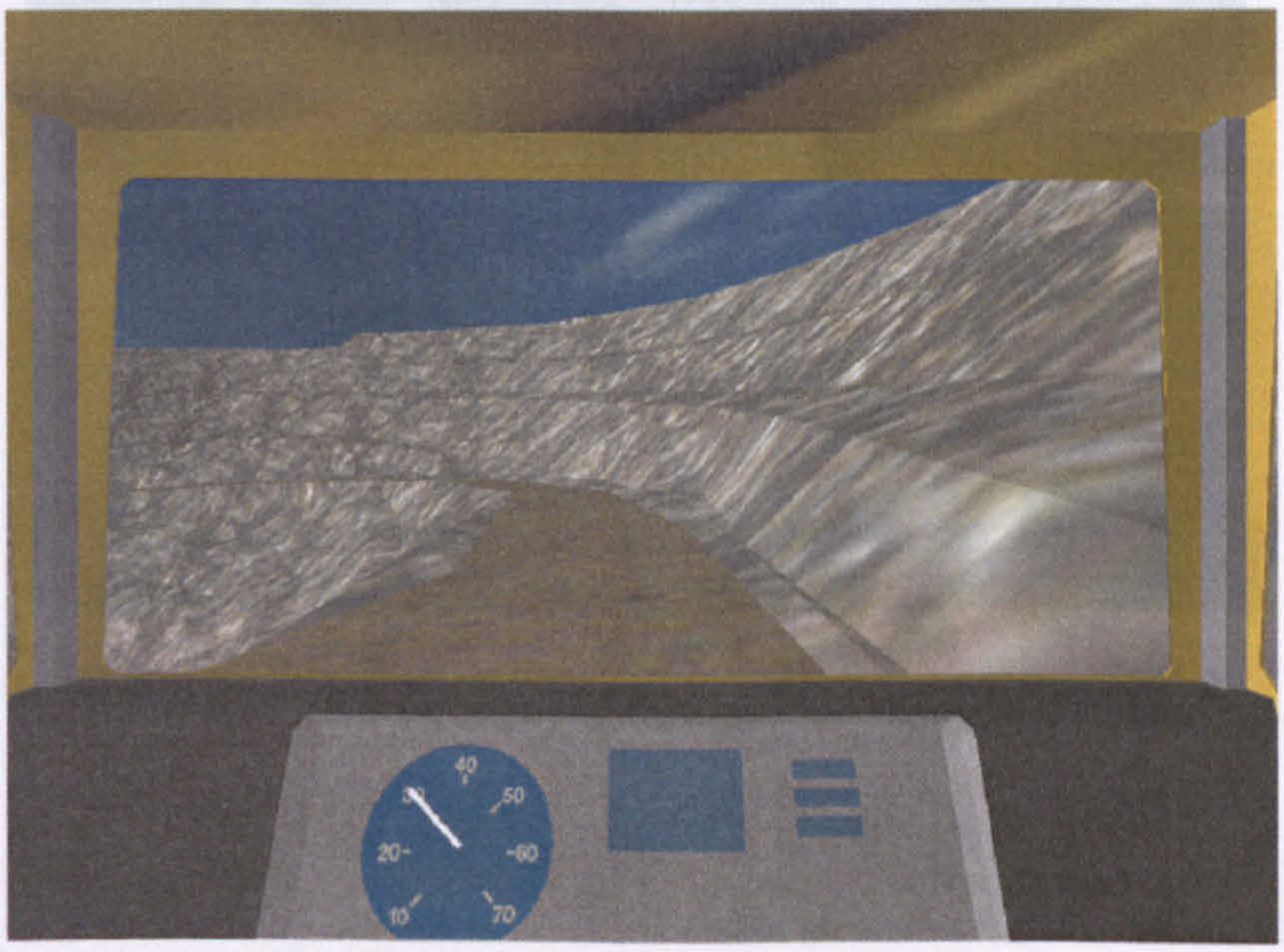

Figure 6.47 View from the vehicle cab.

6.4.3.2 Driver Demonstration (automatic mode)

VTruck presents the user with a view from the cab of the vehicle specified during scenario creation. This vehicle is controlled by the computer and will drive through the mine following the route specified in VEdit.

Although the user cannot control the vehicle they are able to alter the viewpoint within the cab. The user can look around the cab out the right or left window (Figure 6.48) using any of the input devices.

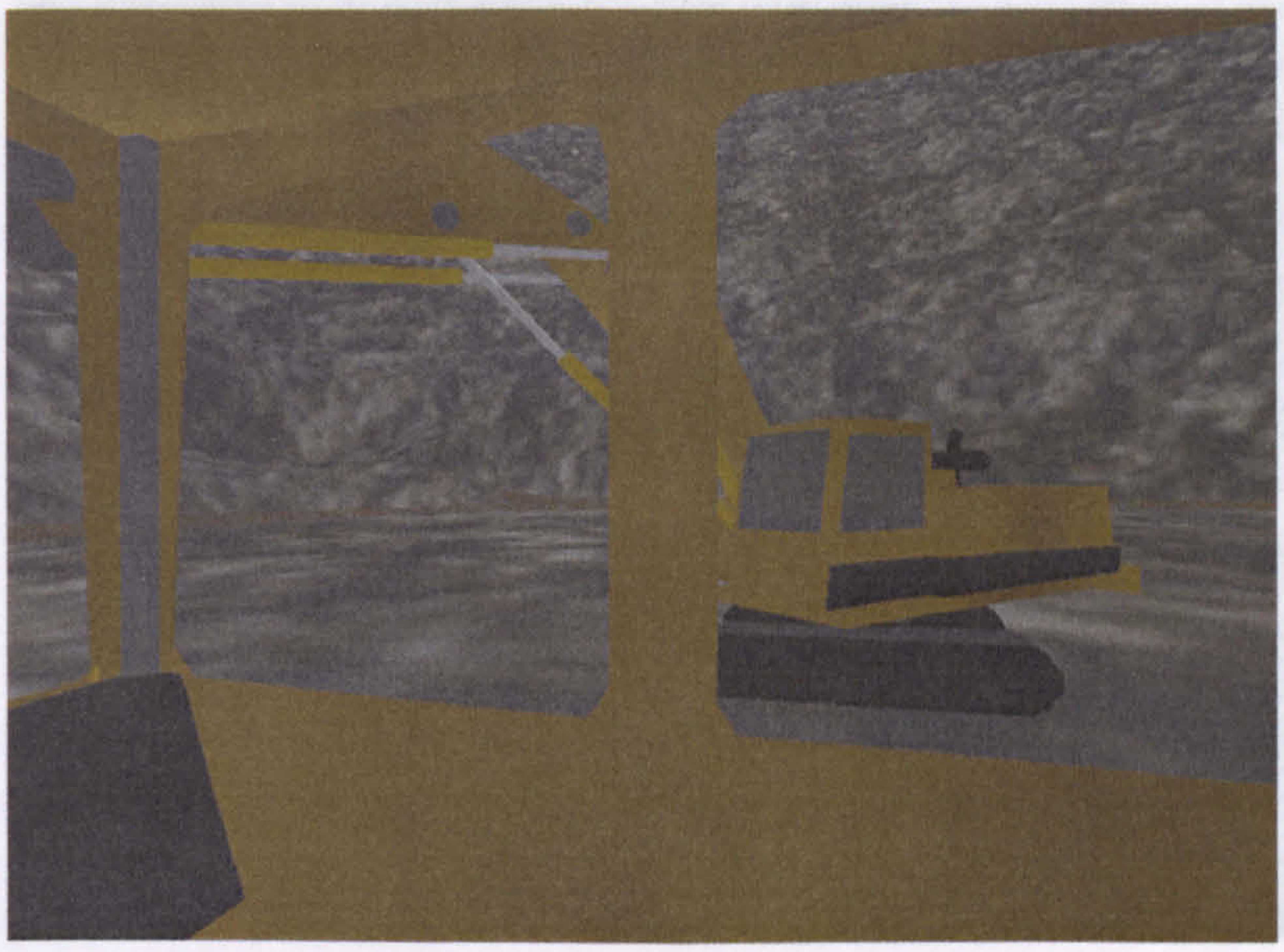

Figure 6.48 View through the right window of the vehicle cab.

6.4.3.3 General Operation (floating mode)

In this mode the viewpoint is not associated with any object in the simulation or any graphical representation in the virtual environment. There are no restrictions placed on movement through the virtual world, as such the viewpoint may be moved to any location. Navigation is achieved using any of the input devices described previously. A view from the floating viewpoint is shown in Figure 6.49.

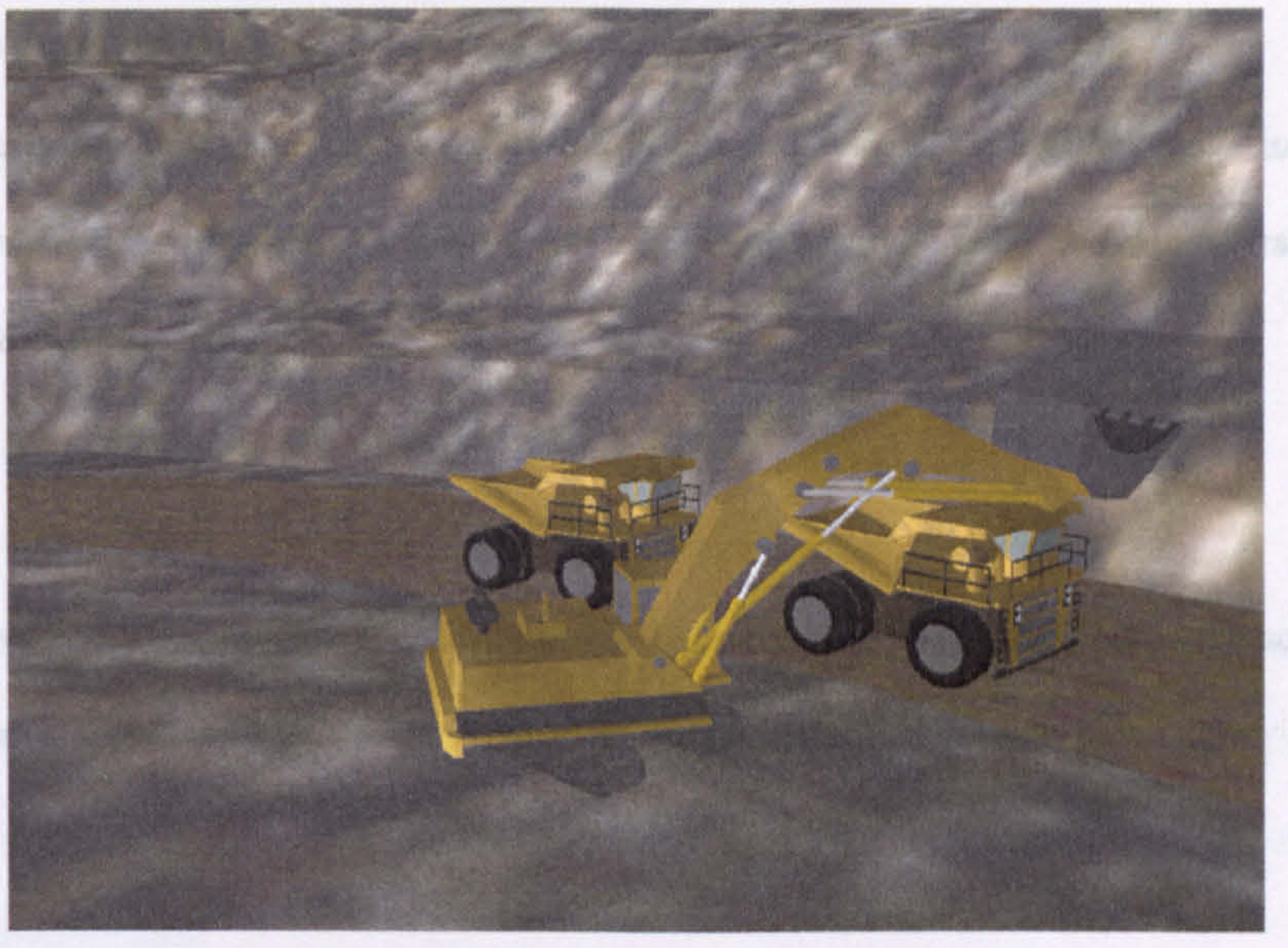

Figure 6.49 View of a surface mine load point in floating viewpoint mode.

6.4.4 *Hazard Identification Framework*

The hazard identification framework implemented allows hazards to be specified by the trainer and subsequently identified by the trainee. On completion of a training session VTruck provides an evaluation of trainee performance which can be used to assess or test the ability of trainees to operate safely within the environment.

The mechanism uses hazard information attached to objects in the virtual world, this is defined from within VEdit prior to execution in VTruck training system. This information describes all possible hazards and subsequent choices that are displayed to the user during a training session. Setting up a scenario for use within a training session will involve the following steps:

1. Ensure that all possible hazards, risk-levels and corrective actions have been defined, these are specified within VEdit. This hazard information is not intended to be scenario specific, the available hazards for each object and their corresponding risk levels and corrective actions will typically be used across all generated scenarios

within a given mine.

2. Specify the known hazards, correct risk-levels and actions for a given scenario within VTruck. This provides a known set of hazards that can be used to evaluate trainee performance.
3. Use the scenario for a training session.

Stages two and three involve identification of hazards, risk-levels and corrective actions within the VTruck application; this is termed the hazard identification procedure.

6.4.4.1 Hazard Identification Procedure

The identification procedure involves the completion of the following six steps from within the VTruck application.

1. Pause the simulation.
2. Identify the object with which the hazard is associated by selecting it on-screen.
3. Select the appropriate hazard from a multiple-choice list.
4. Evaluate the level of risk, by selecting from a multiple-choice list.
5. Indicate any corrective action that needs to be taken, by selection from a multiple-choice list.
6. Continue the simulation

Once an object has been identified as hazardous (step 2 in the above list), by selecting it using an on-screen cursor, the trainee is forced to complete the entire procedure. This prevents any information being inferred from the displayed multiple-choice list.

6.4.4.2 Evaluating Performance

Trainees performance is evaluated by comparing hazards, risk levels and actions identified by the trainee against those identified by the trainer. Individual trainee performance is measured using the following variables; these are calculated automatically by VTruck.

- Number of hazards correctly identified by the trainee.
- Number of hazards incorrectly identified by the trainee.
- Cumulative hazard score, the sum total of the values attached to each hazard that were correctly identified. This in conjunction with the number of hazards correctly identified and the number of hazards missed helps to identify the severity of the hazards missed.
- Total number of hazards in the scenario.
- The following are recorded only if the correct hazard has been identified:
    - Number of risk levels correctly specified by the trainee.
    - Number of risk levels incorrectly specified by the trainee.
    - In the case of an incorrectly specified risk level the difference between the trainee identified risk level and the correct risk level is added to a cumulative risk level score. This helps to identify if there is a tendency for the trainee to under or overestimate the level of risk.
    - Number of correct actions taken by the trainee
    - Number of incorrect actions taken by the trainee
    - For each correctly specified action the score assigned to the action is added to a trainee action score. This score can be compared to an expected score, which must be calculated on the basis of hazards correctly identified. This helps to determine the severity of incorrect actions taken by the trainee.

Although it is not within the scope of this work to evaluate the effectiveness of these measurement criteria, it is the authors' view that these should provide a reasonable measure of performance within the VTruck system. These variables also demonstrate the ability of a VR system to automatically record and evaluate trainee performance. A report containing these variables is displayed to the trainee after the scenario has been completed.

6.4.5 Presentation of the Virtual World

The virtual world is typically presented to the user as a full-screen 3D virtual environment. The view is output from the computer through a standard VGA connector and as such may be displayed on any standard PC display devices, such as a computer monitor or a projection system. A windowed view onto the virtual world is also available, this allows the user to execute VTruck whilst retaining access to the Windows desktop.

The distinction between a full-screen and windowed application is important. If the application executes in full-screen it is able to gain more control over system resources than a standard windows application. This strategy is typically used in computer games and allows dramatic increases in performance.

In this mode VTruck is able to control is the resolution of the display. Reducing the resolution of the display reduces the number of pixels that need to be rendered and hence the time (and resources) taken to render them. However, it also reduces the quality of the visuals, there is an obvious trade-off between quality and speed. VTruck offers full control over the display device and resolution of the display. This has allowed the system to take advantage of the increased rendering performance available on hardware accelerated graphics cards.

VTruck uses Microsoft's DirectDraw and Direct3D (part of the DirectX API) to render and display the visuals to the user. This API was chosen because of the wide support available for 3D accelerated graphics cards. DirectSound (also part of DirectX) is used to control and play sound.

6.4.5.1 Rendering

Certain rendering techniques can be used to increase the realism of the generated images. Care should be taken when choosing which options to use, some provide little benefit but are computationally expensive, whilst others increase the quality of the visuals significantly whilst requiring only a small increase in the level of computation. There are a large number of options and techniques available, those considered most important by the author are detailed below:

The sky object, shown in Figure 6.50, is a textured hemisphere that is automatically loaded, textured and scaled to the dimensions of the pit environment. Whilst the viewpoint remains within the surface mine it provides a good representation of the sky.

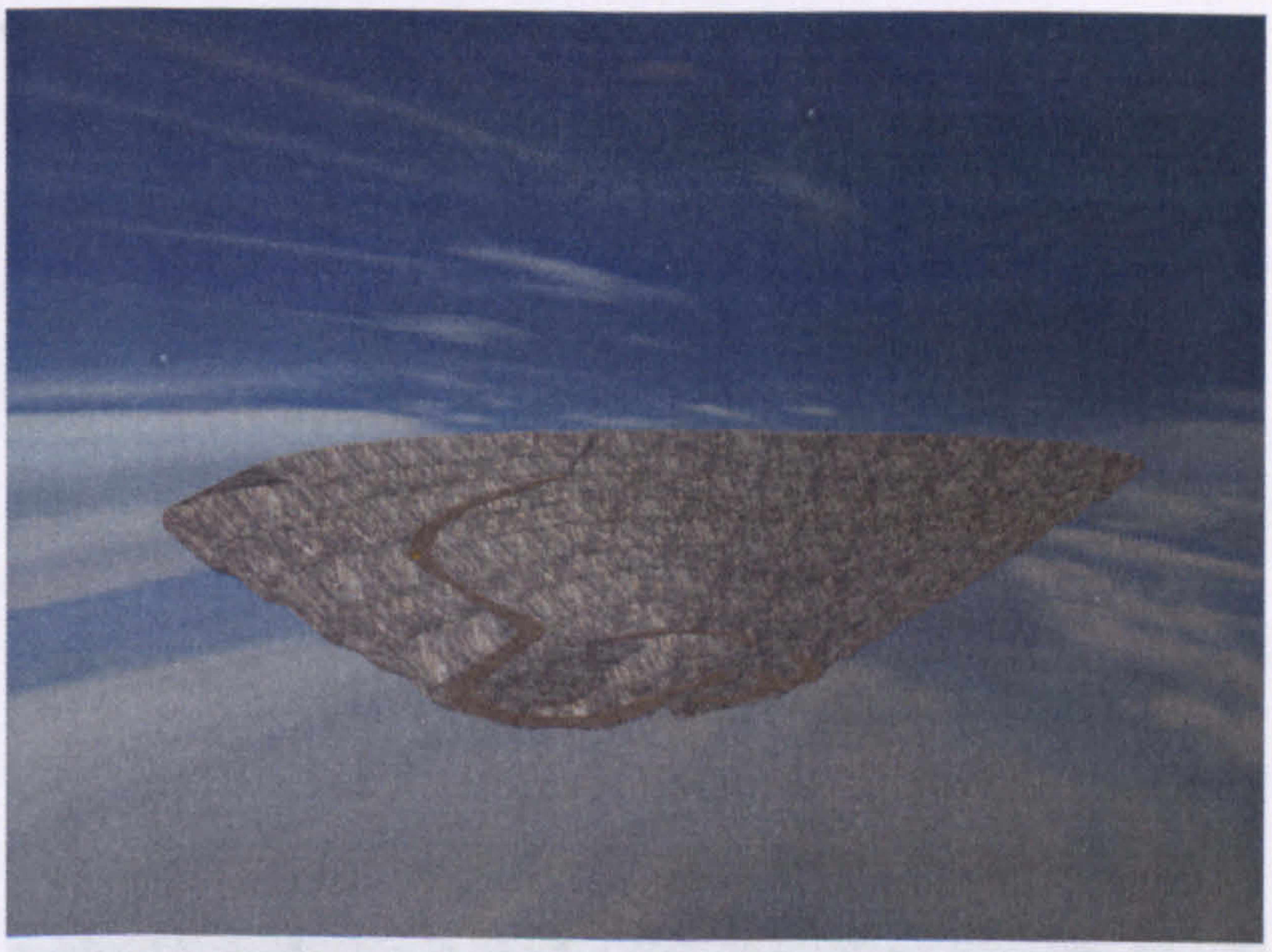

Figure 6.50 Screenshot of a surface mine showing textured sky object (sunny conditions).

Different bitmaps can be used for the sky to represent different environmental conditions. Figure 6.51 shows the surface mine under cloudy conditions.

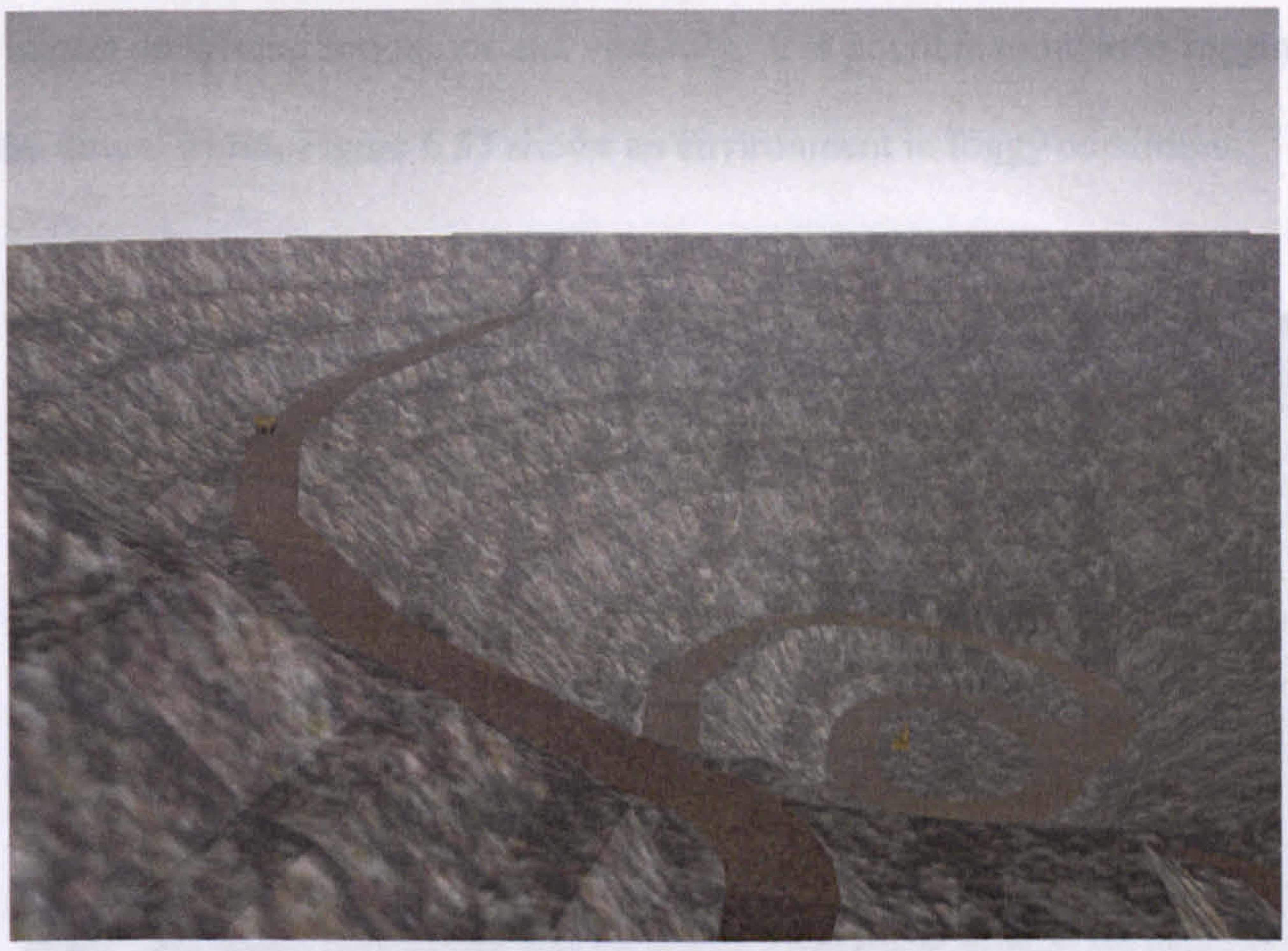

Figure 6.51 A surface mine under simulated cloudy conditions.

The lighting of the environment can be adjusted to represent changes in the weather or the time of day. Figure 6.52 shows an environment during simulated darkness.

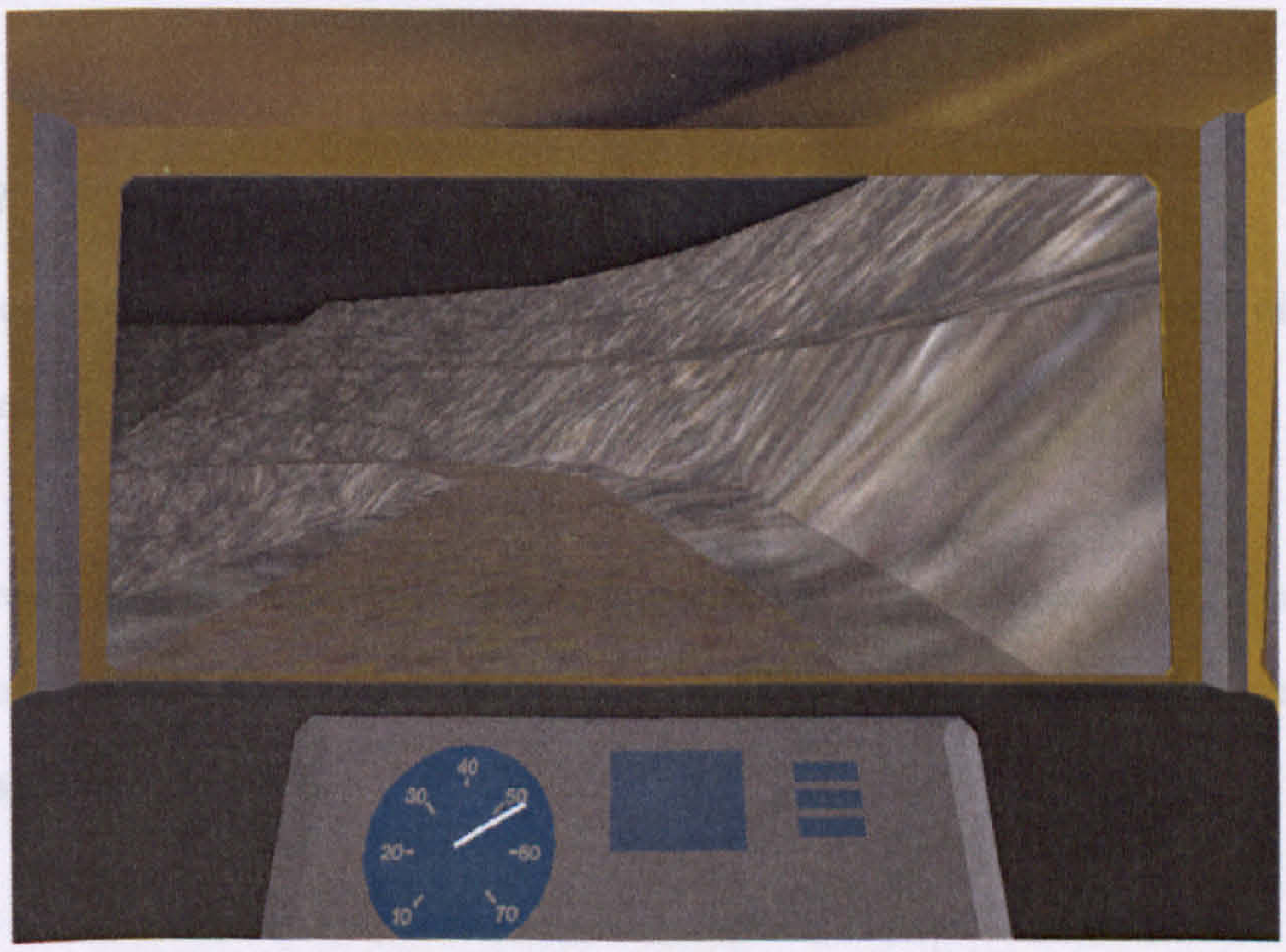

Figure 6.52 A surface mine under simulated darkness (road is lit due to vehicle headlights).

Heavy or light fogging conditions restrict the visibility in a surface mine, these can have a serious impact on driving conditions and visibility. It is possible to include fogging within the virtual world, Figure 6.53 shows an environment in foggy conditions.

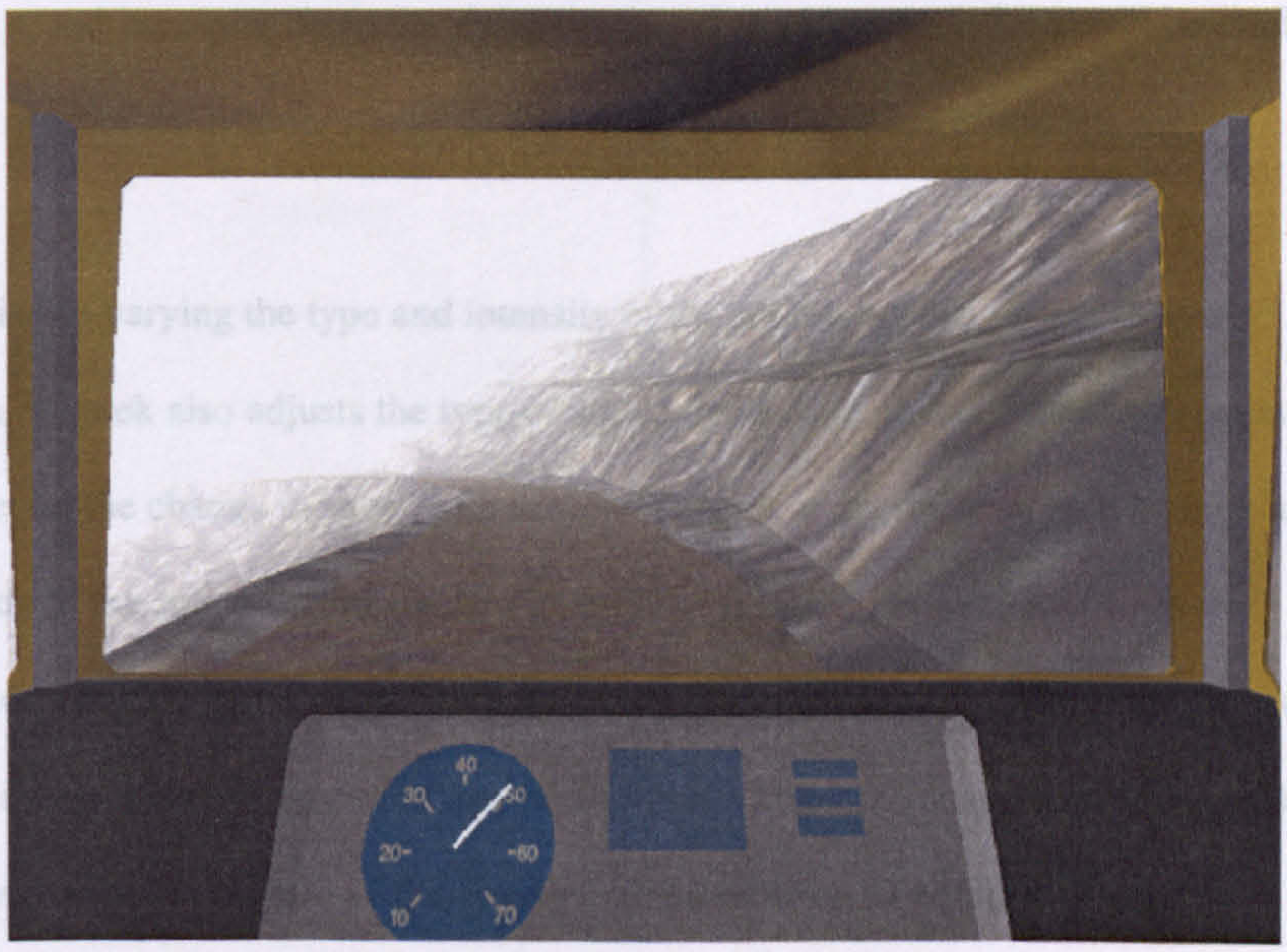

Figure 6.53 A surface mine in simulated foggy conditions.

6.4.5.2 Sound

Sound can provide a haul truck driver with essential information as to the health of their truck and the position and state of equipment in the surrounding area.

In the real world, the perception of a sound's position in space is influenced by a number of factors, the main factors taken into account (and those used by DirectSound) are as follows (Microsoft, 1999):

- Volume. The farther an object is from the listener, the quieter it sounds.
- Interaural intensity difference. A sound coming from the listener's right will sound louder in the right ear than in the left. This effect is familiar to anyone who has listened to a stereo sound system.
- Interaural time difference. A sound emitted by a source to the listener's right will

arrive at the right ear slightly before it arrives at the left ear.

- Muffling. The orientation of the ears ensures that sounds coming from behind the listener are slightly muffled compared with sounds coming from in front. In addition, if a sound is coming from the right, the sound reaching the left ear will be muffled by the mass of the listener's head as well as by the orientation of the left ear.

In addition to varying the type and intensity of the sounds according to the user's position, VTruck also adjusts the type of sound depending on the state of the equipment. In particular the change in speed of a vehicle's engine is represented by a change in the frequency of the sound coming from that engine. Information available from the simulation component of VTruck is used to adjust the frequency of the sound as the vehicle accelerates, changes gear, and decelerates. This has shown to provide good auditory cues as to the state of the engine and the location of equipment.

6.4.6 Input/Output Devices

A wide variety of different input and output devices are available for use with PC based desktop VR systems. The system was designed so that it could be used in a number of different configurations, a typical configuration is shown in Figure 6.54.

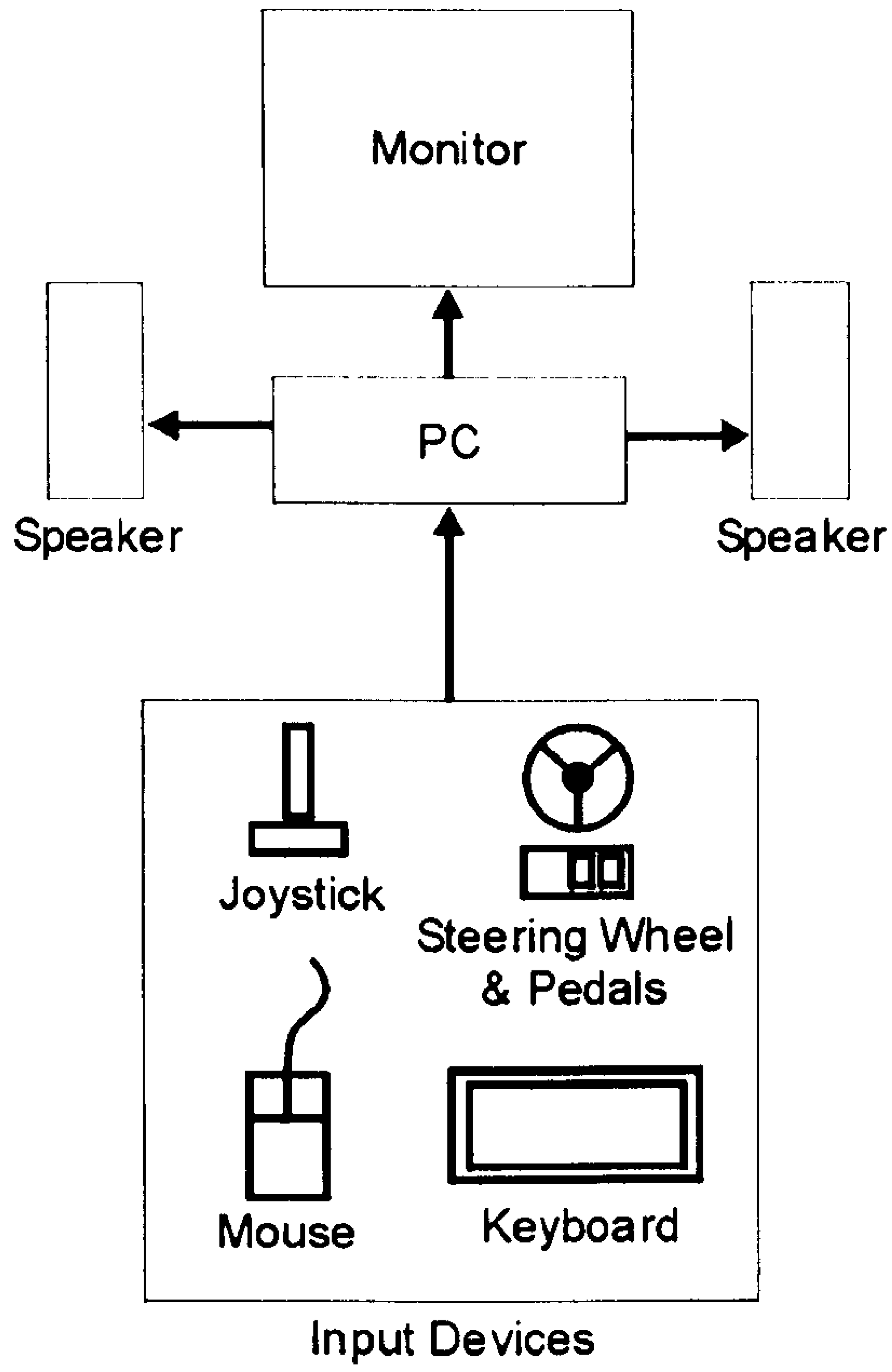

Figure 6.54 Typical configuration of VTruck

6.4.6.1 Input Devices

It was considered important to provide a natural interface for the trainee, this would allow them to become familiar and feel comfortable in the simulator in a short period of time. The input devices must be capable of performing the two types of operation that are required by the VTruck system, these are:

1. Ability to navigate through the world.
2. Ability to select objects within the world and to subsequently identify options from a multiple-choice menu.

Navigation

A number of different input devices have been used to navigate through the world. These include a joystick, a steering wheel and pedal device, a spaceball and the mouse and keyboard. Some of these are shown in Figure 6.55 and Figure 6.56.

Figure 6.55 Picture of joystick and spaceball

Figure 6.56 Steering wheel and pedals

The most natural interface for driving a vehicle is to use the steering wheel and pedals.

Specifications were provided to external contractors who built the steering wheel and pedals that can be used to navigate through the world. This device was rewired so that it could be connected to a standard PC games port and so that it's output could be read by the Windows operating system

A number of commercial steering wheel and pedals are now available such as Microsoft's SideWinder Precision Racing Wheel. These can be used in place of the custom built device.

Each of these devices can be configured through the 'Game Controllers' option in the Windows 95/98-control panel. This allows many different devices to be configured, calibrated and subsequently used with the VTruck system. Figure 6.57 shows the test utility in Windows 98 for the custom built steering wheel and pedals input device.

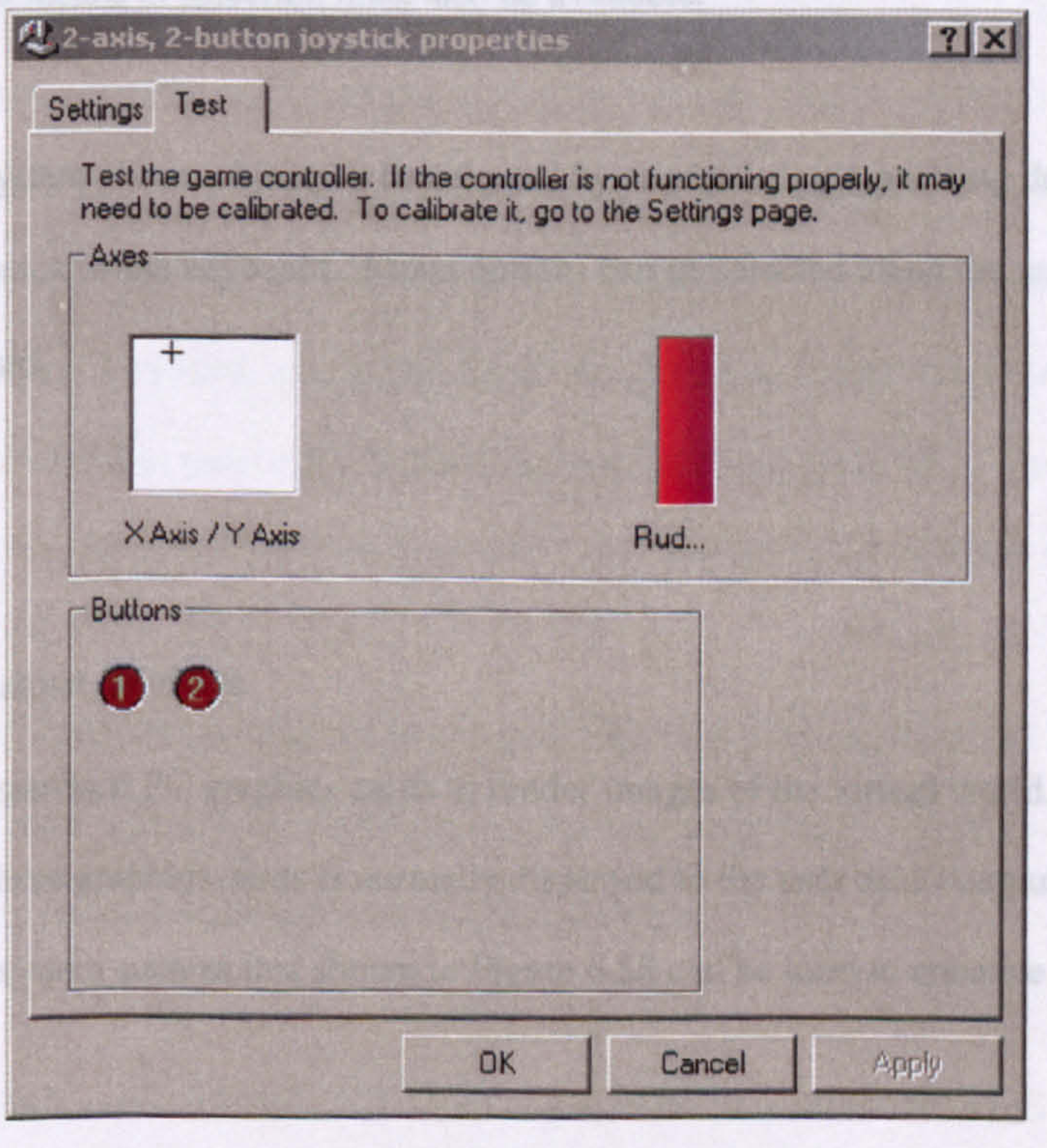

Figure 6.57 Windows test utility for game controllers, the device being tested is the custom built steering wheel

Once the device has been configured and calibrated in control panel, the values can be read directly by VTruck and translated into commands used to control the vehicle or to navigate through the world.

Object/Menu Selection

The user must also be able to select objects in the 3D world and subsequently identify options from a multiple-choice menu. There are a number of possible input devices that could be used for this purpose.

Perhaps the most intuitive and natural method of selection would be a touch-screen device. Simply pressing on the desired object or menu option on screen could select that object or menu choice. However, this input device is not suitable for a projection screen, and so another means of selection must also be available.

The current system allows objects to be selected by manipulating a pointing device using either the joystick or the keyboard. Menu options can be selected using the number keys on the keyboard.

6.4.6.2 Output devices

VTruck uses standard PC graphics cards to render images of the virtual world. The output from these graphics cards is normally displayed to the user on a computer monitor. A projection system such as that shown in Figure 6.58 can be used to enhance the experience.

Figure 6.58 VTruck used with a projection system

The projection system increases the field of view, in some cases the feeling of immersion is increased; however this could be due to other factors such as the reduced lighting levels. Projection systems have also proven useful when demonstrating the system to groups of people. However, the practicality of a projection system is questionable, the quality is heavily affected by the intensity of light in the room, the distance and area over which the image is projected, and the quality of the projector and projection screen. It has often proven difficult to reduce the lighting to a level sufficient for a good quality projection. This prevents the highest quality images from being presented to the user.

Recent developments in graphics hardware and in the Direct3D software API have meant that it is possible to use 3D glasses in conjunction with a standard monitor setup. This provides stereo images to the user and the illusion of true 3D.

A surround sound audio system can be used to heighten the effect of sound generated by the VTruck system. It can improve the ability of the system to generate realistic 3D sound sources. Additional speakers are used giving the system an improved capability to render sounds that appear to the right/left and behind the user.

6.4.7 VTruck – The Application

The VTruck application was written using Microsoft Visual C++, and runs on a PC under Windows 95/98. VTruck uses Microsoft's DirectDraw and Direct3D (part of the DirectX API) to render and display the visuals to the user. This API was chosen because of the wide support available for 3D accelerated graphics cards. DirectSound is used to render the 3D sound, and DirectInput is used to read input from devices such as joysticks, steering wheels and spaceballs. Both DirectSound and DirectInput are part of Microsoft's DirectX API.

The VTruck application has three distinct phases. First the user must select the scenario and configure VTruck (initialisation). Once the user has confirmed these options VTruck enters the second phase (virtual training environment). In the final stage VTruck performs any final processing, writes any stored data and restores any resources used (exit).

6.4.7.1 Initialisation

During the initialisation, the user has to select a number of options from a series of dialog boxes. The dialog box shown in Figure 6.59 allows the user to select a scenario, the mode of operation and whether VTruck is recording or evaluating the hazards spotted (via the 'Advanced' button).

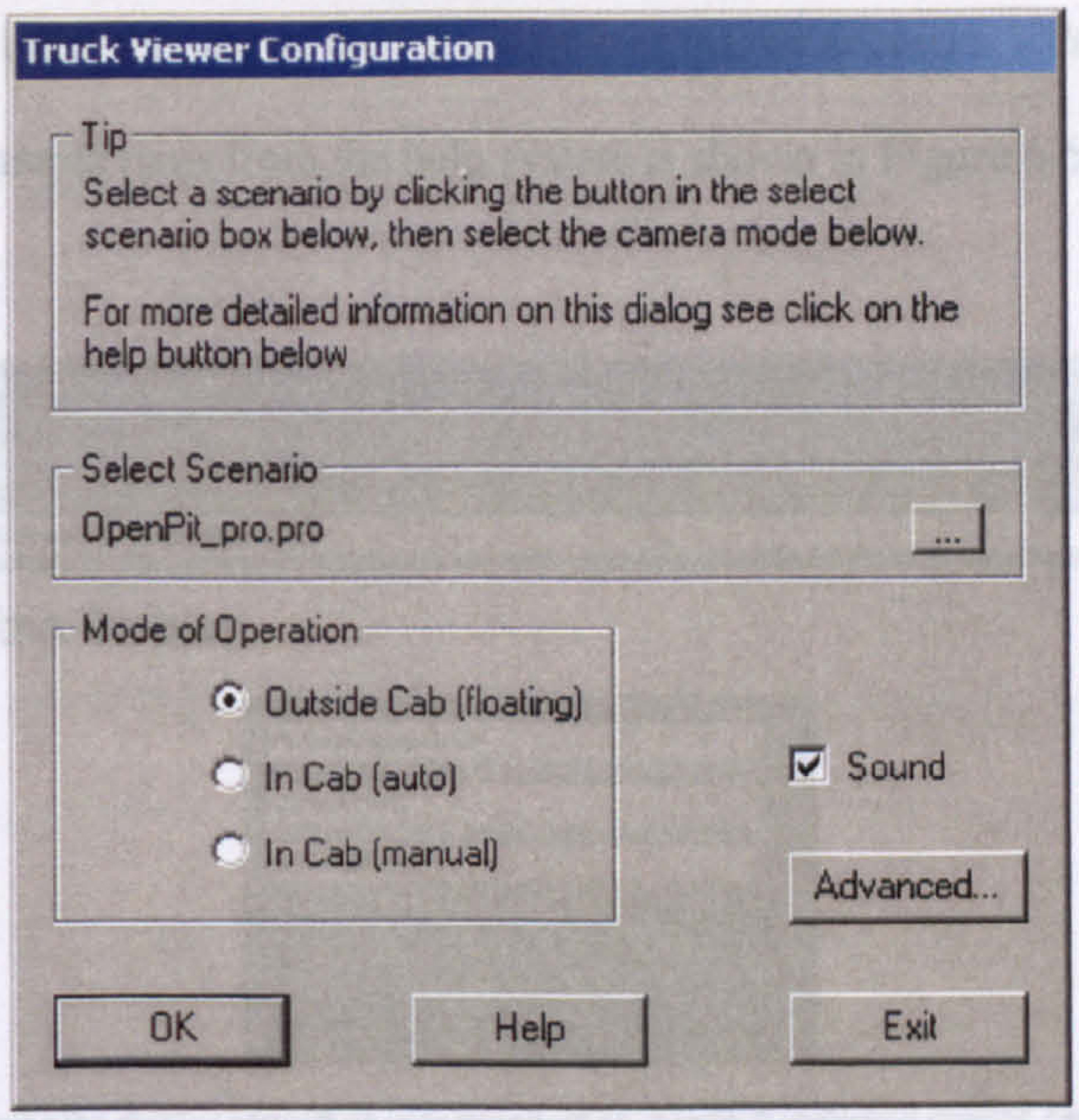

Figure 6.59 Selection of scenario and mode of operation in VTruck

The user must also choose a number of rendering options from a further dialog box (shown in Figure 6.60). This is a three-stage procedure; first the user must select the device in the computer on which to render the images, this is typically the computer's graphics card. The user must also select the driver (either hardware or software) and the display mode (both resolution and colour depth).

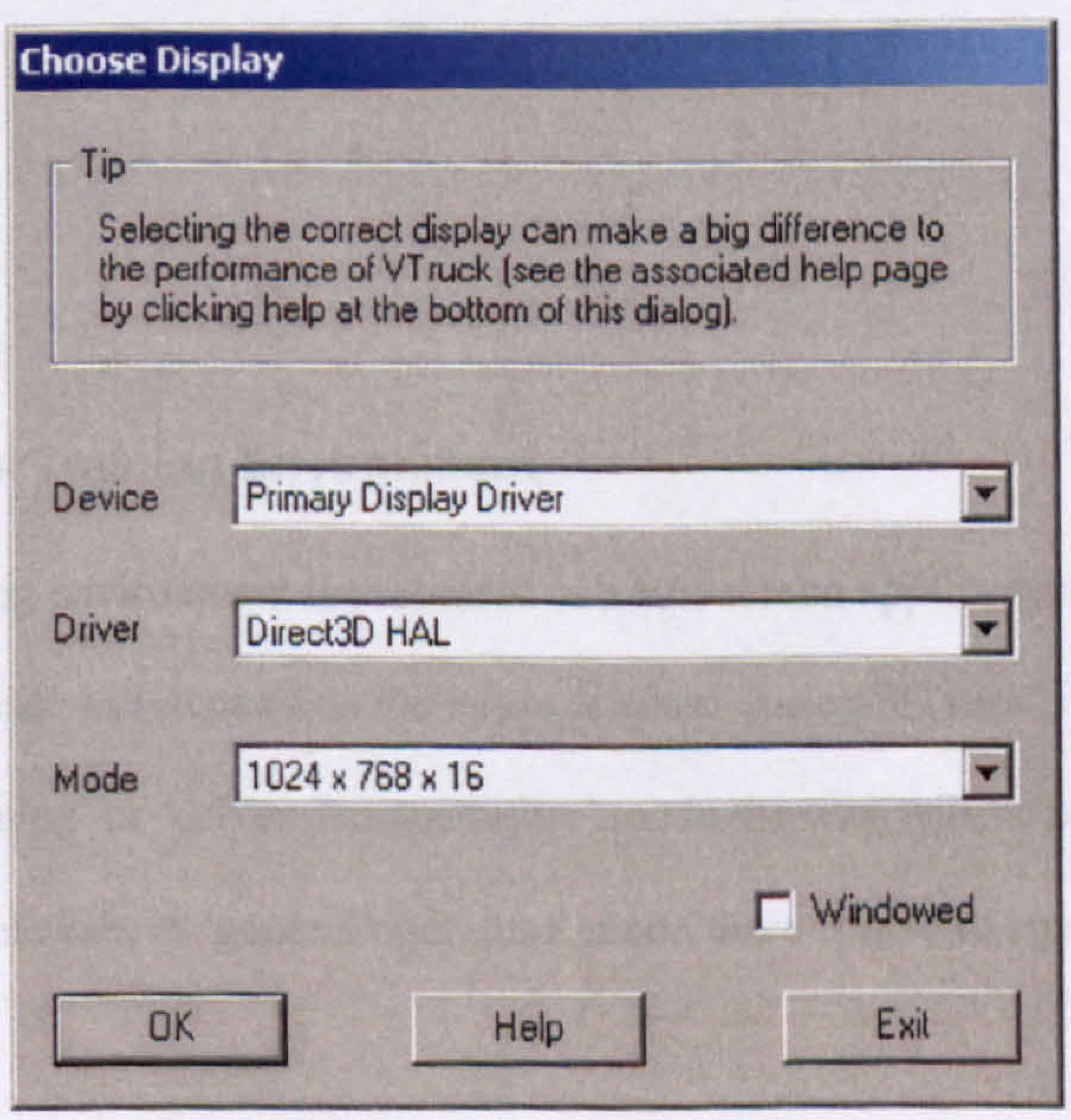

Figure 6.60 VTruck renderer selection

Pressing the help button in any of the initial setup windows accesses VTruck's on-line help system. A sample page from the help system is shown in Figure 6.61.

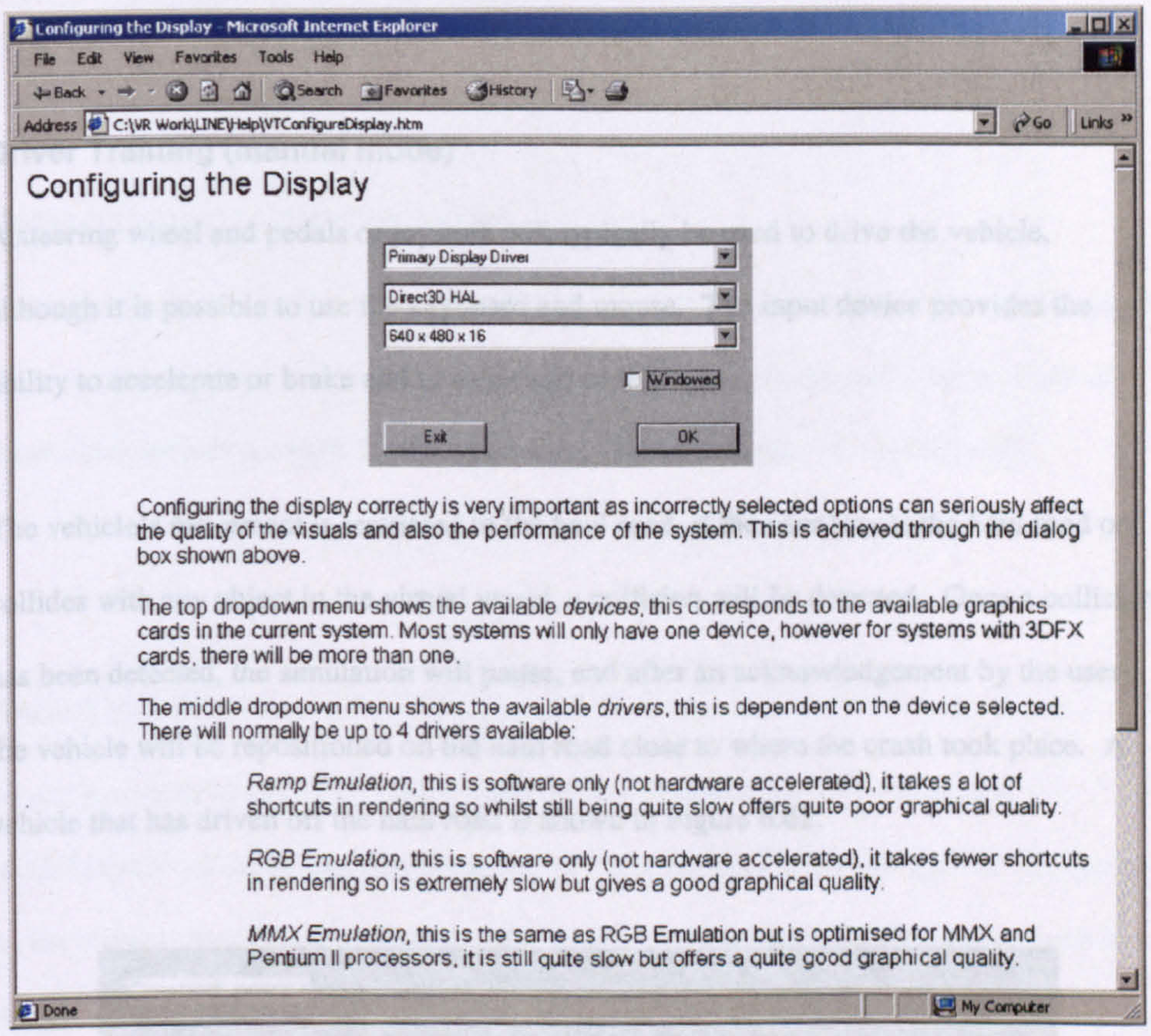

Figure 6.61 VTruck's on-line help system

6.4.7.2 Virtual Training Environment

The virtual training environment is presented as a full-screen application. The display presented to the user will depend on the mode selected during VTruck's initialisation. In either 'driver training' or 'driver demonstration' mode the user will be presented with a view from a vehicle cab, in 'general operation' mode there is no cab environment.

Navigation

The type of input device used to navigate through the world will depend on VTruck's mode of operation.

Driver Training (manual mode)

A steering wheel and pedals or joystick will typically be used to drive the vehicle, although it is possible to use the keyboard and mouse. The input device provides the ability to accelerate or brake and to turn right or left.

The vehicle's movement is restricted to the haul road, if the user leaves the haul road or collides with any object in the virtual world, a collision will be detected. Once a collision has been detected, the simulation will pause, and after an acknowledgement by the user the vehicle will be repositioned on the haul road close to where the crash took place. A vehicle that has driven off the haul road is shown in Figure 6.62.

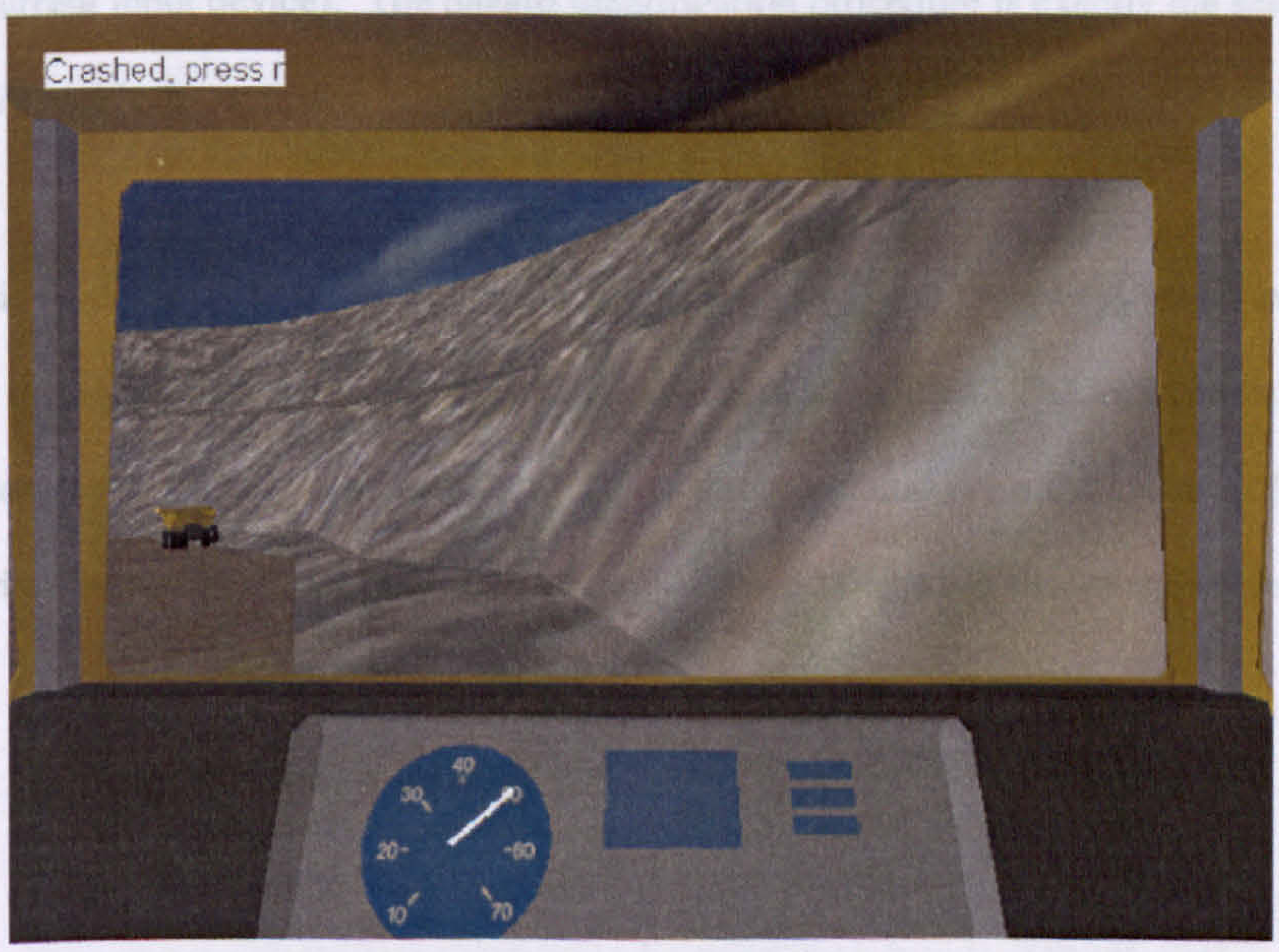

Figure 6.62 A vehicle crashed into the side of the road

Driver Demonstration (automatic mode)

In this mode the computer drives the vehicle but the user is able to look right or left from the vehicle cab to identify hazards. The joystick, mouse or keyboard is normally used to control the viewpoint in this mode.

General Operation (floating mode)

In this mode the user is free to move to any location within the virtual environment. Input devices typically used in this mode include the joystick, keyboard and mouse. Each of these input devices provides the ability to move freely through the virtual world.

Hazard Identification

At any time, and in any of VTruck's three modes, the user can enter the hazard identification system by pressing the spacebar on the keyboard (or the appropriate button on the current input device). The hazard identification procedure is exactly the same in any of VTruck's three modes.

Once this mode has been entered, the simulation is paused, and the user is asked to identify the object with which the identified hazards is associated. The user must move the cursor, represented by a yellow square, over the object and press the spacebar (or the appropriate button on the current input device). This procedure is shown in Figure 6.63.

Figure 6.63 Selecting an object from within VTruck

Once the object has been identified the user is provided with series of multiple-choice menu from which the hazard, risk-level and action can be selected. This process is shown in Figure 6.64.

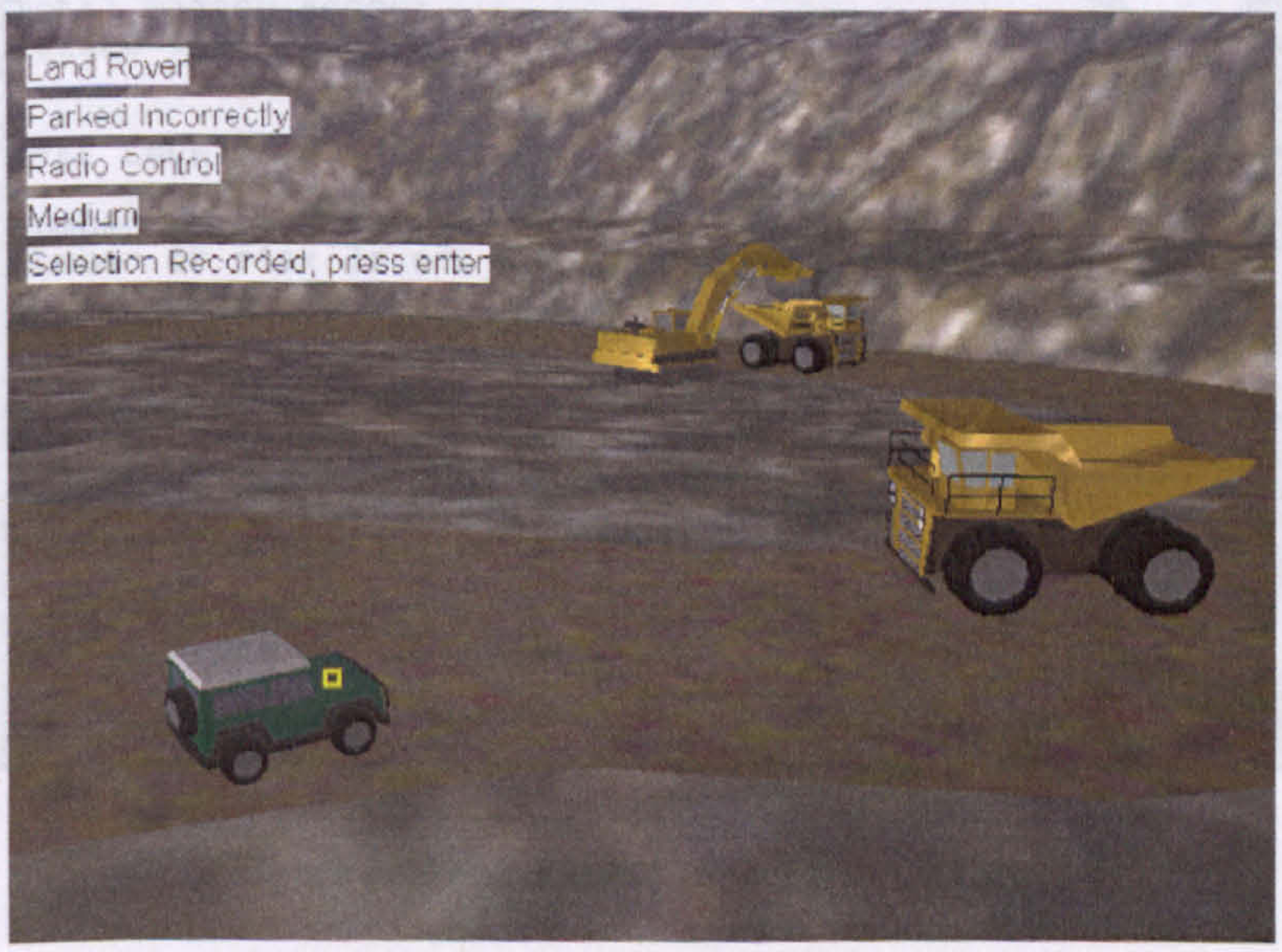

Figure 6.64 Selecting the hazard, risk-level, and action from a multiple choice menu

The same hazard identification system is used when VTruck is recording the hazards and when it is evaluating the performance of a trainee.

6.4.7.3 Exit

During the exit phase of the application VTruck will evaluate or write the hazards identified during its execution. If VTruck is being used to identify the hazards prior to a training session then it will write the hazards identified to a file. This file is defines the hazards in the environment and is used to compare against the hazards identified during a training session. The result of this comparison is a report detailing the performance of the trainee. This report is saved to a file and presented to the user after the system has exited. An example report is given in Figure 6.65.

```
hazard_spotted.txt - Notepad
File  Edit  Format  Help
VTruck executed on:        Fri Apr 21 09:19:25 2000

Hazards
-------------------------------------------------------
Number of hazards correctly identified:          5
Number of hazards incorrectly identified:        2
Total number of hazards in scenario:             8

Total hazard score:                              70
Hazard score possible:                           130

Risk Levels
-------------------------------------------------------
Number of risk levels correctly specified:       3
Number of risk levels incorrectly specified:     2

Cumulative risk level difference:                20

Actions
-------------------------------------------------------
Number of correct actions taken:                 2
Number of incorrect actions taken:               3

Total action score:                              50
Action score possible:                           90
```

Figure 6.65 Assessment report from VTruck

6.5 Results

The system has been presented to a wide cross section of people, including those both inside and outside the minerals industry, the general public, and at a number of conferences. The evaluation of the system presented here is based upon the comments received.

They were surprised at the speed and simplicity of scenario generation and very positive about the incorporation of existing data producing realistic environments. They felt that performing training in environments similar to those faced in reality would provide significant benefits. Additionally, the provision of realistic environments opened up the system to be used for a variety of other tasks.

They liked the method of defining the haul road as sequence of line segments, in particular the flexibility it offered and the speed with which the road could be defined. They commented that the quality of the haul road produced in terms of integration with the imported landform was good.

The provision of object libraries allowed quick incorporation of objects and the specification of object movement was found to be simple to understand. Furthermore they felt that the ability to add new or customise existing objects provided good scope for producing realistic environments.

In the training system, people were surprised at the realism of the environment produced. Factors identified as important included the high quality of the visuals, 3D sound, realism of object movement and simulation and the speed of the update maintained. Environmental effects such as fogging and cloudy sky were considered to enhance the virtual environment significantly. The visual representation of the haul road was identified as an area requiring improvement, there was a lack of berms at the side of the road and it was too flat and uniform.

The representation of the cab environment was not considered sufficient for the purposes of training. Important features of the environment were missing including fuel gauges, warning lights, and rear view mirrors. People did not generally comment on the driving position within the virtual environment though they found it difficult to estimate the size of the vehicle, this resulted in collisions that they did not feel were justified.

The view provided onto the virtual world was found to be restrictive, people wanted to see left, right and behind. Manipulating the current view to 'turn around' was found to be cumbersome and unnatural, it was subsequently identified that the provision of additional screens would be the best way of supporting additional views.

People liked the flexibility offered by the training system, in particular they anticipated that the three modes of operation could be used for a wide variety of tasks including visualisation and demonstration. The available input devices provided a natural way of interacting with the system. In particular the use of a steering wheel and pedals provided a good method of controlling the haul truck. Observations showed that people became familiar with the driving controls quickly. Controlling the free movement mode using a joystick required additional time, though this was could be attributed to the increased freedom of movement available.

The hazard identification system provided a simple method of testing employee knowledge and protocols, though this would require further development and customisation to meet each organisations requirements. The method for identifying hazards and subsequently selecting menu options was considered cumbersome and did not fit well with navigation through the virtual world. The use of a touch screen input device was identified as an important future development.

In general people commented that the environment produced provided a good representation of that faced in reality and that this was likely to provide a good environment in which to train.

6.6 Summary

The haulage training simulator was implemented as two distinct applications. The first allows virtual environments to be authored whilst the second provides a virtual environment suitable for training.

The construction of a virtual training environment can be a complex and time consuming process. A PC based Windows application (VEdit) was developed to:

- Automate much of the process of scenario creation, reducing the time taken to construct scenarios.
- Allow integration of existing data from mine design packages. This ensures that the training worlds are geographically realistic and allows them to reflect the environment faced on a day to day basis.
- Allow fast modification and customisation of scenarios.
- Provide data so sufficient quality for the training module.

Existing landform data is imported into the application from a mine design package, this allows the scenarios generated to be geographically realistic. The haul road network is overlaid onto this terrain as a series of straight and curved line segments. This sequence lines is converted in a full road network consisting of 2D straight, curved and junction road segments. This road network is subsequently integrated into the terrain such that a realistic haul road suitable for use in a simulation is produced. Route information is generated as part of the haul road, allowing computer controlled vehicles to move through the virtual world efficiently.

The resulting terrain is populated with objects such as equipment, personnel and buildings. A framework was developed that allowed the incorporation of a number of different types of objects. This included the placement of static objects and also the definition of route information for moving objects.

Hazard information comprises the name of the hazard, a risk level, and a corrective action, this can be attached to any object in the virtual environment. Each hazard, risk level and action has an associated score that can be used in the training simulator to evaluate performance. Libraries of pre-defined objects are available, these help to improve the speed of scenario generation as existing objects can be reused in newly created virtual environments.

Tools are in place allowing generated scenarios to be tested and modified until a realistic environment is produced.

The PC based virtual training system (VTruck) uses data generated by VEdit to provide:

- A realistic environment in which to train, this includes the provision of high quality visuals, and realistic audio.
- Realistic simulation of vehicle behaviours and performance.
- Natural method of interacting with the environment.
- Provision of a hazard identification framework that allows assessment of trainee performance.

A simulation engine was developed inside the VTruck package. This allows the specification of equipment performance in the form of industry standard rimpull and retarder curves. This allows an accurate simulation of vehicle performance to be maintained. Additionally the simulation engine supports basic object behaviour for individual vehicles, each vehicle is considered as an individual entity and is able to modify its behaviour based upon an analysis of the local environment.

A number of modes were implemented allowing the user to drive, be driven or fly freely through the environment. When either driving or being driven through the environment a virtual cab is presented to the user as part of the virtual world. The three modes allow flexibility to undertake different tasks within the virtual world, including and evaluation of the generated environment and to either record (or set up) the hazards within the environment.

The virtual world is presented as a full screen application, the use of a graphics acceleration allows realistic images to be produced whilst maintaining a frame rate close to that of film. VTruck has been used with both a standard monitor and a projection system to display images to the user. 3D sound is also generated by equipment in the environment, this can be enhanced with a surround sound audio system. The type of input device will depend on the mode of operation, though a steering wheel and pedals, a joystick and a mouse and keyboard are all supported.

Training is accomplished using a hazard identification mechanism that can be accessed at any point during the simulation. Trainees identify hazards in the environment by pausing the simulation and selecting on screen the object with which the hazard is associated. After identifying the object and the hazard they are required to indicate any corrective action they would choose to take and also select a level of risk.

When running in training mode, VTruck will record the performance of a trainee based upon the hazards, risk levels and actions taken in the simulator. A report is produced at the conclusion of the simulation detailing statistics that can be used for assessment.

7 Conclusions and Recommendations

7.1 Introduction

The purpose of this work was to identify and investigate the potential of producing commercially viable VR systems that could be used within the minerals industry. In particular it set out to develop the existing concept of risk regions and to further identify and investigate the potential for using VR to improve aspects of safety. In this chapter a brief overview of the work is given followed by the presentation of conclusions and recommendations.

7.2 Overview of Thesis

It was identified that VR is a technology that is already being used for a wide variety of applications. The rapid advancement in technology has improved the quality of VR whilst also reducing the cost associated with such systems. The rapid progress of low cost VR systems has allowed this technology to be considered in areas once ruled out due to the high cost involved.

Applications were identified that demonstrate the potential of VR to improve safety in a wide variety of industries. These often show that VR is successfully applied when the situation is dangerous or when it is expensive or impractical to recreate the environment. The minerals industry is a dangerous environment that has many aspects of safety. Following a preliminary investigation into general aspects of safety within the minerals industry the potential for applying VR technology was investigated in two areas, risk assessment and training.

The AIMS Research Unit had already undertaken some preliminary work on a risk assessment tool. Work was undertaken to develop and refine the concepts introduced. A physical process or system is recreated on a desktop-based VR system. This world is enhanced with a risk-based overlay and tools are provided that allow the risk at any location to be evaluated and logged. A prototype application was built and two case studies were conducted to evaluate the effectiveness of the concepts developed.

The second area investigated the viability of producing a low cost training system for haul truck drivers operating within a surface mine environment. A system was developed with the aim of demonstrating the potential of VR to enhance the current training program. The system developed supports full customisation of the environment, including the incorporation of mine specific geometry and road layouts as well as the individual placement of objects and routes of mine equipment. The trainee can either navigate freely, drive, or be driven by the computer through the constructed virtual environment. Hazard identification is used as the primary tool for transmitting and testing knowledge.

7.3 Conclusions

This section presents the conclusions drawn from the research undertaken.

7.3.1 Risk Visualisation System

It was envisaged that the 3D visualisation of operations would provide the assessor with a better understanding of the layout, the size and the movement of objects within the environment. Enhancing the environment with a risk-based overlay would allow the assessor to further investigate the risk-based relationships within the environment. It was hoped that the development of such tools would enhance understanding leading to a better risk assessment and a safer work place.

In situations where it is impossible to gain first hand experience of an environment, visualising it in 3D provides a good alternative. The application developed allows the world to be viewed from any position and angle, including those not possible in the real world. The rate of time within the world can be controlled and many different viewpoints can be displayed simultaneously in real time. This provides a powerful means of experiencing and investigating the environment that is often not possible in the real world.

Modelling the process itself can also aid understanding, limits on the transfer of knowledge using a paper based approach mean that it is sometimes difficult to understand the order of procedures and the time taken to complete them. Viewing the operations in real-time and in 3D allows the assessor to become familiar with both the time and spatial relationships of the operation.

Using regions to represent the increased risk around each dangerous factor provides a good basis for risk assessment. The inclusion of some function of proximity to the classic definition of risk is important when assessing the risk based relationships in a 3D environment.

The algorithms developed provided a good representation of the risk in the environment. For each risk marker the calculated risk values were reasonable given their location. The ability to calculate the level of risk at a particular location has proved useful in other industries. In particular this allows a direct comparison of the risk experienced in two different locations or environments.

Great care must be taken when defining the shape, size and values associated with risk regions, as this can impact the result of the assessment. The resolution to which the risk regions are modelled is also important; they should be modelled to a level that is suitable for the environment under consideration.

The approach adopted allows each piece of equipment to be considered in isolation, the associated region is dependent only upon the equipment's state. Increased use of the system could therefore lead to refinement in the size, shape and values associated with each region system. Benefits of this might include an improved assessment and a reduced modelling time. Region systems could be developed for each piece of equipment used within the mining industry and subsequently shared between operators. The development of a common approach to risk assessment and one that reduces the level of interpretation required by an assessor could prove attractive to organisations.

The risk region systems used have shown to provide a flexible means for modelling many types of risk. As new types of risk are included different types of risk region system could be defined to accurately model the risk experienced.

The application written to investigate the new approach was sufficient to evaluate effectiveness and to demonstrate intended use. The PC based system provided adequate computing power to model the environments considered in the two case studies. A desktop system proved ideal for the task under consideration, the use of a joystick in combination with a mouse and keyboard provides a good method of interacting with the 2D interface and also of navigating through the virtual environment.

VR technology allows a much more complex spatial analysis of the environment to be conducted and presented to the user. It is the ideal medium for displaying levels of risk and the complex relationships between equipment, risk regions and markers.

The visualisation of operations and risk in 3D could also be used for purposes other than risk assessment. Training and educating personnel prior to undertaking tasks in the environment is one example. The system could be used to highlight dangerous areas and factors within the environment or perhaps to illustrate the sequence of procedures for an entire operation. It is also possible that the system could prove useful in the design and analysis of new or existing operations. The results of assessing the environment can be incorporated into operational design perhaps leading to safer or more efficient procedures.

It is expected that the methodologies developed here could be used in industries and environments other than those investigated with little modification.

7.3.2 Haul Truck Simulator

Haul truck operation was identified as an area that offered potential for improvement through the use of a VR training system. Investigations were carried out and a training system designed and implemented that demonstrates the potential for low-cost VR training systems within the minerals industry.

7.3.2.1 Scenario creation

Historically scenario construction is a time consuming and expensive task; this has proved a bottleneck in many existing VR training systems. The automation of much of the procedure allows scenarios to be created and modified quickly allowing trainers to generate and expose trainees to a wide variety of hazards. The simplicity of the system allows people with no experience of VR and only limited training to build and edit scenarios to a high quality.

The methodology used to construct scenarios proved to be successful in meeting all of the objectives discussed. It allows the incorporation of existing and new data to construct scenarios that were of sufficient quality to be used in the VR training system.

The use of existing data to generate the virtual environments provides realistic scenarios in which to train. Evaluating the benefit of providing the trainee with the actual environment in which they work will require additional work. However, it is expected that there will be significant benefit from experiencing the actual road layout and traffic movements prior to exposure in the real world. The cost of scenario creation is also considerably reduced as the system uses existing data.

Defining the haul road network as a string of connected nodes proved to be a flexible and simple mechanism. This was sufficient to accommodate most networks experienced in real life. The algorithm developed that integrates the road network with the imported terrain produced good meshes that can be used in a driving simulator.

The decomposition of the environment into dynamic, static and landform objects allows many different types of objects to be included. Additionally any number of further custom objects can be defined providing flexibility for further expansion or customisation of the system. This has so far been sufficient to model a number of environments containing different equipment.

7.3.2.2 Training system

The choice of C++ on a Windows platform proved a cost effective and powerful combination. The increase in availability and power of 3D graphics acceleration has significantly improved rendering performance on the PC platform. The C++ language provided the freedom and speed necessary to achieve all of the objectives defined. The use of libraries such as Microsoft's DirectX (Microsoft, 2000) also enabled development to be undertaken in a much shorter time frame and allowed access to many features not previously possible (e.g. 3D audio and custom input devices). However, programming 3D worlds using C++ still requires a high degree of expertise and patience.

A good update rate (above 30 frames per second) was achieved with a reasonable number of objects (around 20) populating the environment; this is a good target and provides a 'smooth' experience. As the complexity of the environment and the number of objects increases the update rate slows, this was found to hamper responsiveness of the system and in turn to frustrate users of the system. Improvements in computer power should increase the capabilities of the system sufficiently to handle most mine environments. It is considered important to keep the frame rate as constant as possible as an erratic frame rate can give the impression of jerkiness and can disrupt the experience, this was an issue during coding.

The author believes that the use of low-cost technology does not prohibit good quality outputs and realistic simulation. Significant benefits are available from using PC based systems rather than more expensive workstations. These include not only initial financial outlay but also in terms of other factors such as portability, flexibility and the maintenance and support of such systems.

The modelled rimpull and retarder curves provided a good mechanism for entering vehicle performance into the system; these provide a reasonably accurate simulation. The simulation of vehicle behaviour currently works well, though the behaviour is still relatively simple. The modular and customisable design of the simulation engine provides a good basis for developing further objects with more sophisticated behavioural algorithms.

Experimentation with different rendering techniques and parameters to recreate different environmental conditions produced some interesting results. Further development would be required to adjust vehicle performance depending on environmental conditions, and to verify that the conditions accurately reflect those encountered in real life.

The steering wheel and pedals used to control the vehicle provide a good natural interface for the system. People using the system found that the controls were easy to use, they normally felt comfortable driving the vehicle using the steering wheel and pedals in a short space of time. The joystick was also considered a good method of navigation, people felt comfortable navigating in any of the three modes using this device.

The projection system provides a good method of demonstrating to groups of people, however, it is questionable whether this is a good way of delivering content to an individual. A projection system requires a larger area and is more sensitive to conditions than a standard monitor. In terms of actual delivery subjects that had used the system seemed to prefer a standard monitor system. They were more familiar with the device and it typically provides a higher quality image. Additionally using a monitor would allow the inclusion of a touch screen system for identifying hazards.

Only limited work on the cab environment was undertaken. Including the cab in the virtual world provides a high degree of flexibility as it is possible to alter the layout easily. However, it did not provide a good representation of the environment faced in reality. A better representation of the dash could be provided by a real life mock up of the instruments and dials.

The three modes of operation that were included in VTruck provided a good amount of flexibility. The ability to investigate the environment in floating mode allows a complete investigation of the environment to be undertaken, it is useful during demonstrations, and for specifying hazards. Manual mode is typically used for training, whilst automatic mode is often used for demonstrations or could be used during a review phase of the training program.

The hazard identification framework has already shown significant promise as a valid means of training personnel. The method does seem to be compatible with this type of simulator and is thought to provide a good method of knowledge transferral and reinforcement. Hazards currently included were well represented and easily identifiable in the virtual world though they were quite limited in scope.

Future VR training systems using similar hazard identification techniques should be integrated with a touch-screen device as this provides a natural method of interaction with the system. It was also found that manipulating a cursor through the keyboard or joystick was clumsy and disrupted the continuity of the experience.

It is the author's belief that the system developed demonstrates that there is good potential for VR systems to enhance existing training programs.

7.3.3 Overall Conclusions

Two VR applications were successfully developed during the course of the research work. The author believes that both these applications demonstrate the potential of such systems within the minerals industry. VR has allowed novel approaches to be adopted in two areas of safety, risk assessment and training.

The development platforms chosen (both in terms of hardware and software) made for each application remains valid and viable for applications today.

C++ in combination with the DirectX API (Microsoft, 2000) has provided a powerful combination allowing a great deal of flexibility. However, it should be realised that there is a substantial learning curve both in terms of C++, 3D concepts and Windows programming. In terms of software design an object-oriented approach was found to provide benefits in terms of modularity and code re-use.

3D Studio MAX (Kinetix, 1999) provides a good environment for modelling 3D objects. The workflow, from initial modelling through to the virtual world is a good mechanism for constructing 3D objects to populate the virtual environment. The use of animation key-frames embedded in individual 3D models allows realistic motion to be modelled effectively.

During the course of the research work, graphical accelerators have become standard on the PC platform vastly increasing their rendering power. The PC platform remains the ideal choice for most desktop VR systems. It allows a flexible configuration, has support for a wide variety of input and output devices, and is low-cost.

The level of immersion offered by each of the two applications was found to be sufficient in both cases. In particular the engaging nature of the driving simulator helped to provide a good environment in which to train.

The research work undertaken demonstrates that it is feasible to use low-cost VR technology in a commercial environment. The low cost approach used here did not prohibit good quality visuals and the simulation of a realistic environment. It is anticipated by the author that the use of low cost technology will allow VR technology to become much more widespread within both this and other industries. Applications once ruled out because of cost can now be considered as viable propositions.

In summary the research work concluded the following:

- There is potential to develop commercially viable low-cost VR systems.
- The medium of VR opens up the possibility of using novel approaches to solve existing problems.
- Use of low-cost technology does not prohibit the presentation of high quality realistic virtual environments.
- It is possible to create geographically realistic virtual environments that are suitable for training and to reduce the cost of scenario creation and modification significantly.
- VR is particularly suitable for use within the minerals industry. Typically environments are hazardous and it is often difficult to experience them in the real world.

7.4 Further Work

The risk visualisation system developed showed good initial promise, it provides a good mechanism for visualising and analysing the risk based relationships in the environment. However, further evaluation of the algorithms developed for calculating the risk levels is essential. It is difficult to determine if this is an effective mechanism until the system is used within the industry.

Substantial effort is involved in constructing the virtual environment and assigning the risk regions to objects. This is somewhat prohibitive in a commercial environment where 3D modelling and programming skills are in short supply. Further development of the system should therefore include the development of an effective authoring system that allows faster creation of the virtual world and a better mechanism for defining and assigning risk regions.

The simulator developed to aid the training of haul truck operators in a surface mine demonstrated techniques that allow the fast authoring and subsequent editing of scenarios. The authoring application (VEdit) could be extended to include 3D preview windows. This would allow a more precise positioning of objects in the virtual world, and remove the need to enter the training system to evaluate the constructed scenario. This would facilitate a much cleaner workflow from scenario construction through to hazard specification and training. Support would also be required for more complex road geometry, including multiple lane roads. One of the key features of the current system is simplicity, in any future development it is important that the system remains easy to use.

In terms of the training system, there is a requirement for the vehicles to have more sophisticated behavioural algorithms. In particular to respond in a more realistic manner to actions by both the trainee and other computer controlled vehicles. Giving each vehicle more autonomy is not necessarily the solution some degree of control must be retained over each object in the environment otherwise authoring a scenario can become difficult. Improvements in the simulation would also allow vehicles to more accurately reflect real life vehicle performance. There is also the possibility of adjusting performance to reflect the current road or environmental conditions.

The graphical representation of the haul road has also been identified as requiring improvement. Haul roads in real life are not always completely flat and will most often have berms on the sides of the road. This is difficult to geometry to generate, and can incur significant graphics penalty in terms of rendering speed. With the increase in the performance of computers it is possible that this could be achieved in the future.

The use of multiple monitors has been used on a number of systems to increase the field of vision and to provide additional views to the trainee. This presents obvious benefits in terms of training as it provides a more realistic viewpoint and allows the trainee to identify objects that are not in their direct line of sight. This configuration should be possible given current technology, though further development work will be required.

The representation of vehicle instrumentation is not considered sufficient for a commercial application. Future work should consider the possibility of building a real life cabin with dashboard instrumentation controlled by the computer. More sophisticated input devices are also available, specifically the VTruck system would benefit from touch screen input devices for identifying hazards and selecting commands from menus, and force feedback input devices to give a more realistic sensation of driving.

The hazard identification system employed in the VTruck application demonstrates the potential for such a mechanism in a driving simulator. However, it would benefit significantly from the inclusion of a wider array of hazards, this might require the definition of more sophisticated hazards that react to user input. Event triggers could be used to activate hazards when a user enters a defined area or performs a certain action. This could help to provide a more personalised experience for each trainee improving levels of interaction and engagement.

7.5 Concluding Remarks

This research set out to investigate and demonstrate the potential for VR technology in the areas of risk assessment and training, with particular reference to the minerals industry. The two applications developed have been shown to a variety of people from different academic and industrial backgrounds. It is the author's belief that the two applications developed show the potential for low cost BR solutions in an industrial environment.

The focus of this work on a low cost solution has meant that the system is very accessible to mine operators, and as such it has been used extensively for demonstrations. Additionally a commercial application has since been developed based upon this work that is now being distributed by Earthworks (Earthworks, 1998).

8 Further Material Produced

8.1 Publications

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8.3 Software

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10 Appendices

Appendix 1: Annual refresher training material for equipment operators in a surface mine (MSHA)

GROUND CONTROL
ANNUAL REFRESHER 1995

*Date Approved:*___________________________

Course Description: *Students will review ground conditions relative to an open pit opèration through an interactive latent image exercise.*

Course Objectives: *By the end of this lesson, the student will be able to:*

- *describe the proper emergency actions to take in the event of brake failure*
- *recognize situations requiring additional lighting*
- *describe conditions which warrant ground inspection*
- *describe adequate inspection procedures*

Materials/Equipment:

1 each	*Overhead projector*
1 set	*Run Away Truck (questions A-J) overheads*
4 each	*Run Away Truck answer booklets*
4 each	*Latent Image Markers*

Optimum Class Size: *30 - 35 students*

Introduction:

Instruction Keys	*Content*
	Every year, miners are faced with life and death emergencies. Many of these occur while operating equipment. Today's lesson plan deals with just such an emergency.

Overheads: *BACKGROUND,QUESTIONS A THROUGH J.*

QUESTION A

The road hasn't been used for 6 weeks. A grader has opened the road for use. Your truck is the first piece of equipment down this road. You should:

1. Dump your load quickly and return to your loading unit.
2. Use a hand held flashlight to examine berm conditions.
3. Ask someone else to go first.
4. Proceed cautiously, examining road conditions as you go.

QUESTION B

As you begin the decline your headlights pick out some large boulders in the road. You swerve to avoid the rocks. What should you do first?

5. Use caution tape and/or flares to warn other drivers.
6. Stop and attempt to move the rocks.
7. Call for a light plant and support equipment to move the rocks.
8. Continue your descent.

QUESTION C

You alert your foreman to the rocks, asking for light plants to illuminate the roadway and support equipment to remove the rocks. They will bring the light plants but it will take at least 15 minutes to get them in place. What should you do? Your foreman tells you to use your best judgement. You:

9. Continue your descent.
10. Set flares along the road as you go to illuminate the way for support equipment.
11. Return to dispatch and wait for the rocks to be moved.
12. Stop at your present location and wait for the rocks to be moved.

QUESTION E

You are becoming frightened. The last light plant was placed approximately 200 feet behind your present location. Your headlights are unable to pick out any landmarks. You should:

17. Turn into the berm.
18. Attempt to gear down.
19. Take off your seat belt and attempt to jump free.
20. Continue applying the brakes. Look for emergency ramp.

QUESTION F

You believe the end of the grade is near. You are approaching the lift. You should:

21. Stay where you are -- ride it out.

22. Turn into the berm.

23. Take off your seat belt and attempt to jump free.

24. Radio in your resignation.

QUESTION G

You see the face of the dump, with an undersized berm approaching. You:

25. Maneuver your truck to impact the berm with the sides of your tires.
26. Quickly free yourself from your seat belt and attempt to jump free.
27. Impact the berm head-on.
28. Attempt to dump your load, hoping the drag will slow you down.

QUESTION H

As you are wiping the sweat from your palms onto your pants, you feel the ground beneath your truck giving way. Your truck is sliding! What should you do now?

29. Take off your seat belt and attempt to jump free.
30. Radio for "Help!"
31. Stay where you are --ride it out.
32. Take off your seat belt and get down low in the cab to protect yourself in case of a roll-over.

QUESTION I

By some miracle, your truck doesn't roll over. You come to rest with the driver's side front and rear tires in a gully. The truck is tilted at about a 45 degree angle with the driver's side on the low side. Happy to be alive you:

33. Unbuckle your seat belt and walk downhill away from your truck.
34. Unbuckle your seat belt and walk to the high side (against the lift) and sit down.
35. Unbuckle your seat belt and begin a complete walk around looking for damage.
36. Stay where you are. Call for help.

QUESTION J

Your foreman arrives with support equipment to pull your truck out of the gully. You've been asked to write a report on the accident. What contributing factors were present?

37. ground failure
38. inadequate inspection procedures
39. mechanical failure
40. inadequate roll-over protection
41. illegal grade, too steep
42. improper radio communications
43. no task training
44. poor road maintenance
45. inadequate illumination
46. weather conditions

QUESTION A (Choose only ONE unless directed to "Try Again!")

1. [You have a way to go before you can dump your load. Try again!]

2. [A hand held light will not provide adequate illumination. Try again!]

3. [Don't be a slouch! Try again!]

4. [Correct! You must be cautious when entering an old, unused area. Go to next]
[question.]

QUESTION B (Choose only ONE unless directed to "Try Again!")

5. [You've left your truck unchocked. It is rolling downhill away from you. Try]
[again!]

6. [While attempting to move a rock, a larger one rolled down the hill and smashed]
[your foot. Limp to your truck and try again!]

7. [Correct! Portable light plants must be set up to illuminate the area while dozers]
[and scrapers clear the road. Go to next question.]

8. [You run over a large boulder and blow a tire. Try again!]

QUESTION C (Choose only ONE unless directed to "Try Again!")

9. [You cannot go any further on such a rocky road. Try again!]

10. [You shouldn't leave your vehicle unattended. Besides, where did you get the]
[flares? Try again!]

11. [You are needed to help direct the placement of the light plants. Try again!]

12. [Correct! Go to next question.]

QUESTION D (Choose only ONE unless directed to "Try Again!")

13. [Your seat belt is stuck and you are unable to get free. Try again!]

14. [Are you sure there is a berm? Try again!]

15. [No one can hear you. Try again!]

16. [Correct! Unfortunately, your emergency brake has little or no effect on your] [speed. Go to next question.]

QUESTION E (Choose only ONE unless directed to "Try Again!")

17. [You don't know where the berm is! Try again!]

18. [Unfortunately, your speed is too high to gear down. Try again!]

19. [Your seat belt is stuck and you are unable to get free. Try again!]

20. [Correct! Keep trying the brakes while you look for your escape route. Your] [speed has slowed to 25 mph! Go to next question.]

QUESTION F (Choose only ONE unless directed to "Try Again!")

21. [Correct! Go on to next question.]

22. [Unfortunately, the berm along this stretch of road has eroded to nothing. Try] [again!]

23. [This time you are successful in getting your belt off but your door is jammed.] [Try again!]

24. [It's too late to quit now! Try again!]

QUESTION G (Choose only ONE unless directed to "Try Again!")

25. [Correct! Through careful maneuvering, your truck is stopped at the edge of the] [lift. Go on to next question.]

26. [Congratulations, you jump free! Unfortunately, the rear wheel of your truck ran] [over your head. Try again!]

27. [Great lift off! Your truck flies 50 feet in the air and lands on the cab. Try] [again!]

28. [Remember, this is a haul truck, not a dragster. Try again!]

QUESTION H (Choose only ONE unless directed to "Try Again!")

29. [The ground is now 80 feet down. You've just broken both your legs. Try] [again!]

30. [It's too late now! Better try again!]

31. [Correct! You've gotta lotta guts! Go to next question.]

32. [You are now able to fly freely through the windshield! Try again!]

QUESTION I (Choose only ONE unless directed to "Try Again!")

33. [Your truck slides further downhill, pinning you between the tire and a sagebrush.] [Try again!]

34. [Support equipment cause additional ground failure, burying you in the process.] [Dig out and try again!]

35. [You'll have plenty of time for that later. Try again!]

36. [Congratulations! This is your best bet. Additional ground/equipment movement] [could injure or kill. Go on to next question.]

QUESTION J (Select as MANY as you think are correct.)

37. [Correct! The lift sloughing was ground failure.]

38. [Correct! The old road should have been inspected prior to work commencing.]

39. [Correct! The brake failure was a mechanical problem.]

40. [All heavy equipment has mandatory roll over protection. Try again!]

41. [MSHA does not state an "illegal grade" in 30 CFR. Try again!]

42. [No sensitive or private information was given (that we know of). Try again!]

43. [Your task training is not under question - yet. Try again!]

44. [Correct! Support equipment should have cleared road prior to opening.]

45. [Correct! Headlights are insufficient for night work illumination.]

46. [Correct! The thaw and freeze created a treacherous roadway.]

QUESTION A (Choose only ONE unless directed to "Try Again!")

1. [ ]

2. [ ]

3. [ ]
4. [ ]
[ ]

QUESTION B (Choose only ONE unless directed to "Try Again!")

5. [ ] [ ]

6. [ ] [ ]

7. [ ] [ ]

8. [ ]

QUESTION C (Choose only ONE unless directed to "Try Again!")

9. [ ]

10. [ ] [ ]

11. [ ]

12. [ ]

QUESTION D *(Choose only ONE unless directed to "Try Again!")*

13. [ ]

14. [ ]

15. [ ]

16. [ ] [ ]

QUESTION E *(Choose only ONE unless directed to "Try Again!")*

17. [ ]

18. [ ]

19. [ ]

20. [ ]
[ ]

QUESTION F *(Choose only ONE unless directed to "Try Again!")*

21. [ ]

22. [ ] [ ]

23. [ ] [ ]

24. [ ]

QUESTION G *(Choose only ONE unless directed to "Try Again!")*

25. [ ] [ ]
26. [ ] [ ]
27. [ ] [ ]
28. [ ]

QUESTION H *(Choose only ONE unless directed to "Try Again!")*

29. [ ] [ ]
30. [ ]
31. [ ]
32. [ ]

QUESTION I *(Choose only ONE unless directed to "Try Again!")*

33. [ ] [ ]
34. [ ] [ ]
35. [ ]
36. [ ] [ ]

QUESTION J *(Select as MANY as you think are correct.)*

37. [ ]

38. [ ]

39. [ ]

40. [ ]

41. [ ]

42. [ ]

43. [ ]

44. [ ]

45. [ ]

46. [ ]

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A hand held light will not provide adequate illumination. Try again!

Don't be a slouch! Try again!

Correct! You must be cautious when entering an old, unused area. Go to next question.

You've left your truck unchocked. It is rolling downhill away from you. Try again!

While attempting to move a rock, a larger one rolled down the hill and smashed your foot. Limp to your truck and try again!

Correct! Portable light plants must be set up to illuminate the area while dozers and scrapers clear the road. Go to next question.

You run over a large boulder and blow a tire. Try again!

You cannot go any further on such a rocky road. Try again!

You shouldn't leave your vehicle unattended. Besides, where did you get the flares? Try again!

You are needed to help direct the placement of the light plants. Try again!

Correct! Go to next question.

Your seat belt is stuck and you are unable to get free. Try again!

Are you sure there is a berm? Try again!

No one can hear you. Try again!

Correct! Unfortunately, your emergency brake has little or no effect on your speed. Go to next question.

You don't know where the berm is! Try again!

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Your seat belt is stuck and you are unable to get free. Try again!

Correct! Keep trying the brakes while you look for your escape route. Your speed has slowed to 25 mph! Go to next question.

Correct! Go on to next question.

Unfortunately, the berm along this stretch of road has eroded to nothing. Try again!

This time you are successful in getting your belt off but your door is jammed. Try again!

It's too late to quit now! Try again!

Correct! Through careful maneuvering, your truck is stopped at the edge of the lift. Go on to next question.

Congratulations, you jump free! Unfortunately, the rear wheel of your truck ran over your head. Try again!

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Remember, this is a haul truck, not a dragster. Try again!

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You are now able to fly freely through the windshield! Try again!

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Support equipment cause additional ground failure, burying you in the process. Dig out and try again!

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Correct! The lift sloughing was ground failure.

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MSHA does not state an "illegal grade" in 30 CFR. Try again!

No sensitive or private information was given (that we know of). Try again!

Your task training is not under question - yet. Try again!

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Correct! Headlights are insufficient for night work illumination.

Correct! The thaw and freeze created a treacherous roadway.

Appendix 2: Method of work for removal of a hydraulic support in a longwall face operation (RJB Mining)

Method of Work for Salvaging 46s Chocks

GENERAL

1/ Chocks to be salvaged via 46s Loader Gate starting at the Supply Gate end of face line and stored in 47s Supply Gate.

2/ Chocks to be transported using Eimco 912X excalibur.

3/ It is very important to maintain a roadway of as large a cross sectional area after chocks have been withdrawn as possible because 46s face line will form 47s Return Airway.

4/ Supports to be salvaged in conjunction with plan BIL SPT 360.

Materials Required

Supply of 3' Chock Nogs.
Gob Side Ring Legs Plates, Bolts and Struts.
Hydraulic Props, Horse Heads and Rails.
Splice Girders Plates and Winch.
Black Box Remote Control for Chocks.
912 Excalibur, Flatbed with Winch.
30 mm Bryco Pulling Bolts, 6' long and Resin.
19 mm Brothers.

PROCEDURE FOR THE WITHDRAWAL OF 46s CHOCKS

1/ Chocks control unit to be pulled forward, chocks to be cleared of debris in leg pockets, position holes etc, chocks to be uncoupled in banks of 5.

2/ Wander hoses to set up to chock, chock to be disconnected from its neighbour and steel blanks to fitted to all open ports. Wander hoses also to be set up to adjacent chock.

3/ Couple remote control unit (black box) to chock.

4/ Lower off adjacent chocks, pack between chock beam and previously set rings with chock wood, reset chock.

5/ Lower off salvage chock as far as possible from a position of safety. Slide bars forward and secure to beams using pinners and also by resting on the adjacent chock beam. This must be done from a position of safety, be aware of flushing at all times.

6/ Reinforce the support of these bars by setting hydraulic props under the bars as per support plan.

7/ Clear the exclusion zone and drive up to the chock with the excalibur.

8/ For the following operations, the excalibur driver and two chock operator will be allowed within the exclusion zone if required.

9/ Driver slacks off hydraulic winch, operator couples 19mm special chains to chock pontoon and to hydraulic winch. (see diagram 2)

10/ Lower the chock and spin in the chock by pulling the chock base round the base of it's neighbour.
Note
While ever the chock is being moved the exclusion zone must be cleared - Any stored energy within the chains must be released before chains are adjusted.
If difficulty is experienced in spinning the chock out of line install a bryco pulling bolt, allow at least 30 minutes for res to set. Using the chock ram ease the chock forward and release the ram, then repeat the procedure for spinning.
(see diagram 3)

11/ The operators withdraw and the driver winches the chock up the flatbed between the girders the chock will be held in position by the winch. Then remove wander hoses and fit blanks.
(see diagram 5 & 6)

12/ The FSV route is cleared and the chock transported to loader ga gate end and onto 47s.

13/ Set gob side legs to any exposed beams making sure setting the legs will not interfere with spinning the next chock.

14/ Immediately behind the gob side legs, between the leg and the waste a solid wood chock must be built every meter and set tigh to the roof.

15/ Establish a line of 14 splice girders with a solid nog under each joint down the centre of the face line extending each time enough room is available.

16/ Prepare the next chock for withdrawal.