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Visualizing safety assessment by integrating the use of game technology

ABSTRACT

Construction is undoubtedly the most dangerous industry in Hong Kong, being responsible for 76 percent of all fatal accidents in industry in the region – around twenty times more than any other industry.

In this paper, it is argued that while this rate can be largely reduced by improved production practices in isolation from the project's physical design, there is some scope for the design team to contribute to site safety. A new safety assessment method, the Virtual Safety Assessment System (VSAS), is described which offers assistance. This involves individual construction workers being presented with 3D virtual risky scenarios of their project and a range of possible actions for selection. The method provides an analysis of results, including an assessment of the correctness or otherwise of the user's selections, contributing to an iterative process of retraining and testing until a satisfactory level of knowledge and skill is achieved.

BACKGROUND

Occupational injury and death result in substantial economic losses to the Hong Kong community every year. A total of HK$1.02 billion was paid in compensation and 1.7 million working days were lost in 2007 alone. Productivity is also affected by the amount of sick leave involved, causing additional losses to the region (Occupational Safety and Health Council, 2006).

The industries in Hong Kong with the highest accident rates are manufacturing, catering and construction. Of these, the construction industry has by far the highest, with an accident rate per thousand workers of nearly 1.5 times that of catering and 4 times manufacturing in 2007 (Table 1). The Hong Kong construction industry has also a far higher fatality rate than other industries, with its number of fatal accidents representing about 76% of all such accidents in Hong Kong in 2007. This is around 20 times more than any other industry (Table 2). Construction safety is therefore an important issue in Hong Kong and any means of bringing about improvements is likely to be beneficial to the community as a whole.

In this paper, we develop a new construction safety assessment system by using game engine technology. This aims to provide a new means of assessing construction safety knowledge and safety attitudes of construction workers. The system is developed to suit the use of construction workers as they are the frontline of the industry. The number of construction workers also dominates the industry. Compared with traditional safety assessment practices in Hong Kong (i.e. the Green Card system), we suggest the use of a more structured database of questions, from which relevant questions are automatically selected with respect to the background of users. A new regime for certificating users is suggested, involving the use of a game engine. The use of game engines for serious applications (i.e. training) in other industries such as the aircraft industry, has provided a strong foundation for research in construction industry. In order to investigate the system's use in practice, a case study was conducted followed by a set of interviews. Discussion on this and future implications is provided at the end of the paper.

IMPORTANCE OF HAZARD IDENTIFICATION

Abdelhamid and Everett (2000), Suraji et al (2001) and Toole (2002) have carried out comprehensive investigations into the causes of construction accidents. These indicate the main causes of construction accidents to be:

- *Unsafe site conditions*. A physical environment that is unsuitable for work; an environment that violates the prevailing safety standards; or a workplace that is abnormally hazardous. Poor security, broken working platforms and other means of accessing the work place are also included.
- *Unsafe worker behaviour.* Lack of proper training is a contributory factor. Workers who are not well trained tend to be less able to recognize and avoid hazardous activities, although even well-trained workers may have a negative attitude towards safety.
- *Unsafe working methods or sequencing*. Insufficiently planned construction tasks can be more hazardous to carry out, especially if the work involved is of an unusual nature. This may be due to inadequate method statements, design of temporary work, layout plans, schedules or site investigation.

Limiting or preventing these causes is essential in improving the safety performance of construction projects. Generally, these factors are managed by a safety management team on site, where the identification of construction hazards is usually carried out before the commencement of work. While this aims to identify and eliminate all potential hazards, there are still many problems which hinder the process. Carter and Smith (2006) have briefly presented a procedure for hazard identification in the U.K. and question the effectiveness of the traditional process. They believe that only a limited number of potential hazards are identified during the safety risk assessment of method statements. The use of two dimensional engineering drawing is one of the causes. As Hadikusumo and Rowlinson (2002) demonstrate, the traditional way of identifying construction site safety hazards is through two-dimensional (2D) information provided for planning purposes and this involves obvious visualisation difficulties. This is compounded by the fact that different people interpret drawings in different ways (Hartmann and Fischer 2007). Furthermore, 2D drawings represent only construction *components* (walls, beams, columns, etc.), rather than the construction *processes* involved (Young 1996). As a result, it is almost impossible to identify all hazards before the start of construction.

Ineffective hazard identification results in unsafe site conditions and construction processes. If potential threats are not identified during the early stages, the only way to manage safety is to provide on-site safety supervision by a safety officer.

THE TRADITIONAL CONSTRUCTION INDUSTRY SAFETY TRAINING SYSTEM

It is very difficult, if not impossible, for a contractor with 10 to 20 staff to manage the safety of hundreds of workers simultaneously involved in many different activities in many different places. Safety management teams find it more difficult to control and assess the degree of risk for certain trades, as only a limited amount of information is available before the start of construction. As a result, a hazardous working environment exists, which eventually leads to construction accidents and fatalities. In this situation, the construction workers themselves act as the last protection from construction accidents. The ability to identify hazards is important not only for safety management team, but also construction workers. Therefore, the ability of individual workers to identify hazards is extremely important.

Training is one of the most effective means of improving the safety performance of the construction industry. Sawacha *et al* (1999) found that suitable training of operatives and site supervisors helps improve safety on site. The training provided to the workers may be the factor most affecting workers' safety awareness. Van Buren and Erskine (2002) point out that training methods are changing rapidly and safety training is increasingly conducted by computer. There have been no major changes in safety training practice in construction industry, however, in recent years. Aranda (2000), for example, may be the writer to suggest using navigable films to train construction workers in hazard identification.

In addition to the lack of a more effective training method, Wallen and Mulloy (2006) comment that OSHA only requires the training, and not the content, to be understandable. The lack of a standard format for providing skills and safety training to new workers is another hindrance for safety management (Goldenhar et al 2001). As a result, it is important to assess the workers after they have completed the training, in order to ensure they are properly trained.

In Hong Kong, workers who have been issued with a construction industry safety training certificate (Green Card) are eligible to work in the construction industry for a period of three years. The certificate is issued after one day of training and a short multiple-choice test and is the only safety assessment required of workers before they can work in the construction industry. To successfully complete the assessment, the applicant must choose 12 correct answers from of a total of 20 questions.

In the UK, the NVQ system is employed. A worker needs to obtain an NVQ level 1 to work as a labourer on a construction site. Alternatively, a worker can obtain a green card by employer recommendation. The situation in Australia is similar to that in the UK, as candidates need to answer 45 multiple choice questions order to obtain a Construction Skills Certification Scheme (CSCS) card.

Both systems require less than one day of training. The systems have been criticized by Biggs *et al* (2005), who believe that the training is focused solely on the knowledge and observance of legal requirements. Only a limited amount of attention is given to the competencies needed. There is also no evidence of any correlation between the current training system and improved safety performance.

A comparison between the safety test and motor car test in Hong Kong is made in Table 3. Although both construction workers and motor car drivers require a high level of safety knowledge and skill to prevent accidents, the training and testing regime of the construction industry is much simpler than that of the motor car licensing process.

Clearly, current safety training and assessment practices are rather cursory for an industry with such a poor safety record. The weaknesses of the current system can be summarised as the following: (1) the questions involved in the process are rather simple and general. Ideally, more specific questions are needed for different trades. For example, the questions for timber workers should be different to those for scaffold workers; (2) the current assessment method may not truly reflect the knowledge required of the workers. The workers are only required to select the correct answers of multiple-choice questions. The workers could have selected the correct answer by luck (about 25% probability for each question); (3) it is also questionable that these questions can describe complex safety problems effectively. Questions which include construction process, location and site environment are difficult to present in text form only. Questions, such as the correct use of the temporary access to the workplace, are impossible to describe in text form alone. The weakness of using 2D is also pointed out in the previous paragraph. Incorrect access to the workplace at height could easily lead to a serious fall; (4) the assessment also needs to consider the worker's ability to convert knowledge into site activities and appropriate attitudes to safety. Workers may memorize a regulation and safety knowledge but find difficulties when they need to apply the knowledge in a real life situation; (5) workers are only required to be assessed after the one day of training. As a result, they have no platform on which to assess themselves even if they are unsure about their ability to deal with safety hazards.

Five weaknesses of current training practice are identified above. In order to improve the general safety performance of construction workers, it is important not only to address these weaknesses, but also to formulate new measures to improve the situation. In the following section, the different techniques used to improve management and training are reviewed and discussed.

USE OF VISUALIZATION IN THE CONSTRUCTION INDUSTRY

Visualization has become a solution to numerous construction problems in recent years. It is achieved by the use of new technologies, including Building Information

Modelling (BIM) and Virtual Reality (VR). Chiu and Russell (2010) have found that data cognition is improved by the visualization of construction data. Hadikusumo and Rowlinson (2002 and 2004) have also developed a safety knowledge management tool by using visualization. The use of visualization not only presents a more comprehensive construction process than 2D drawings and information (Chau *et al*, 2003), but also helps communication between different project stakeholders (Jongeling and Olofsson, 2007). The use of visualization for safety has been studied by Chantawit *et al* (2005), with a 4D Computer Aided Design (4DCAD) approach developed for safety planning. The use of visualization has successfully improved the effectiveness of construction management. Some research has also studied the possibility of integrating visualization with interactive platforms. This is discussed in the following section.

INTERACTIVE TRAINING AND ASSESSMENT PLATFORMS IN OTHER INDUSTRIES

In the area of safety knowledge, most of us are familiar with the interactive 4D flight simulators for air pilot training, which tests and helps develop pilot skills in reacting to and managing high risk situations. The use of the Microsoft Flight Simulator and Flight Simulator for teaching purposes dates back to 1991 (Moroney and Moroney, 1991). In these systems, the trainee not only learns the capability of the simulator, but also the human factors in aviation relating to psychology and engineering. According to Hampton (1997), there are as many as six different personal-computer (PC)-based flight simulators.

Perhaps less well known is that a similar technology also exists for hazard perception in motor car driver training and testing (e.g., Dumbuya 2005), with tests on learner and provisional drivers now mandatory in some Australian States such as Victoria and Queensland. The use of visual motor car driver training is common. Numerous software applications are available on the market, such as TRL TruckSim and CarSim from UK and the COV Driving simulator from the Netherlands.

Clearly, such approaches have potential application in construction site safety, with the possibility of adapting existing 4D technology to construction processes for use in testing worker safety knowledge within a computer simulated environment.

VIRTUAL SAFETY ASSESSMENT SYSTEM (VSAS)

Background

A game engine *Unity 3D*, developed by Unity Technologies, is employed in the development of the Virtual Safety Assessment System (VSAS). *Unity 3D* is a game development environment that allows users to create games easily and it is one of the most powerful game engines available for the close-to-reality real-time rendering needed for the development of the proposed platform. The development of the VSAS includes the use of C# and Java script.

For the development phase, a high performance computer was used. The development of VSAS required the use of the best available display card as the performance of the display card defines the level of detail, the size and the complexity of the created virtual environment. For the usage phase, the hardware requirements are less demanding, so that users can easily run the VSAS on a typical domestic computer. The system requirements are listed in Table 4.

Visualization of safety Information

The visualization method is discussed here after introducing the system requirement. The VSAS aims to visualize the causes that have been identified for safety assessment. The visualization process involves a combination of virtual environments and 3D simulations, as detailed below:

1. Visualizing unsafe site conditions

   Before visualizing unsafe site conditions, a complete virtual site environment is needed. This virtual environment contains all available details, including both temporary and permanent structures, building services, construction material storage, waste, construction equipment and tools. A close-to-reality virtual environment is a basic requirement for providing a 3D experience to the trainee. The use of materials and textures can easily improve the rendering performance of the system, especially in real-time, as demonstrated in Figure 1. By repeating the process with different models, the system can provide a virtual environment that is close to reality. Different hazards, such as building platforms without suitable fencing, are then inserted into the virtual environment. The system allows trainees to observe within the environment and make their own decisions regarding safety, based on their knowledge and experience. An example of a virtual environment is shown in Figure 2.

<Take in Figures 1 and 2>

2. Visualizing unsafe working behaviour

The presentation of hazardous working behaviours is achieved by using virtual workers within the virtual working environment. The working behaviours are presented in 3D or 3D animation. Virtual workers are then inserted into the environment and assigned to different construction activities. For example, Figure 3 shows a virtual worker in a typical hazardous working situation of welding without wearing suitable gloves.

<Take in Figures 3 >

3. Visualizing unsafe construction methods or sequencing

The visualization of unsafe construction is similar to the visualization of unsafe working behaviour. Construction equipment is inserted into the virtual environment and presented in the form of 3D animation. Virtual workers perform construction activities accordingly within the virtual environment. An example is the hazardous dismantling of a tower crane before all the workers have left the area.

VSAS Database

Following the way in which safety information is visualized through VSAS, the structure of training questions is now presented. The identification of the weaknesses of the current assessment in the previous section provides the basis for the questions involved (unsafe site conditions, behaviours, construction method or sequencing), with those in the VSAS being classified with related attributes. This classification of the questions and their attributes allows the system to select questions that are relevant to the user's background. All questions are stored in 3D graphical or 3D animation format. The information contained in the questions, containing different attributes, is then stored in a 3D or 4D model as illustrated in Figure 4.

<Take in Figure 4>

The object name reflects the nature of the simulated construction activity. The question number indicates the number of questions related to the activity as sometimes there are several questions relating to each construction activity. The two attributes provide the activity's category and its related trainees. The use of attributes in this way allows the system to select suitable questions for workers with different backgrounds.

Virtual experience in VSAS

Although the questions are presented in text format, users need to study the entire virtual environment carefully in order to select the correct answers. Several clues are inserted into the environment to assist users in their answers. Users can walk through the virtual environment and talk with any virtual workers to obtain further information. In a similar manner to that which happens in the real-world, users can also observe the environment from different perspectives. This virtual experience allows users to identify hazards in a virtual, and risk-free, environment.

The question and answer mechanism of VSAS

The VSAS system allows users to answer at any time after login. It allows time for the user to clearly analyze the situation and to select the correct answer. In VSAS, this involves the use of dialog boxes. An example is shown in Figure 5.

<Take in Figure 5>

After the users have selected their answers, these are stored in the VSAS database. As VSAS offers only a multiple-choice test, users are required to answer by simply clicking the related answer box. Users can change the answers any time before the end of the test. Users are also required to complete all the questions within a limited time. When all the questions are answered, the user can then submit the test. The system checks users' answers by comparing them with those in the database. An attribute is given to the activity to highlight the importance of the activity. Higher factors mean that accidents are more likely to be fatal than those of lower factors. These factors affect the final report of the test.

The questions are randomly selected based on the information provided by user, however, the sum of the weighting factors for all users is the same. The system has three different weighting factors. Factor 1 means the accident may cause minor injury, while Factor 2 means more serious injury. Fatal accidents are always referred by factor 3. For each test, the weighting factors of all the questions sum to 30.

The validation of answers starts automatically upon completion of the test, whereupon the system reports the performance of the user. A screenshot of this report is shown in

Figure 6. The background of the incident and the correct answer is also reported to the user, with an explanation of the importance of the incident.

<Take in Figure 6>

The scoring in this system is considerably different to the traditional Hong Kong safety test. Users are required to complete the test and give correct answers for all questions with a weighting factor of 3. Users should also avoid making more than 2 mistakes for factor 2 questions and the sum of factors for all incorrect answers should not be more than 8. These high standards of the VSAS should ensure an enhanced standard of safety performance on construction sites, subsequently reducing the occurrence of serious accidents.

CASE STUDY

In order to evaluate the VSAS, a case study was conducted. The VSAS is a system consisting of a large database comprising numerous different construction activities. In this case study, the database of the Personal Protective Equipment (P.P.E) module is demonstrated.

The database of the case study focuses mainly on the proper use of P.P.E. More than 20 cases that include all three different weighting factors were stored in the database. The cases are typical causes of construction accidents in Hong Kong. One of these is the inappropriate use of safety belts. In order to create an environment for the users to recognise safety problems, a construction site with an external temporary platform next to the edge of the building floor was built and surrounded by scaffolding and a safety net. Examples of the visualization of the different accident causes in this scenario are summarized in the Table 5.

<Take in Figure 7 and 8>

The current assessment practice was compared with that involving the use of VSAS. To do this, a group of construction workers and professionals were invited to try the VSAS. Twelve construction workers, six engineers, four safety officers and three construction managers were therefore assessed by the VSAS on the topic of “proper use of P.P.E.”. They were required to complete the test within thirty minutes. All the participants were currently the holders of construction industry safety training certificates and are eligible to work in the construction industry. The results of the test are shown in Table 6, and show the average number of construction accidents that were prompted during the assessment. For example, every construction worker was likely to cause at least one minor injury. For every three construction workers, one caused a fatal construction accident. The performance of engineers, safety officers and construction managers was better than that of the workers. This difference in performance suggest that workers paid less attention to safety, and also indicate that traditional safety assessment methods may not accurately assess safety knowledge. This is similar to the critique made of current practice in the previous section.

The value of VSAS

The VSAS development aims to provide a new assessment platform and improve safety performance in the construction industry. To evaluate the use of the VSAS system, group interviews were arranged to obtain individual feedback. The interviewees were divided into four groups according to their occupations, and the questions focused on the effectiveness of VSAS in representing safety questions in the 3D / 4D format. The result of the interviews are summarised in Table 7.

These results indicate that the interviewees generally agree that the use of VSAS can assess the users' knowledge in identifying 1) unsafe working environments; 2) unsafe working attitudes, and; 3) unsafe working methods / procedures. These three aspects are the major cause of construction accidents (Abdelhamid and Everett 2000; Suraji *et al* 2001; and Toole 2002). The result can be explained by the use of a game engine, which includes: 1) the transformation of 2D questions into 3D and 4D formats which can provide much more information for users to study before answering, and; 2) application questions that simulate the interviewees' daily working environment, method and procedure, which the interviewees could answer according to their experience.

In addition, the interviewees generally agreed that the final report pinpointed the weaknesses in their approach to safety. The new rating system also allowed the interviewees to understand the seriousness of the resulting accidents.

However, some of the users also expressed the opinion that control of the 3D navigation within the system is complex and that it was difficult to control the user's viewpoint.

The use of VSAS, in contrast with the traditional assessment approach, the VSAS provides a new assessment platform for workers. The workers can access the system on-demand after the system is installed on their computer (system requirements are listed in Table 4). The iterative process of retraining and testing successfully pinpointed the users' safety weaknesses. By addressing their own weaknesses, the process helps the users to improve their safety knowledge and practice in specific areas. The detailed effects of the iterative process, however, were outside the scope of the research.

CONCLUSION

The use of computer technology to enhance specific individual performance is not new, and the use of game technology and the reuse of game engines have proven to be successful in other industries outside construction. Game technology is useful for simulating high risk activities, such as in the training and assessment of aircraft pilots and motor vehicle drivers. In this study, a virtual safety training system was successfully developed and evaluated by trials and post-use interviews. The results indicate that VSAS helps pinpoint the weaknesses of users (construction workers) who have already passed the traditional assessment process. The case study also indicates that users who have not received any prior training perform particularly badly with VSAS, with a simulated four fatal accidents occurring among only 12 such users in the case study! The study also demonstrated that the use of the game engine is a more effective means of assessment than the traditional method. The process is closer to the working procedures involved in practice than multiple-choice questions in text format, and the visualization technique allows the system to ask more complicated questions, which require users to check and think carefully before they can choose the correct answer.

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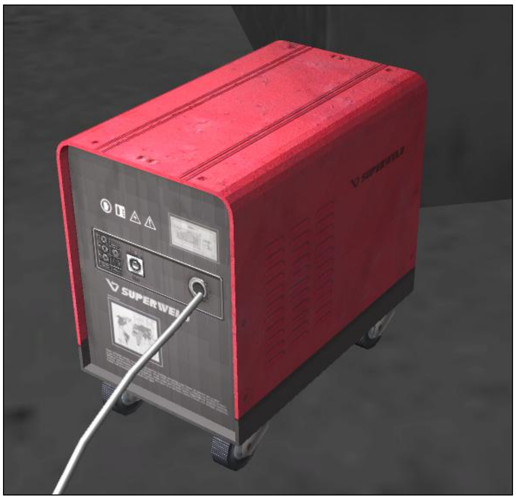

Figure 1. Welding machine with texture

Figure 2. Example of a virtual environment within VSAS

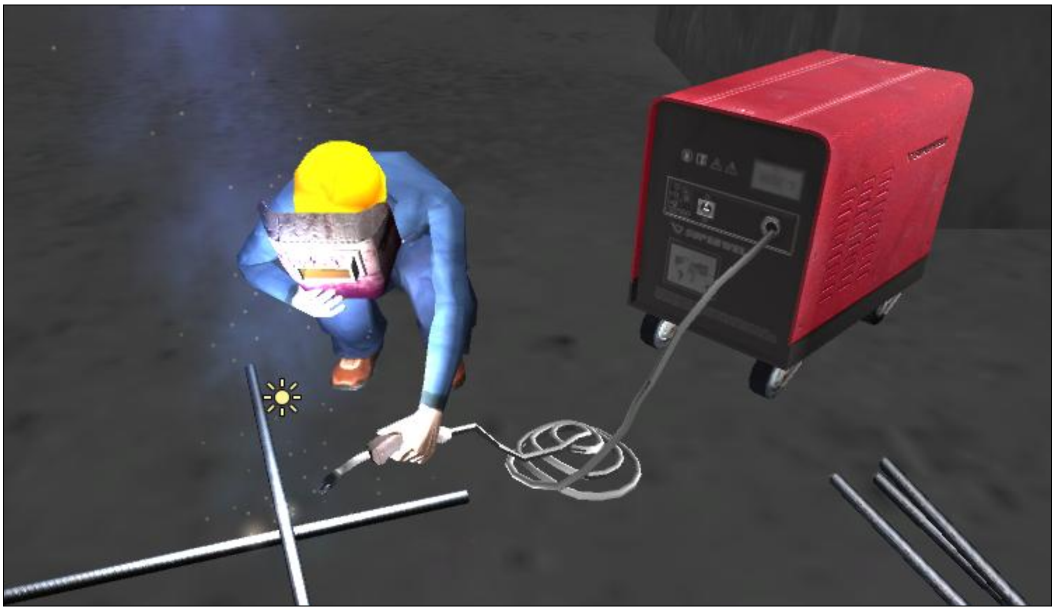

Figure 3. Simulation of the use of the welding machine

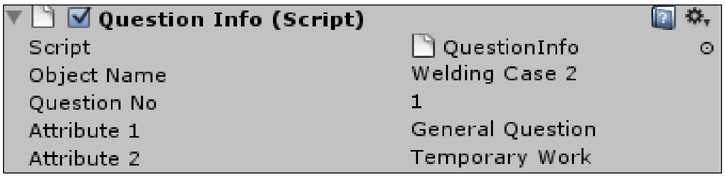

Figure 4. Database of a construction activity

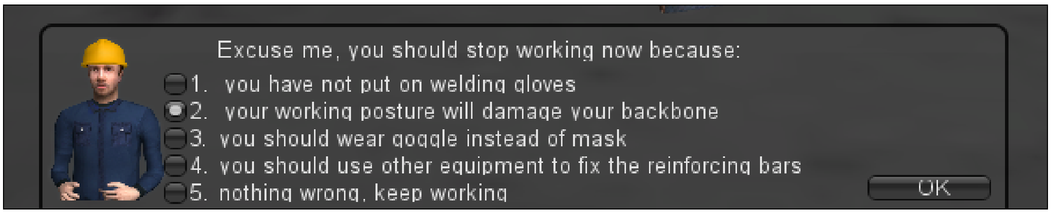

Figure 5. Example of a dialog box for users to answer

Report on USER1 safety performance

Test contents: Proper use of Personal Protective Equipment (P.P.E.)

Incident: 1

Background:

Working at height is the working nature in construction industry. Ladder is available for construction use which is below 2 meters. Working on higher level requires the use of temporary working platform.

Suitable answer:

You should erect temporary working platform instead of ladder

Possible result:

Serious injury

Figure 6. Screenshot of the report generated by the VSAS

Figure 7. Working at height without a safety belt

Figure 8. An incorrect lifting method

		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
No. of accidents in	Construction Industry	19588	14078	11925	9206	6239	4367	3833	3548	3400	3042
	Catering Industry	13011	12549	12621	11914	10149	8527	9410	8902	9294	8876
	Manufacturing Industry	6334	5499	5436	4385	3636	2719	2936	2912	2949	2735
Acc. rate / 1000 workers in	Construction Industry	247.9	198.4	149.8	114.6	85.2	68.1	60.3	59.9	64.3	60.6
	Catering Industry	73.9	66.9	66.2	61.5	54.7	49.6	51.5	47.3	47.2	43.5
	Manufacturing Industry	24	22.2	23.4	20.7	18.8	15.7	17.5	17.7	18.4	17.4
No. of fatalities in	Construction Industry	56	47	29	28	24	25	17	25	16	19
	Catering Industry	0	0	2	0	0	0	0	0	0	0
	Manufacturing Industry	2	2	3	3	0	2	2	0	6	3
	All industries	*68*	*52*	*43*	*34*	*25*	*28*	*24*	*29*	*26*	*25*
Fatality rate/1000 workers in	Construction Industry	0.709	0.663	0.364	0.349	0.328	0.390	0.268	0.422	0.303	0.379
	Catering Industry	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Manufacturing Industry	0.008	0.008	0.013	0.014	0.000	0.012	0.012	0.000	0.037	0.019
	All industries	*0.102*	*0.080*	*0.066*	*0.053*	*0.042*	*0.051*	*0.043*	*0.053*	*0.047*	*0.045*

Table 1: Accident statistics of major industries in Hong Kong (1998-2007)
(Occupational Safety and Health Council, 2007)

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
No. of fatalities in										
the Construction Industry	56	47	29	28	24	25	17	25	16	19
the Catering Industry	0	0	2	0	0	0	0	0	0	0
the Manufacturing Industry	2	2	3	3	0	2	2	0	6	3
all Industries	*68*	*52*	*43*	*34*	*25*	*28*	*24*	*29*	*26*	*25*
Fatality rate/1000 workers in										
the Construction Industry	0.709	0.663	0.364	0.349	0.328	0.390	0.268	0.422	0.303	0.379
the Catering Industry	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
the Manufacturing Industry	0.008	0.008	0.013	0.014	0.000	0.012	0.012	0.000	0.037	0.019
all Industries	*0.102*	*0.080*	*0.066*	*0.053*	*0.042*	*0.051*	*0.043*	*0.053*	*0.047*	*0.045*

Table 2. Fatal accidents in major industries in Hong Kong (1998-2007) (Occupational Safety and Health Council, 2007)

	Construction industry	**Motor car driving license**
Regulations:		
T raining	New applicants are required to take a full-day training course with regular half-day training to renew their certification.	New applicants are required to take driving school lessons – typically two before attending the test.
Written test on regulations	New applicants are required to pass a written test at the end of training. At least 12 correct answers out of 20 multiple choice questions are needed.	New applicants are required to pass a written test after the lessons. At least 16 correct answers out of 20 multiple choice questions are needed.
Skill:		
Training	No further training is required.	New applicants are required to pass a combined test after attending at least 10 off-street and on-road practice sessions and lectures.
Test	No further test is required.	New applicants are required to pass a three-part combined test: 1) Sight test: applicants must be able to read a car number plate 23 meters away or fail the test immediately. 2) Off-street test: applicants must be able to safely stop the car, park the car and perform U-turn. 3) On-road test: applicants should show they are capable driving on the road without interfering with other drivers. They are assigned a minor mistake if they make an unsafe act without affecting other drivers, or a major mistake if other drivers are affected. Three minor mistakes are equal to a major mistake and applicants making a major mistake fail the test immediately.

Table 3. Motor car training and construction training

CPU:	Intel Pentium 4 2.8 GHz , Intel Core 2.0 GHz, AMD Athlon 2800+ or better
RAM:	512MB
Video Card:	NVIDIA GeForce 6800 GT, ATI Radesorry800 Pro or better
VRAM:	256MB of Graphics Memory
Storage:	1GB

Table 4. VSAS system requirements

Accident causes	**Examples of visualization**	**Question format**
Unsafe site conditions	Working at height without a safety belt (Figure 7)	3D model
Unsafe working behaviour	Welding without welding gloves (Figure 3)	3D Animation
Unsafe construction method or sequencing	Incorrect weight lifting (Figure 9)	3D Animation

Table 5. Visualization in the case study

Users	Average number of incorrect answer causing		
	Minor injury	**Serious injury**	**Fatality**
Construction workers	1.42	0.5	0.33
Engineers	0.33	0.17	0
Safety officers	0.25	0	0
Construction managers	0.66	0	0

Table 6. Results of using VSAS

1=ineffective, 3= normal 5= highly effective	Average VSAS rating for assessing the user's ability in:		
	Identifying an unsafe working environment	Identifying an unsafe working attitude	Identifying an unsafe working method/ sequence
Construction workers	3.75	3.91	3.83
Engineers	3.66	3.83	4.33
Safety officers	3.75	3.75	4
Construction managers	3.67	4	4

Table 7. Effectiveness of VSAS