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Modelling issues in the development of a simulation game for teaching construction management

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ABSTRACT: Simulation is becoming increasingly popular in construction for training, planning and for assessment of projects. There are, however, significant problems inherent in simulating construction which are not common to other simulations. This paper describes the development and use of computer-based game for teaching and learning of some aspects of construction project management. It is concerned with the development of a model used to simulate the construction of a rock- and clay-fill dam. It includes detailed physical modelling of the performance of individual pieces of equipment and their interaction with the ground, the geography of the project and the weather in which the equipment operates. The behaviour of all of the individual pieces of equipment when acting as fleets is also discussed. The paper also describes the modelling issues of non-technical aspects of earthmoving operations. These include environmental impact, safety, quality and risks. The problems of integrating these with the physics-based models of the equipment performance are discussed. The paper also draws on real experience of using the game in classes in three universities in different countries.

Keywords: Construction; Simulation; Game; Modelling

1. INTRODUCTION

Simulation has been used in construction for training for many years (see, for example [1] for one of the earliest examples). As computers have become more powerful people's expectations of the simulations have increased until, at present, they are easily turned away from the simulation if the representation of the problem under consideration is not realistic. To some extent this has been driven by the rapid improvement in computer games designed for entertainment. These include life-like characters obeying the laws of physics either as they exist in this universe or another consistent set defined for the game universe.

This demand for verisimilitude has meant that the older style games have lost favour despite their suitability for the task for which they have been designed.

Further, the modelling of construction processes has become increasingly common as its benefits have become better understood and the amount of affordable computer power has increased. It is used to understand the modelled processes better; to design and plan specific instances of the processes; and to help educate and train those people responsible for the processes. In order to fulfil these uses, it is important that the model behaves realistically. It should therefore be based on accepted theories linked together in a manner which reflects the complexity of the real-life situation whilst still allowing effects of the interacting aspects to be identified clearly.

The main problem with this is that the more complex the real life situation, the more suitable simulation is to help people understand it and learn to manage it but the more difficult it is to produce a model of it which behaves realistically.

The management of a construction project is a typical area which is complex with many interrelated aspects. It is difficult to teach much of this in a traditional manner. It is also expensive and potentially dangerous to allow a person to learn the management skills on-the-job. It is therefore an area in which simulation might naturally be used.

This paper describes the modelling of a project which was used in the construction of a game intended to be used for training in planning, control and risk management of construction. It contains sections on the choice of project; the site layout; environmental aspects; the performance of equipment; and the interaction of equipment, people and the environment. All these are discussed with reference to the productivity of the project, the quality of the work, the safety on the project and the environmental impact.

2. CHOICE OF SIMULATED PROJECT

The choice of project around which to build a simulation game is crucial to its success. It must be within the field of expertise of the potential players, complex and large enough to illustrate all the objectives of the game and yet small enough and simple enough to allow the resulting game to be played within a reasonable time scale.

The size and complexity of the project will also determine the ease with which the simulation can be developed. Most teaching and training software is not developed by large teams of programmers. It is more likely to be produced by small teams or even individuals who are specialists in the technical field rather than specialist programmers. This can improve the technical aspects of the simulation but it may also reduce the programming quality. Perhaps more importantly, the lack of programming expertise may bring about a reduction in the content.

It is possible to develop a project specifically for the simulation, to use a real project or to use a section from a real project. Real projects have the advantage of having a large amount of data available for them. This data can include photographs and videos which add significantly to the verisimilitude. Made-up projects need the data-set developing. This is often a significant task and can take as long as the development of the software itself. These artificial projects, however, have the advantage of being more controllable in content.

The project chosen for this simulation is an artificial one for the construction of a rock and clay fill dam. The specific physical work of the project simulated is the excavation of the rock fill, the transport of the rock to the dam site, the compaction of the rock, the excavation of the clay, the transport of the clay to the dam site and its compaction and the maintenance of all haul roads.

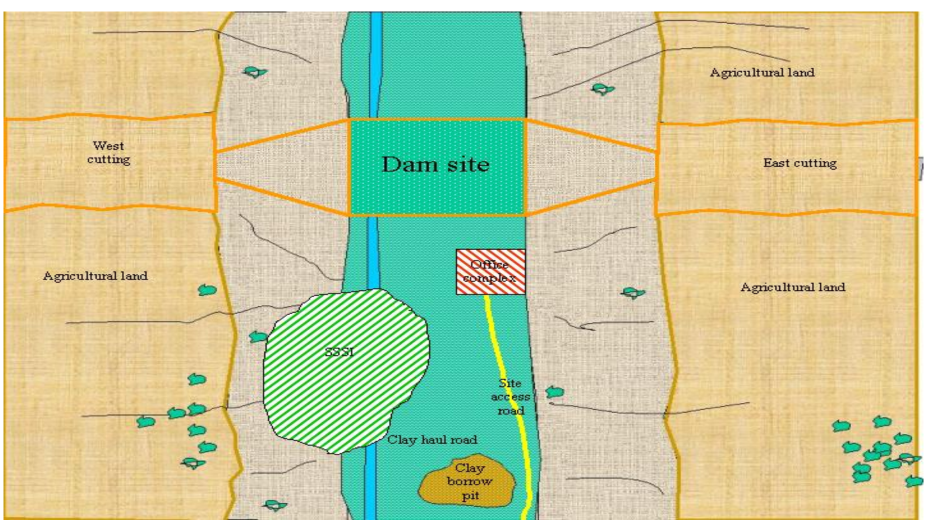
The other features of a dam construction project such as the construction and removal of a cofferdam, the water take-offs, the spillways and any cut-off walls or curtains required in the existing ground under the dam are not included. Figure 1 shows a schematic general arrangement of the project site.

The simulation under consideration in this paper is intended to allow the player to learn about and gain experience in project planning and control and risk management. It is therefore necessary to include these aspects in the simulation. It therefore requires risk events to be simulated; the player to select all the major equipment and the technical and administrative staff to be used on the project; and the player to decide on what training to give the staff and what expenditure to incur to manage the risks identified. It also has to simulate the operation of all these aspects and their interaction. Further, because of the different measures of success of a project, the simulation has to include financial, quality, safety and environmental aspects in addition to the physical construction of the work.

The size of the project has been constrained to allow players to complete the work in a relatively short time. The dam is therefore limited to 30m high and the project duration to 40 weeks. This enables players to complete the work as part of a two or three day intensive course for in-service training or as part of a typical semester-long course in a university.

The actual site for the project could be in any country but the equipment and methods used might vary. The localisation of the simulation is not discussed here but is a very important part of maintaining the verisimilitude of the model.

Figure 1. Overall view of project site



3. SITE LAYOUT

On most construction projects, the layout of the site affects the performance of the equipment and the sequence of the work that can be done. It can also influence what risk events occur, their probability of occurrence and their impact should they occur. For all these reasons, it is necessary to consider the layout of the site when designing a simulation.

Construction projects differ from other types of projects in that the layout is generally dynamic and three-dimensional. Both of these features significantly complicate the simulation. The dynamic nature of the layout of the site is particularly difficult since it means that the simulation has to continuously monitor the layout and adjust the performance of the equipment and consequently many other aspects of the operation of the project. This increases the complexity of the simulation significantly.

The site layout of the project shown in Figure 1 illustrates that both the three-dimensionality and the dynamic nature of the project have been kept to a minimum. The only aspects which really change are the dam and the haul roads. The height of the dam is calculated by the simulation based on the output of the resources. This is then used, together with information provided by the player to determine the position and state of the haul roads.

Figure 1 provides some indication of potential environmental aspects as it indicates the position of a Site of Special Scientific Interest (SSSI). It can be seen that this lies between the clay borrow pit and the dam site. It might, therefore, be expected that the player recognised the potential for the clay transporting equipment to interfere with the SSSI as a risk event affecting the environment.

4. PERFORMANCE OF EQUIPMENT

Knowledge of the productivity of construction plant and equipment is of prime importance if a project is to be estimated for, planned and controlled in a scientific manner. Unfortunately, the output of a piece of plant is exceedingly difficult to predict with any accuracy even for a well defined task. Several methods have been suggested for determining the output, amongst the most common being:

- Use of site records
- Use of company records
- Use of manufacturers data
- Calculation from basic physics

Site records are collected, or should be, on all projects. They are required for control, feedback to estimators and site planning. They may also be useful for claims evaluation. The detail of collection and analysis of site records is a large subject and despite being discussed in detail in many of the Construction Management texts, it is still widely misunderstood. Consequently there are often large problems with the data collected from a project when people attempt to rely on it. Problems with the use of company and site stem from two main areas

- the fact that the resources work in teams that change
- There is rarely enough information collected about the site conditions under which the productivities were collected

Manufacturers' information is useful for global estimating or comparison between different pieces of equipment but is not suitable for simulation. It is therefore necessary to calculate productivity from basic physics.

The methods adopted in this simulation are described in [2] and [3]. Whilst these might be considered as almost standard in planning and estimating applications, their use in modelling is less common. Readers are referred to the texts for a full description of the methods.

The main equipment productivity that requires calculating in the simulation of the dam construction is related to the movement around the site. It is based on the forces causing motion and the forces opposing it and relies on knowledge of the ground conditions.

The forces causing motion are derived from the engine power of the machine. Such information is available from several sources of which perhaps the most readily accessible is the manufacturers' web sites (see for example, [4]).

In this project the initial condition of the ground on which the equipment moves has a rolling resistance of 100 kgf / tonne and a coefficient of traction of 0.75. These represent an uneven earth road. They are made worse by the movement of dump trucks and scrapers and improved by the use of graders. The change in ground state is not easy to model scientifically and another method had to be found to enable the simulation to produce realistic answers.

Table 1 Factors affecting performance of the equipment

Factor	Value
Change in coefficient of traction per grader per millimetre of rainfall	1.01
Change in rolling resistance per grader per millimetre of rain	1.01
Maximum rolling resistance	200 kgf / tonne
Minimum rolling resistance	20 kgf / tonne
Maximum coefficient of traction	0.9
Minimum coefficient of traction	0.2
Rainfall below which there may be dust problems	3 mm/day
Improvement in performance for relevant training expenditure	1% per $100 expenditure
Improvement in performance for relevant supervision	10% per engineer / supervisor

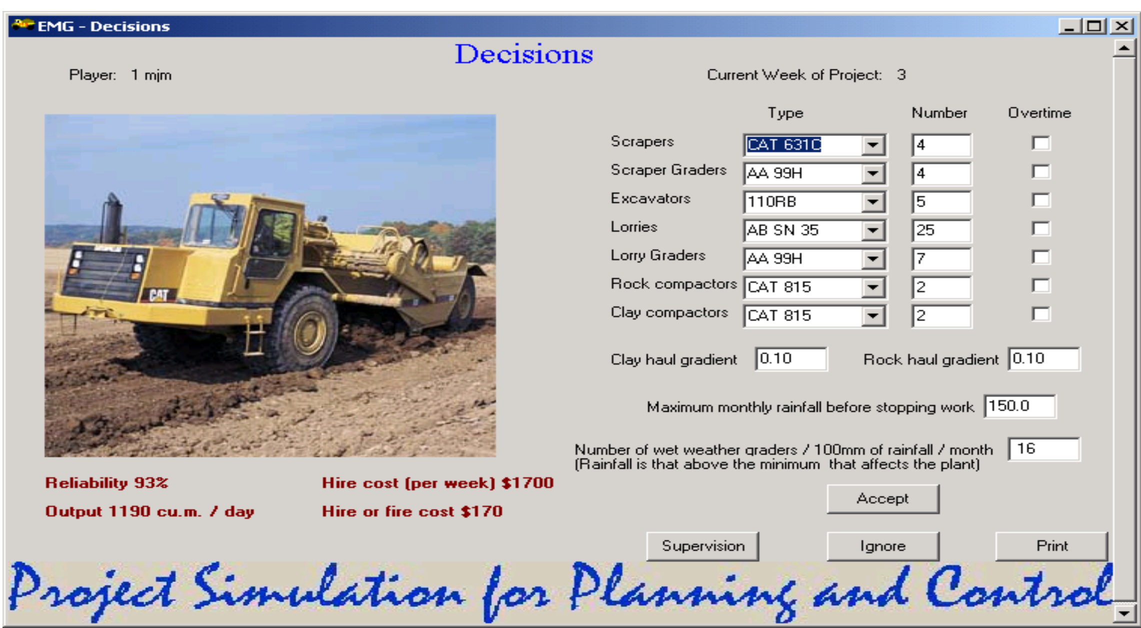
The balance between the degradation and performance changes as the simulation progresses depending on the balance of equipment and the use of the haul roads. It is also affected by the rainfall and the amount of attention paid to the management of the roads as indicated by the number of engineers assigned to the clay and rock. The actual effects of these cannot be based on detailed site records as, even if they were collected, it would be very difficult to analyse them to determine the effects of the engineers' skill and experience on these. However, managers consulted over the effects suggested that management action by the engineers did affect the state of the haul roads. A small survey suggested that the effects should be as shown in Table 1. This same survey also suggested the risk events to be considered, their probability of occurrence and their effects.

5. ENVIRONMENTAL ASPECTS

The environmental factors included in the simulation of the dam project are:

Figure 2. .Equipment decisions

Figure 3. .Management, supervision and training decisions



- The rainfall
- The Site of Special Scientific Interest
- Dust blowing onto surrounding agricultural land

The model has the ability to simulate the actual and forecast rainfall for any run based on the rainfall figures provided for the region where the dam is assumed to be built. The rainfall affects the coefficient of traction and rolling resistance as determined by the survey mentioned above and illustrated in Table 1. It also affects the amount of dust which might be created. The dust produced by the vehicles moving on dry roads can blow onto adjacent land. This can be minimised by correct supervision of the operation. The greater the number of supervisors /engineers and their training, the lower the chance of this causing a problem.

6. MANAGEMENT DECISIONS

The management decisions modelled in this simulation are shown in Figures 2 and 3. Figure 2 shows a typical choice of equipment to be allocated to the project whilst Figure 3 shows the decisions related to the management, supervision and training allocations.

It can be seen that these decisions are directly related to the factors and their effects described in the paper. The choice of equipment should be based on its performance and the maintenance of the quality of the haul roads. The choice of supervision and training should be based on the effects that it will have in improving the operation of the fleet of equipment.

7. INTERACTION BETWEEN FACTORS AND RISK EVENTS

All the aspects described – the equipment, the site layout, the environment, the supervision, the management and the training – are combined by the model using the basic physical model and the information from the survey to simulate the construction of the dam. The whole process is dynamic in that the site actually changes during the construction. The height of the dam changes and the length and position of the haul roads therefore necessarily change.

As the work progresses, the whole is subject to random events. Most of these can be predicted and have a relatively minor and predictable effect. The main one of these is the rainfall. The rainfall is chosen daily from a random distribution with the mean and standard deviation of the rainfall provided in the localisation of the package. The rainfall affects the outputs of the equipment as described above.

Another relatively predictable random effect is the breakdown of a piece of equipment. Company records have been used to determine the reliability of each type of equipment selected by the player.

Less predictable events are the risk events. These are affected by the management decisions as well as the physical operation of the site. For example, the greater the supervision and training are the lower the probability of a safety problem (accident) on site. The actual risk events and their effects were determined through a survey of experienced contractors. Typical ones are shown in Table 2.

Each day in the model, the potential output for each piece of equipment is determined in isolation before being combined to produce the output of the fleet as a whole and thus the production on the dam.

The rock production is determined by the smallest of the output of the excavators producing the rock, the dump-trucks transporting it and the compactors compacting it. The clay production is determined by the smallest of the output of the scrapers excavating and transporting the clay and the compactors compacting it in the dam. There is also a constraint on the maximum difference between the clay and the rock heights to ensure that the construction method is realistic.

8. THREE EXAMPLE APPLICATION OF THE GAME

Many aspects of the game, its design and the choices made in modelling of its various elements have been discussed within the related sections of the paper. This section contains some general discussion about the game and its applications in three different universities in different countries. The discussion is made under different headings as follows:

Table 2. Risk events & effects

Risk Event	EFFECT
Clay compaction quality problem	Increased cost of $100 - $1000
Clay plant exceeding site speed limit	Increased cost of $100 - $1000 plus 1 day delay for retraining
Clay compactor drivers not tested	Increased cost of $100 - $1000 plus 1 day delay for retraining
HSE comments on overcrowding in West Cutting	Increased cost of $100 - $1000 plus delay for re-organisation
Poorly maintained clay equipment	Increased cost of up to $2000
Unsupervised rock working	Increased cost of up to $5000 and delay of up to 2 days
Clay haul road river crossing considered unsafe	Increased cost of up to $10000 and delay of up to 3 days
Speeding scraper hits land rover. Clay engineer killed	Increased cost of up to $50000 and delay of 5 days

8.1 Measurement of the benefits of using the game

For measuring the benefits and effectiveness of the game for developing some of the generic attributes required in civil engineering graduates, as compared with traditional teaching methods, a survey between 53 students who have played the game was carried out previously at Curtin University. The results of the survey indicated that the game had both given the students a better understanding of construction management procedures and experience in using project planning and control techniques. There was also a realisation and appreciation that the exercise was developing skills and knowledge that could not be given using traditional teaching and learning methods. For more detailed information on the questions used in the survey, its objectives and results see [5] and [6].

8.2 Language Issues

Language is always an issue when considering professional education. English is often referred to as the language of business and it is certainly widely used in engineering. However, it is not the native language of everybody and not all people feel comfortable in it. If the participants have to think about the language they will not find the learning as easy or as pleasant an experience as if they did not have to.

This was illustrated in feedback from students in The Netherlands. The Dutch are generally good at languages and at English in particular. The lectures for a module had been delivered in English, the notes and text books had been in English. The game was used as an exercise at the end of the module to reinforce the lecture content. The students found the game much more difficult than expected since they measured success in terms of profit from the project whilst the 'staff' measured success in terms of lessons learned. The improvements suggested by the students were a change of language and a change of 'mathematical' language.

8.3 Culture Issues

'Culture Issues' is taken to include the construction methods employed, the skills of the workforce, the methods of planning and control, the importance of aspects such as quality, safety and the environment and the significance of money to the process.

Table 3 gives an indication of the relative importance of various aspects of a construction project in two regions. It is important to say that these are generalisations and are not intended to represent any particular country.

The game produced is based on the 'developed country' values. They use equipment intensive construction methods to carry out projects in which safety, environmental and social impacts are very important. Two examples illustrating this are:

- An impingement into an environmentally sensitive area will have great impact on the cost and speed of construction
- The poor training of managers in safety issues and a reduction in spending on safety supervision severely affects the project outcome

All students playing the game initially consider the cost and time as being the important issues in terms of completion of the project. As other issues arise within the game, the students from the 'developed' countries quickly adjust to the situation and their management processes change to take social and environmental issues into consideration. Students from developing countries are much slower to make this change and remain committed to time and cost even through quite severe quality and safety problems might occur.

Cultural issues have been included in the game in the form of umpire data which the staff can change depending on the issues they want to stress and the format in which the game is being run..

8.4 Legal Issues

'Legal issues' is the term used to encompass the framework within which construction exists in a region. It includes such aspects as the procurement route for a project, people involved with a project and their roles, the payment methods, and the dispute resolution.

These are all obviously important and vary widely. Despite potentially affecting the planning and control objectives they have been largely ignored from an internationalisation point of view in the game described here.

9. CONCLUSIONS

The paper has described methods which can be used to model different aspects of a project for the construction of a clay and rock fill dam. It has been shown to be necessary to use several different approaches: some require a modelling of the underlying physics of the equipment operation; others require a much less formal approach and the development of a set of rules based on experience.

It has suggested that, in order to be really successful, a game should be internationally applicable. The internationalisation will depend on the choice of project and the environment in which the project is set. The language used for the game was not considered to be important although the construction culture of the country of origin of the students was. It was important to allow the umpire to alter such aspects as the relative importance of time, cost, quality, safety and environmental issues in order to reflect the country and to ensure total student commitment.

It has suggested that students obtain more value from the game if they can associate directly with the topic of the game however the effectiveness of a game is very difficult to assess. Since it is also very difficult to assess the effectiveness of lectures for some topics, it is suggested that this should not be used to prevent game being used.

Three examples of the same game being used in three different ways in three different countries indicate that game can be successfully internationalised.

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