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INTERACTIVE PARADE GAME: IMPACT OF MANAGERIAL REACTIONS TO WORKFLOW VARIABILITY

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SUMMARY: *One of the primary concerns in the lean construction community has been understanding and managing the combined impact of variability and interdependency on construction performance. The parade game has been extensively utilised for enhancing construction practitioners' intuitive understanding of construction production systems. However, the current parade game does not incorporate managerial actions that are usually taken in practice to offset the impact of variability of activity duration or productivity. These managerial actions often radically change the production profile (e.g., quantity of resources, level of production capacity); thereby significantly affecting project performance. For this reason, exclusion of managerial actions in the parade game can result in less realistic estimation of project performance. Also, given that the pedagogical value of a simulation-based game can be maximised by user interaction, managerial actions are a key element that should be incorporated in the parade game. Based on this recognition, this paper aims to develop an interactive simulation game as an extension of the current parade game. For application in the construction education setting, this game incorporates managerial decision making processes and highlights trade-offs associated with managerial decision. Being developed as an Internet-based application which can be accessed through any platform, the interactive parade game has been applied in construction education. Its application showed that the interactive parade game can successfully help students to actively participate in the learning processes and discuss their findings, and to gain a deeper understanding of the dynamics of construction production systems.*

KEYWORD: *simulation, management game, construction production, variability, managerial actions*

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1. INTRODUCTION

Non-value adding activities (NVAAs) are wasted efforts that take time and resources (i.e., cost) without adding any value (Koskela 1992). Consuming about 50% of operational time (Horman and Kenley 2005), these activities are a major source of productivity loss, ultimately lowering project performance. For this reason, it is generally accepted that successful execution of a construction project is directly related to minimisation of NVAAs (Han et al. 2007).

To find an effective way of reducing NVAAs, construction researchers have striven to identify root causes of NVAAs. Koskela (1992) who arguably first coined the term of NVAAs into the construction area pinpointed that variability, especially which of activity duration, is the major source triggering NVAAs in construction projects. In particular, the negative impact of variability on project performance can be drastically amplified in time-compressed environments where interdependency between activities increases (Howell and Ballard 1994). Therefore, understanding and analysing the combined impact of variability and interdependency on project performance is a critical management skill required for construction managers to successfully execute their projects.

The combined impact of variability and interdependency, however, is incompletely understood and poorly analysed through CPM/PERT (Tommelein et al. 1999), which is the *de facto* standard applied for scheduling and monitoring in the construction area (Senior and Halpin 1998; Martinez and Ioannou 1997). Accordingly, the need has been raised for an enhanced tool which can assist construction managers in better understanding and analysing the combined impact of variability and interdependency. As an effort to address this necessity, Tommelein et al. (1999), inspired by the 'boy-scout hike' model (Goldratt and Cox 1986), developed the 'parade game' in computer-based simulation environments in order to conduct stochastic analysis of the combined impact in faster and more systematic ways. Being able to effectively visualise how the combined impact can lower project performance, the parade game has some pedagogical value in terms of enhancing managers' intuitive understanding of construction production systems (Tommelein et al. 1999).

However, it is also true that the parade game has some limitations to be utilised as a comprehensive and practical educational tool, particularly in that it does not explicitly include managerial actions to offset the negative impact of variability. Namely, the parade game has been applied mainly as an estimation tool, forecasting the extent of negative impact brought about by a pre-defined range of variability under a given interdependency before execution (e.g., execution time, size of required intermediate buffer). However, the parade game has not taken into consideration managerial reactions that, in reality, would be taken to deal with unexpected variability during execution. Controlling unexpected variability during execution is particularly relevant in construction since a construction project by its nature involves inevitable variability to some extent, no matter how carefully it is planned. Therefore, effective control action plans also need to be sought and prepared to shield project performance from unexpected variability during execution.

Alarcón and Ashley (1999) provided an important lesson with regard to controlling variability. Extending the parade game to apply and test lean construction strategies, Alarcón and Ashley (1999) claimed that buffers can be helpful to minimise productivity loss and shield production performance from unexpected variability. Buffering, however, may not be a viable option for a construction manager to adopt, especially under time-compressed environments, because it may rather increase the project duration. For this reason, construction managers often prefer to adopt corrective action (e.g., overtime or overmanning) when deemed necessary, rather than placing buffers between activities. Also, if buffers are inserted between activities, construction managers still may take managerial actions if the buffers do not absorb the impact of variability.

In fact, one of the primary responsibilities of construction managers in practice is to closely monitor variability and take corrective actions to keep the project on track despite this perturbation (Halpin and Woolhead 1973). These corrective actions often drastically alter the production profile (e.g., number of workers or different levels of production capacity), thereby significantly affecting the production rate and performance. Thus, managerial actions are obviously a key element that should be considered and included in a simulation model (Williams 2002).

Incorporation of managerial reactions into a simulation model can not only enhance its predictability, but also provide a chance to evaluate effectiveness of a control policy to deal with unexpected variability prior to its implementation in a real project. For example, the simulation model might test the effectiveness of a policy that triggers the use of overtime whenever the expected delay is greater than 3 days. In addition, inclusion of managerial actions is meaningful particularly for educational purposes because simulation games that can respond to a user's actions allow for a learning experience to take place (AbouRizk and Sawhney 1994). From the educational perspective, when a user can interactively make a decision at each decision cycle (e.g., daily) based on the current progress in a simulation-based game environment, its pedagogical value can be maximised because the decision making process provides the opportunity for the user to observe the direct influence of their decision on the project progress (Halpin and Woodhead 1973). Furthermore, such an interactive gaming environment can evoke enthusiasm and active involvement of students, even those who do not normally participate in the classroom discussion (Steger 1968). Considering that students can learn more effectively and permanently when they can actively participate in the learning process (Chi et al. 1989), the pedagogical value of an interactive simulation based-game is tremendous.

To reap these education benefits, this paper aims to extend the existing parade game to develop an interactive simulation game, which deals with the combined impact of variability and interdependency on project performance - a critical issue in construction production systems. To this end, we first briefly review previous simulation-based games developed for construction education and explore some critical elements for a simulation model to be successfully utilised in construction education settings. We then address how these success factors are incorporated into the interactive parade game proposed in this paper. Finally, we illustrate its application to classroom environments as a construction learning tool and draw some conclusions.

2. SIMULATION AS AN EDUCATIONAL TOOL

It is becoming critical in construction management education to incorporate classroom tasks that improve the abilities of students to manage the complexities, dynamics and uncertainties of construction sites (Sawhney et al. 2001). However, the traditional education methods are often not fully capable of providing students with all the skills necessary to solve the real-world problems encountered in construction (AbouRizk and Sawhney 1994). Simulation has emerged as an important tool to address this deficiency. Allowing repeatable experimentation under controlled conditions that emulate the real world situations, a simulation-based gaming environment enables students to build up critical thinking and problem-solving skills (Chinowsky 1998; Banks et al. 2000; Burr 2001). Particularly where the pedagogical goal is for students to transfer and apply the knowledge to real-world problems, application of simulation as an education tool is more effective than traditional alternatives (Gokhale 1996). Computer-based games that simulate the environment of construction can bridge the gap between the classroom and the construction site by allowing students to take actions and learn from the responses to these actions (Sawhney et al. 2001). Because of these enhanced educational benefits, various simulation models have been developed and applied for educational purposes within various aspects of construction management including estimating, bidding, construction process management, equipment management and evaluating. These are well summarised in Sawhney et al. (2001) and Park et al. (2003).

Despite the claimed benefits of simulation, the complex structure of a simulation tool often makes it difficult for students to understand the concepts the tool is intended to deliver (Al-jibouri and Mawdesley 2001). Therefore, as education tools, simulation models must remain simple in their application, and must provide an experimental environment that is easy to operate, without sacrificing the reality that the models intend to mimic. The difficulty lies in selecting an appropriate level of abstraction of the real world. High levels of assumption in simplified simulation tools can be detrimental to the understanding of the real construction process (Senior 1998) and can misguide students, thereby failing to achieve the target educational goals (Park et al. 2003). Particularly, the exclusion of managerial actions that significantly influence the construction performance can result in less realistic simulation and limited educational effect (Park 2001). In addition, the development of simulation tools has not kept pace with the development of computer technologies. As a result, many simulation tools are still text-based, whilst most computer application programs have moved to a graphical user interface (Al-jibouri and Mawdesley 2001). Some state-of-the-art simulation games run on a specific platform, which limits students' access to the games. Based on this recognition, Park et al. (2003) identified the three success factors for the development of simulation based construction education tools:

- Incorporating managerial actions involved in the construction process
- Focusing on tradeoffs associated with managerial decisions, and
- Developing an easy-to-use standalone tool that runs on any platform without other supporting programs.

Following suggestions provided by Park et al. (2003) for the successful application of simulation models for educational purposes, an interactive simulation game was developed by incorporating the three success factors listed above into the current parade game.

3. PARADE GAME

3.1 Background

Prior to developing the interactive simulation game, this section provides a brief background and description of the parade game. In the game, a project consists of five activities that are interconnected by intermediate buffers (Figure 1). All activities have the same average daily production rate (i.e., 5 units/day) with a known degree of variability. The project scope is to produce 100 production units and production of one unit requires its transfer from activity 'A' to 'E'. Also, production units completed by one activity are prerequisite for the next activity (Tommelein et al. 1999). For example, if activity 'A' produces 5 units today, these 5 units would be stored in the intermediate buffer 'AB' and activity 'B' would be able to process the 5 units tomorrow. However, if activity 'A' generates only 3 units due to unfavourable production conditions (e.g., equipment breakdown) today, the following activity 'B' would be able to execute at most 3 units tomorrow due to deficiency of its prerequisite work, even though its potential production rate would be 5 units. As such, since production rate of an activity can be restricted by its predecessor in this linear production environment, variability in an activity can significantly affect overall project performance.

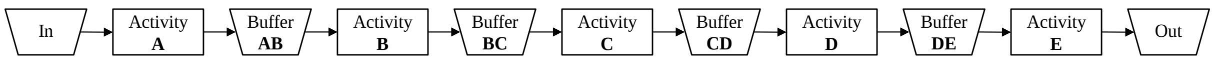

FIG. 1: Parade Game

3.2 Replication

Correlation between variability and project performance has been well proven by Tommelein et al. (1999) and Alarcón and Ashley (1999). Prior to the development of the interactive simulation game, development of a simulation model that corresponds to previous models is required for validation purposes and to prevent any modelling bias. For this reason, based on the data provided by Alarcón and Ashley (1999) which extends Tommelein et al. (1999), a computer simulation model was created using AnyLogic 6 University version (XJ technology 2009) (See Figure 2).

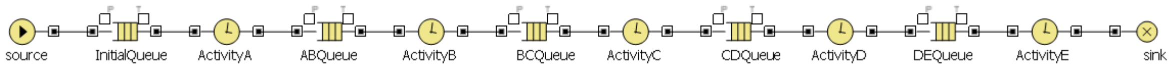

FIG. 2. AnyLogic Model Implementation for Parade Game

At the beginning of the simulation, 100 units are created at the `source` modelling element and then immediately moved to the `InitialQueue` which is the upstream buffer for `ActivityA` (Figure 2). At every production cycle (i.e., day), the simulation model determines capacity (i.e., maximum production rate) of each activity based on the average production rate and the predefined range of variability. For example, if the average production is 5 and the variability is 2 units, the simulation engine will call its random number generator (RNG) and the RNG will pick up a random sample from the Triangular distribution whose min, mode, and max value is 3, 5, and 7 respectively. Then, the simulation model assigns the random sample to the capacity of an activity at a given production interval. In order to implement this, an event was inserted which is triggered every production interval (i.e., day) and contains java programming code as follows.

```
int r = (int)triangular(Mode-Variability, Mode, Mode+Variability);
ActivityA.set_capacity(r);
r = (int)triangular(Mode-Variability, Mode, Mode+Variability);
ActivityB.set_capacity(r);
        (…)
r = (int)triangular(Mode-Variability, Mode, Mode+Variability);
ActivityE.set_capacity(r);
```

However, the actual production rate of an activity is determined by the lesser of its current capacity and the number of units stored in its upstream buffer. In order words, if the capacity were greater than the number of units ready for execution, this excessive capacity would be wasted as ‘productivity loss’. The actual production rate determines how many units an activity will pass to its downstream from its upstream buffer. This process continues until all units arrive at the `sink` element. The simulation engine records the duration of the process and the cumulative lost productivity during the process.

In order to confirm the correlation between variability and schedule performance and to check if the developed model is consistent with Ashley and Alarcón (1999), five simulation scenarios were developed with respect to the degree of variability as shown in Table 1. Then the model was run 1,000 times for each scenario to draw statistically valid conclusions.

TABLE 1: Simulation Scenarios

Scenario Name	Input		Output (1,000 iterations) – Total Duration			
	Variability	Production Capacity	Mean	Min	Max	Range
Base Scenario	0	5	24	24	24	0
Scenario A	1	Triangular(4,5,6)	27.9	27	29	2
Scenario B	2	Triangular(3,5,7)	28.9	27	31	4
Scenario C	3	Triangular(2,5,8)	30.1	27	34	7
Scenario D	4	Triangular(1,5,9)	31.4	26	37	11

Corresponding to Tommelein et al. (1999) and Alarcón and Ashley (1999), the simulation results in Table 1 show correlation between variability and project performance. For example, the mean duration of the scenario A is 27.9 days while that of the scenario D is 31.4 days. This can be better explained by Figure 3 which shows the representative run of the base scenario (i.e., no variability), scenario A (1 unit of variability) and D (4 units of variability). As shown in Figure 3, variability of an activity can be propagated to the subsequent activities. For example, in the scenario D (Figure 3-(c)), production rate of the second activity gets lower at the 8th working day and its following activities (i.e., Activity C-E) start to suffer from lower production ('A' in Figure 3-(c)). Because of this propagation, the negative impact of variability in an activity can be amplified and further reduce the following activities' production rates, thereby lowering the overall project performance.

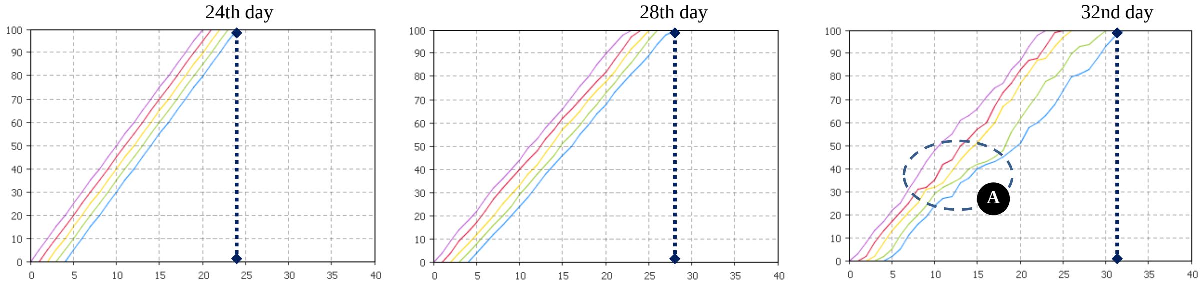

FIG. 3: Impact of Variability on Project Performance

Also, the simulation results show that the expected range of the project duration gets wider as the variability increases. For example, the range of the expected completion dates in the scenario A is 2 days while that of the scenario D is 11 days (see Table 1). A wider range of the expected completion dates implies lower reliability in terms of meeting the scheduled completion date and higher level of efforts in dealing with the variability to meet the planned schedule. These simulation results confirm Koskela (1992)'s argument that variability is the major source triggering NVAAs and lowering performance in construction projects.

As such, the parade game can effectively show correlation between variability and project performance. To maximise its potential to be utilised as a construction management education tool, this game is further developed by incorporating the three success factors identified by Park et al. (2003) into the current parade game.

4. MANAGERIAL ACTIONS

4.1 Relevance of Managerial Actions

For successful application of a simulation model for construction educational settings, it should consider managerial actions involved in the construction process because these actions are prevalent in practice and can significantly alter project performance (Williams 2002). In fact, construction management process is an iterative cycle of planning, monitoring, and controlling (Halpin and Woodhead 1973) and the "planning-monitoring-controlling cycle" is continuously repeated until the project is completed (Meredith and Mantel 2000). Namely, construction managers initially set execution plans and regularly monitor whether their actual progress follows the planned progress. Once the managers recognise intolerable variability which could affect the whole project duration, they would not oversee the schedule slippage but would take managerial actions (e.g., adopting overtime or assigning more labourers) in order to expedite the delayed progress (Peña-Mora et al. 2008; Rodrigues and Bowers 1996; Moselhi and El-Rayes 1993). Managers would be more inclined to take recovery actions particularly in highly interdependent execution environments where negative impact of variability can be amplified through interdependency. For this reason, taking effective managerial actions has long been thought to be critical in successful execution of particularly large and complex fast track construction projects (Kog et al. 1999).

The parade game, unfortunately, does not incorporate managerial actions (i.e., project control functions), which are a critical element in understanding and determining project performance. The game mainly focuses on the impact of variability on project performance but neglects managerial actions taken to offset the impact of variability. From the modelling point of view, the current parade game assumes variability and interdependency as ‘exogenous independent variables’, which are set before the execution of the model and unchanged (in terms of mode and variability of the Triangular distribution from which a random sample is picked up) during the execution of the model while they are the two most important factors governing the project performance. Contrary to this assumption, in practice, both variability and interdependency can be highly affected by managerial actions adopted during construction. This implies that both variability and interdependency should be converted into ‘endogenous interdependent variables’ which can vary during execution of the model and this can be realised by incorporating the managerial actions within the boundary of the simulation model. Based on this recognition, the interactive parade game allows users to take actions to recover or enhance project performance.

4.2 Incorporation of Managerial Actions

Several kinds of managerial actions can be considered; however, inclusion of all possible actions to the game would increase the complexity of the simulation model and diminish the educational effectiveness. In order to keep the model simple but capture the key features that should be represented, the model primarily focuses on the two most widely applied managerial actions in practice; overtime and overmanning (Noyce and Hanna 1998).

Overtime is defined as working beyond the regular working hours (8 hours/day). Among several overtime policies (e.g., 10 hours/day, 12 hours/day, or 14 hours/day), only the 10 hours/day option is considered which is expected to generate additional 25% of production capacity per day. While this game considers only one overtime option for simplicity purpose, other options also can be easily included. Overmanning is defined as the increase in peak number of labourers above the average number of labourers of a given activity (Hanna et al. 2007). This game allows overmanning option doubling the number of labourers (i.e., additional team) which is expected to generate additional 100% of production capacity. Thus, a user can have four options in executing an activity at each time interval (i.e., day). These are Normal, Overtime, Overmanning and both Overtime and Overmanning (Table 2).

As shown in simulation results in Table 1 and Figure 3, schedule can be frequently delayed due to the combined impact of variability and interdependency. If a user completes his/her project behind the planned completion date, the user will be given the penalty ($10,000/day) for late completion. To avoid this penalty, the user can adopt managerial actions to meet the planned schedule. However, these actions also will incur higher cost than the normal option. Therefore, there will be trade-offs in decision making to adopt managerial actions and it would be challenging to find the optimal options in each decision cycle. Thus, the objective of this game is to find a series of optimal decisions that enable completion of the project with the minimum possible cost. Throughout taking managerial actions and observing the game’s response for the actions, the user can learn more effectively and interactively about the dynamics of the construction production systems.

TABLE 2: Four Different Options

Options	Daily Work Hours	Number of Labourers	Mean Production Rate	Daily Cost
Normal	8 hrs	10 labourers	100%	$5,000
Overtime	10 hrs	10 labourers	125%	$7,000
Overmanning	8 hrs	20 labourers	200%	$10,000
Overtime & Overmanning	10 hrs	20 labourers	250%	$14,000

5. TRADE-OFFS IN DECISION MAKING

As mentioned in the previous section, trade-offs exist in making managerial action decisions. These trade-offs make it difficult to determine the optimal choice for each activity at each decision cycle. In addition, since the production rate of a given activity is closely related with its predecessor activity's production rate in the parade game, such production dependency makes the decision making process more complex. Furthermore, managerial actions generally involve productivity loss in a non-linear way and this non-linearity makes it even more difficult to make optimal decisions.

As mentioned before, a user can adopt either or both of the two most widely applied managerial actions (i.e., overtime and overmanning) in the interactive parade game. Overtime is usually preferred since it can increase production rate without coordination problems or delay in hiring additional workers. However, it often involves fatigue, demoralisation, or safety problems, all of which can significantly reduce productivity and increase cost per unit output (Hanna and Sullivan 2004). A multiple regression equation evaluating productivity loss due to overtime was developed by Hanna and Sullivan (2004) who surveyed 400 electrical and mechanical contractors. In order to incorporate the productivity loss due to overtime to the game, Hanna and Sullivan (2004)'s multiple regression model has been adopted, and the equation is as follows.

Productivity Loss (Overtime) = -0.0388 + 0.378 × (OT/Actual) – 0.378 × Ln(OT/Actual) + 0.832 × Log(OT/Budgeted) – 0.0854 × Industrial Equation (1)

Figure 4 shows the best-fit line of the productivity loss due to overtime based on Hanna and Sullivan (2004). As shown in Figure 4, productivity declines due to overtime in non-linear pattern, making it difficult for construction managers to intuitively estimate the impact of overtime policy.

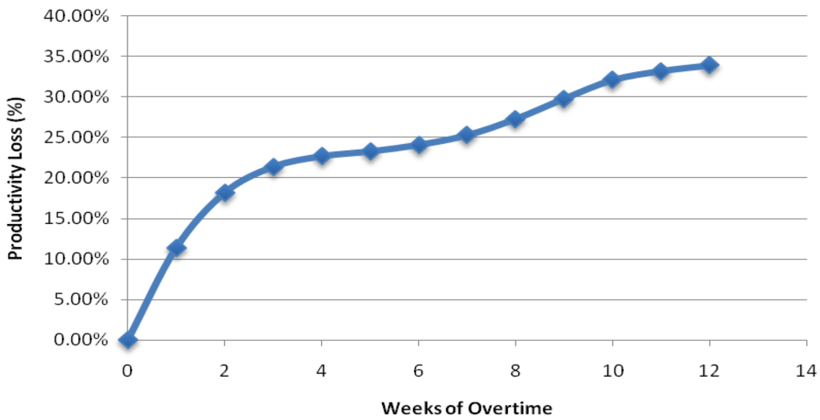

FIG. 4: Productivity Loss due to Overtime based on Hanna and Sullivan (2004)

Overmanning can increase production rates without causing issues associated with overtime such as fatigue, demoralisation, or higher cost per unit output. However, overmanning usually results in congestion and additional coordination problems, which can also lower labour productivity. Also, there might be a shortage of the required skilled workers available in the market; therefore it may involve hiring delays (Hanna et al. 2007). A multiple regression equation evaluating productivity loss due to overmanning was developed by Hanna et al. (2007) who surveyed 33 mechanical and 21 sheet metal projects. In order to incorporate the productivity loss due to overmanning to the game, Hanna et al. (2007)'s multiple regression model has been adopted, and the equation is as follows.

$$\textit{Productivity Loss (Overmanning)} = -0.305 + 0.116 \times \textit{ActPeak} / \textit{Avg} + 0.163 \times \log(\textit{ActPeak}) \qquad \text{Equation (2)}$$

Finally, in an extremely urgent situation, a user may want to apply both overtime and overmanning. To estimate the productivity loss due to the combination of overtime and overmanning, the game calculates the productivity loss from each through the equation (1) and (2), and then sums the total as suggested by Pinnell (2004).

As discussed so far, managerial actions result in non-linear productivity losses and this makes the decision making process even more difficult. Also, dependency in production rates combined with the non-linearity causes a very simple single-line production system to exhibit quite complex behaviour. For this matter, the interactive parade game can be a valuable tool for testing various policies and determining which are effective to control these complexities and non-linearity.

6. INTERNET-BASED INTERACTIVE SIMULATION TECHNOLOGY

The interactive parade game was developed to be executed through the Internet in order to be accessed through any platform. Using the state-of-the-art Java technologies, it provides text, numbers, graphs, and animation in order to enhance students' intuitive understanding on the dynamics of the construction production systems.

Once a user launches the interactive parade game through the webpage, the user encounters the welcome page where he/she can find a brief introduction of the game and set up several key input variables. These include:

- Project scope: the total number of production units required to complete a project
- Average production rate: the constant number of units that can be produced at each production interval when variability is eliminated; the mode value of the Triangular distribution
- Variability: the maximum deviation from the average production rate; this number used to set the range of the Triangular distribution
- Buffer size: the required number of units ready for a given activity to start in order to shield its production from its predecessor's production variability
- Scheduled completion date: the date by which to finish the project in order to avoid late completion penalties
- Late completion penalty: the additional cost incurred per day if a project is completed behind the scheduled completion date

After setting the key variables, the user is guided to the game execution page where he/she can observe current progress and make decisions at each decision cycle. The game execution page consists of three graphs, one animation, the performance panel and the control actions panel (Figure 5). The control actions panel is where the user can choose one of the four activity execution options (i.e., normal, overtime, overmanning or both) for each activity at each time interval. Initially, all activities are set by normal execution options. Once the user makes the decision and clicks the simulation button, the game execution page shows the daily progress made with the selected options under a given range of variability through three graphs, one animation, and the performance panel. Through these graphs, the user can easily observe each activity's progress, each intermediate buffer's inventories, and managerial actions adopted for each activity. The animation panel shows what really happens in each activity and each queue at every decision cycle in more intuitive ways. Finally, the performance panel shows current progress, productivity, cumulative expenditure, lost productivity and required production rate for timely completion of the project. Based on this information including numbers, graphs and animation, the user can take appropriate managerial actions in the control action panel at the following decision cycle in order to achieve the scheduled completion date and minimise the total project cost.

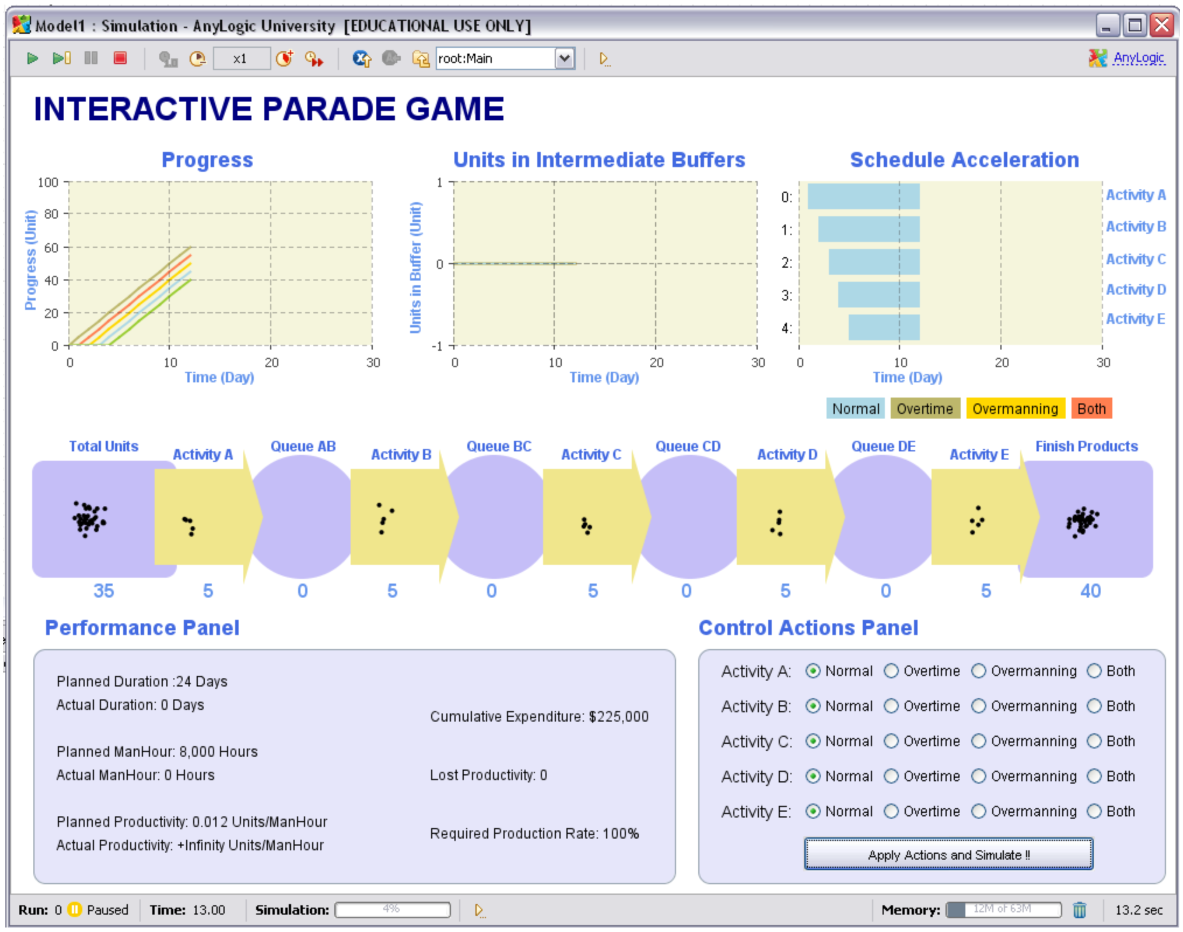

FIG. 5: Internet-based Interactive Parade Game

The system architecture is composed of two main platforms: Windows and Java (Figure 6). Windows platform provides development environments including graphical editor, code generator, debugger, and viewer. The graphical editor and code generator compile the model (i.e., Interactive Parade Game) into Java programming code. Then, the developed model runs on any Java platform on the top of AnyLogic simulation engine. The developed model provides an interface to control its execution (e.g., applying managerial actions and running the model) and to retrieve information (e.g., schedule, cost, or productivity) to the viewer and debugger via a text-based protocol over TCP/IP (Borshchev et al. 2001).

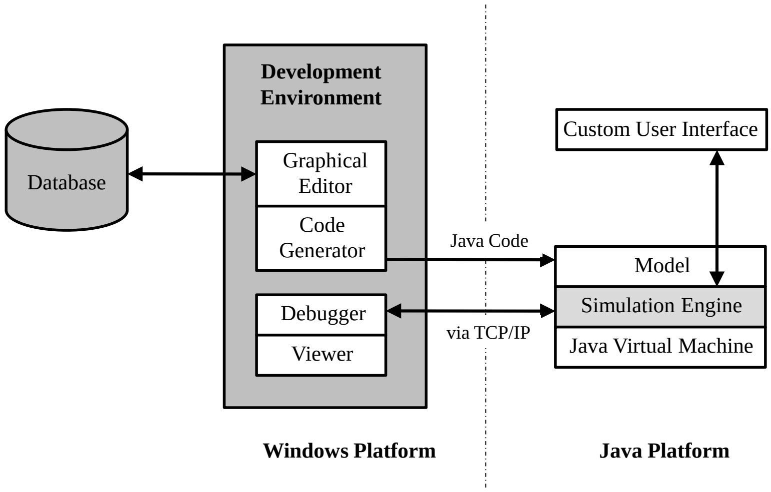

FIG. 6: System Architecture (Modified from Borshchev et al. (2001))

7. APPLICATION

In order to test the validity and usability of the interactive parade game in the classroom environment, the game has been applied for construction management courses at the University of New South Wales and Seoul National University. Prior to implementation of the game, instructors introduced the basic concepts relevant to the game (e.g., parade of trades, line of balance, type of variability or repetitive projects scheduling). Through lecturing on these basic concepts, students could identify potential real life situations where they could apply lessons to be learned through the simulation experimentations. Also, students could set a rough direction for controlling variability that they would encounter during the game execution. After introducing the basic concepts, the students were informed of possible control actions and the expected impact of each action on both schedule and cost performance.

Then, students were asked to launch the simulation game over the Internet. Level of difficulties in executing the game can be adjusted by assigning different value sets for the key variables (e.g., high variability, tight scheduled completion date and high penalty for late completion). After the instructors assigned a set of values for the key variables, groups of three students were asked to run the model and finish the project at the minimum project cost. At each decision cycle, each group discussed what kind of execution option they should adopt for each activity at that moment and what schedule and cost impact these actions will bring under the impact of variability. After finishing the game, students were asked to present their schedule and cost performance and explain how they controlled variability during the game and why their control actions worked well or not.

Some groups successfully finished the game within the planned schedule with relatively low cost while other groups finished their project much behind the planned date, hence spending more money. Through this discussion, groups with poor performance were able to learn some effective control policies from successful groups. However, it should be noted that some successful groups' performances might be attributed to randomness inherent in the game and their control actions might not be effective for the next experimentations. In order to obtain reliable control policies free from statistical bias, students were further asked to formulate their control actions as a set of IF THEN statements. For example, a control policy may be formulated as follows: IF the number of units stored in the upstream buffer is greater than two days' average production (i.e., 10 units) and expected delay is currently greater than two days, THEN overtime is applied until expected delay gets back to zero. These IF THEN statements were then converted to Java programming codes so that the game could interpret and apply them. Each group's control policies consisting of several IF THEN statements were run 1,000 times in order to examine the effectiveness of their policies under stochastic environments. This provided to students a chance to identify some consistent patterns from their ad-hoc decisions made at each decision cycle.

Students were also able to observe which control policies were successful, which were not, and consider reasons the success and failure of varying policies. Finding effective policies to control variability is a valuable learning outcome that the student can apply when managing other similar projects.

Throughout these processes, it was observed that students not only actively participated in the learning processes and discussed their findings but also gained a deeper understanding on the dynamics of construction production systems. Particularly, this game helped students to better understand the combined impact of variability and interdependency on project performance, and appreciate effectiveness of their actions under uncertain and time-compressed environments. To enhance educational applicability and increase validity of the game, students' feedback has been regularly gathered. For example, a recent feedback was to develop a game where five students can participate together as a team, each of them can make a localised decision in a distributed environment. It is expected that such a distributed running environment can increase complexities and dynamics of control decision and increase realism of construction production systems. The game is being further developed in a distributed environment and corresponding results will be reported in the near future.

8. CONCLUSIONS

With trends toward larger-scale, more complex projects with tightening schedules, today's construction environments are becoming more challenging. Increasingly, a small variation can result in tremendous ramifications on overall project performance. It is recognised that providing construction curricula that can bridge the gap between the classroom and construction sites is crucial for effective construction management education. Simulation-based approaches can be effective learning tools to supplement the traditional education methods that are not fully capable of demonstrating complexities, dynamics and uncertainties of construction projects. The parade game is one simulation-based educational tool that analyses a critical issue in construction production (i.e., combined impact of variability and interdependency on project performance). The parade game, however, does not fully capitalise on the advantages of simulation-based game environments since it does not incorporate users' interaction, a key component to maximise pedagogical value of a simulation model.

As an effort to address this, an interactive parade game was developed and its application to classroom settings proved its applicability and validity. Interaction between students and the game enabled their active participation in the learning process. Trade-offs associated with decision-making provided students with an opportunity to think critically and develop a deeper understanding of the dynamics of construction production systems. The state-of-the-art Java technologies utilised for the development of the game removed a platform-dependency issue and enhanced users' intuitive understanding by providing information through various media including text, number, graphs and animation.

While the effectiveness of the interactive parade game has been proven through classroom settings, the game needs to be further developed to represent other critical issues in construction production such as quality problems due to schedule compression or multiple production lines. Involvement of industry partners and students' regular feedback are critical assets for continuous development.

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