PLAYING GAMES: EVALUATING THE IMPACT OF LEAN PRODUCTION STRATEGIES ON PROJECT COST AND SCHEDULE

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ABSTRACT

There are several games which are used to demonstrate the practical implications of some Lean Production Concepts such as the impact of uncertainty on productivity and project duration, push and pull approaches to production or the impact of multitasking. These games are very appealing to the players and the observers by illustrating the detrimental impact of some current practices on project performance. They are also useful by illustrating the impact on some of these practices on project results. This paper reports an attempt to take the benefits of a simple game, the "Dice Game", one step further by using a simulation model inspired in this game to explore some research questions which can not be addressed in the original game. The paper presents the results of an extensive analysis of project conditions where production variability and buffer size were used as the main input variable and project cost and schedule were used as the main output variables. The analysis addresses among other research questions the impact of buffering on project duration and cost, the impact of production variability on project productivity and suggest some guidance to select buffer sizes for minimum project cost.

KEY WORDS

Lean production, lean construction, buffering, management games, project planning, simulation.

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INTRODUCTION

It is quite common for construction projects to be developed under a permanent fight to keep up with schedule and in many cases to accelerate schedule. However, the planning and scheduling practices are usually inadequate to deal with the uncertainties that affect the production system. In many cases the uncertainties are hidden within the system and the management of the schedule becomes contaminated by urgent requirements, for instance, the sequence of activities is chosen without a comprehensive analysis and usually depends on what resources are available first. Similarly, activities that are in sequence are started as soon as the previous activity starts, trying to accelerate the schedule, without consideration of how the uncertainties of the activities upstream could affect productivity of downstream activities.

The lack of empirical data and the absence of means to analyze and demonstrate the detrimental effect of these and other common practices make it very difficult to promote changes and to specify exactly which changes should be made. Under these circumstances, some management games used for training purposes have become a very useful tool to convey new production management concepts and to demonstrate the impact of several aspects of production (Howell 1998, Tommelein et al. 1999, Newbold 1998).

A recent paper by Tommelein, Riley, and Howell (Tommelein et al. 1999) provides an interesting discussion on the theoretical aspects of a game called the "Dice Game". This game can be used to demonstrate the impact of work flow variability on the performance of construction trades and their successors. The paper also provides simulations results that illustrate the impact of uncertainties on buffers (intermediate inventories) and project duration, following closely the rules of the game. A different game, also called "Dice Game," is used by Newbold (1998) to analyze the relationship between balanced and unbalanced capacity of a production system and intermediate inventories, in a multiple project environment. This game is also used to explore the relationship between protective capacity (time or inventory buffers) and the amount of work in progress in the production system. The value of these games is that they use very simple production models, that are easy to understand and without black boxes, in this way the users can associate these games with real life situations and draw their own conclusions from the outcomes of the games.

This paper is an attempt to extend the use of these simple models one step further by developing simulation models that allow further exploration of lean production concepts. The "Dice Game" (Howell 1998, Tommelein et al. 1999) is used to demonstrate the value of the proposed approach. However, the focus of the paper is not on the original game itself but on the use of simulation to evaluate production strategies (decisions) such as buffering (protective buffers), production capacity and uncertainty reduction. The simulation models are used to predict the impact of such strategies on project cost and schedule. The authors believe that this approach can be used to further enhance the exploration of lean production concepts by participants of a training session. If appropriate models are developed, they could also be used as a first approximation to more serious exploration of production strategies for particular projects. For instance, a customized model can be used to explore size and location of schedule buffers or can be used to determine how much should be invested in increasing production capacity or reducing uncertainty in a project production system.

DICE GAME

This game was inspired by Goldratt's "boy-scout hike" (Goldratt and Cox 1986) and it has been used by Howell and Ballard (Howell 1998, Ballard 1999) to demonstrate the impact of uncertainty in the production rate of a simple project in a classroom environment. This game has been further studied and documented by (Tommelein et al. 1998). The project comprises four to six activities that are in sequence with finish to start restrictions. The activities have all the same production rate, with an associated degree of uncertainty. The uncertainty in the production rates is represented by the roll of a die that has only two values in its faces, representing the variability in the production rate. For instance, in the example used in this paper the average production rate is 5, therefore, the die can have the following values in its faces: 5-5, 6-4, 7-3, 8-2, 9-1, 10-0. All the dice will yield an expected production rate of 5 but with different variability. To play the game, the participants in the training session are organized in teams of a size equal to the number of activities. Each team is assigned a different production variability (type of dice) trying to have at least one team for each type of variability.

The game consists in carrying out a project that comprise 100 production units; coins, beans, or other objects can represent the units. Each member of a team represents one activity and he/she will be responsibly for "managing" the productivity of that activity. At the beginning of the game the 100 units will be stored next to member of the team representing the first activity in the sequence, as shown in Figure 1. The first member of the team will roll the die and will pass the number of units obtained from the experiment to the storage next to the following activity in the sequence. The following member of the team will roll the die and will pass on to the next activity the minimum between the number of units indicated by the die and the units available in storage from the previous activity. The same procedure is applied in each step for the subsequent activities, and the members of the team repeat it in turns until all the units are passed through the final activity. This indicates the completion of the project.

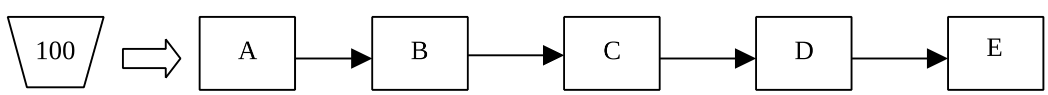

Figure 1: Sequence of Activities for the Project

During the game each member of the team will keep a record of the productivity obtained in each step by drawing the progress for the assigned activity in a "Line of Balance" type of graph (see Figure 2). The final drawings show the complete record of the project and allow comparison of different characteristics of the project such us productivity rates, completion dates, interference between activities, etc. for the different variabilities. The game is played with an initial time buffer (X1) of one unit among subsequent activities, this initial buffer size is kept constant over the game. In general, the game demonstrates how variability affects the production rates and can slow down the general productivity of the project, a point can be made that in many cases it could be better to focus on reduction of uncertainty rather than on increasing production rates.

SIMULATION MODEL

The simulation model used for this game was developed using @RISK (1997), software designed to perform risk analysis using spreadsheets. The value of this tool is that it is simple and easy to understand and the simulation is performed in a spreadsheet environment familiar to most people. @RISK allows the addition of uncertainties in a spreadsheet by replacing some input by probability distributions from a large number of options. In this case the production rates for each activity were replaced by triangular distributions with base X2, as shown in Figure 2. Even though this distribution is different from the one obtained from the game, it was chosen because it is simple and intuitively appealing to represent production rate variability in a project situation.

X2 is the parameter that represents the amount of variability for each production rate and it varies between 0 and 10, being 10 the largest variability. The expected production rate is 5 for all the cases. Another variable X1 represents the initial buffer size between activities, this is a restriction applied only at the beginning of the activities. One activity cannot start until at least X1 units are available for processing from the precedent activity.

The simulation collected data for values of X2 between 0 and 10 and for buffer sizes between 0 and 15. The data was analyzed for increased number of simulations until statistically significant results were obtained. In general, the results shown in this paper were computed for 3000 iterations for each value of X2. Several types of analyses were performed and are presented in the following sections.

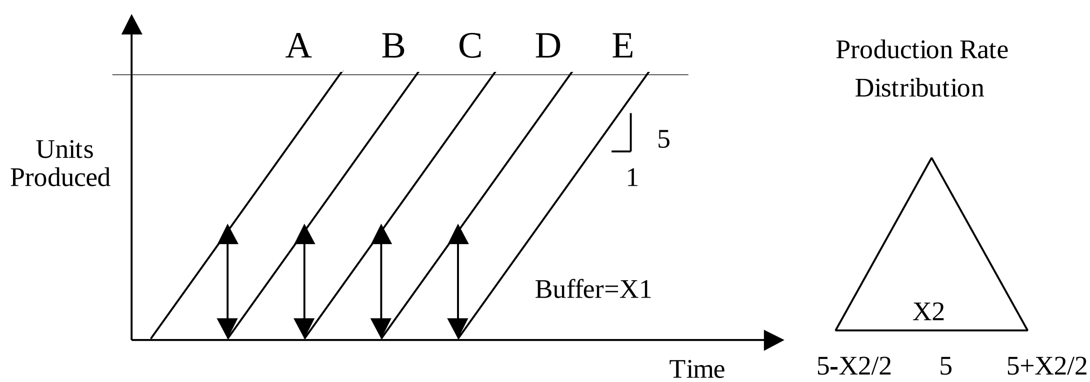

Figure 2: General Characteristics of the Model

COST MODEL

A cost model was also developed in order to analyze the impact of different conditions on project cost. The model described below considers only a combination of Direct and Indirect

Costs, other components such as rewards or penalties for timely completion or other costs could be easily added for specific projects.

$$C = DC + IC$$

C = Cost
DC = Direct Cost
IC = Indirect Cost

$$DC = \Sigma\, P_i * T_i \qquad i = A, B, C, D, E$$

P_i **=** Cost/day for activity i ($10,000/day)

T_i **=** Duration for activity i

$$IC = a + b * TD$$

TD = Total Project Duration
a = constant value ($100,000)
b = constant value ($10,000/day)

(*) Values between parentheses indicate the values used in the analysis

The values of the constants were selected arbitrarily to obtain Indirect Costs of approximate 30% of Project Cost. These values or their proportion can change depending on the particular project; therefore they are used here only for illustration purposes.

ANALYSIS RESULTS

IMPACT OF UNCERTAINTY ON PRODUCTIVITY

Figure 3 shows clearly how the increase in uncertainty affects the productivity of individual activities by comparing the case with no uncertainty (X2=0) with a case with high uncertainty (X2=10). These examples were obtained for a single iteration but they are useful to illustrate how and why project performance is affected by uncertainty in the production rates. In the second case the activities show a lower productivity and an irregular path of progress due to interference, waiting and delays among the individual activities. As a result, an important increase in project duration is observed. These types of situations are usually found in construction projects with linear work sequences. Several examples referred as "parade of trades" can be found in (Tommelein et al. 1999).

Some planning techniques that ignore the lack of production rate reliability can sometimes make things worse for these type of projects by developing schedules that are completely critical, from a CPM perspective. As a result, the projects end up with poor performance and the planning function becomes discredited. Some classic techniques for repetitive construction like the Line of Balance technique described by (Harris and McCaffer 1995) provide time buffers to specifically deal with uncertainties in the production process, this is a way of loosening dependencies between subsequent activities to allow them to develop their individual production rate.

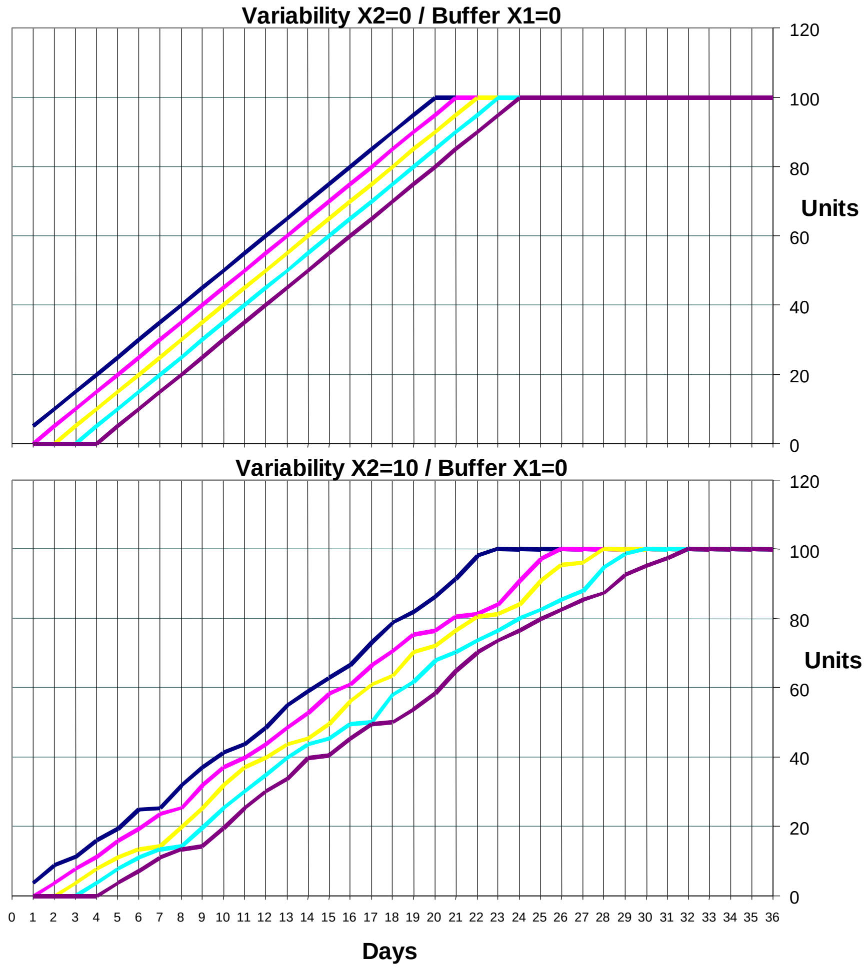

Figure 3: Progress Records for a Project with and without Production Uncertainty

Ballard and Howell have proposed the use of schedule buffers between production processes as a way to shield production from upstream uncertainty (Ballard and Howell 1997, 1998). They suggest that schedule buffers should be located and sized by assessing project uncertainty and the quantitative relationship between buffers and the uncertainty they are intended to buffer. A variable schedule buffer (X1) is introduced in the analyses that follow as a way to explore such a relationship. Figure 4 shows how project duration increases steadily with increases in production variability; this is a generalization of the case shown in Figure 3 for single iterations. The values shown are expected values for different combinations of buffer size (X1) and variability (X2); these values were computed for 3000 iterations for each value of X2. The figure also shows how projects using larger buffer sizes are less sensitive to changes in production variability. In particular, projects with buffer size X1=10 show little increase in project duration after an initial increase when going from a situation with no variability (X2=0) to one with slight variability (X2=1). This situation illustrates the protective action of the buffer on the project schedule.

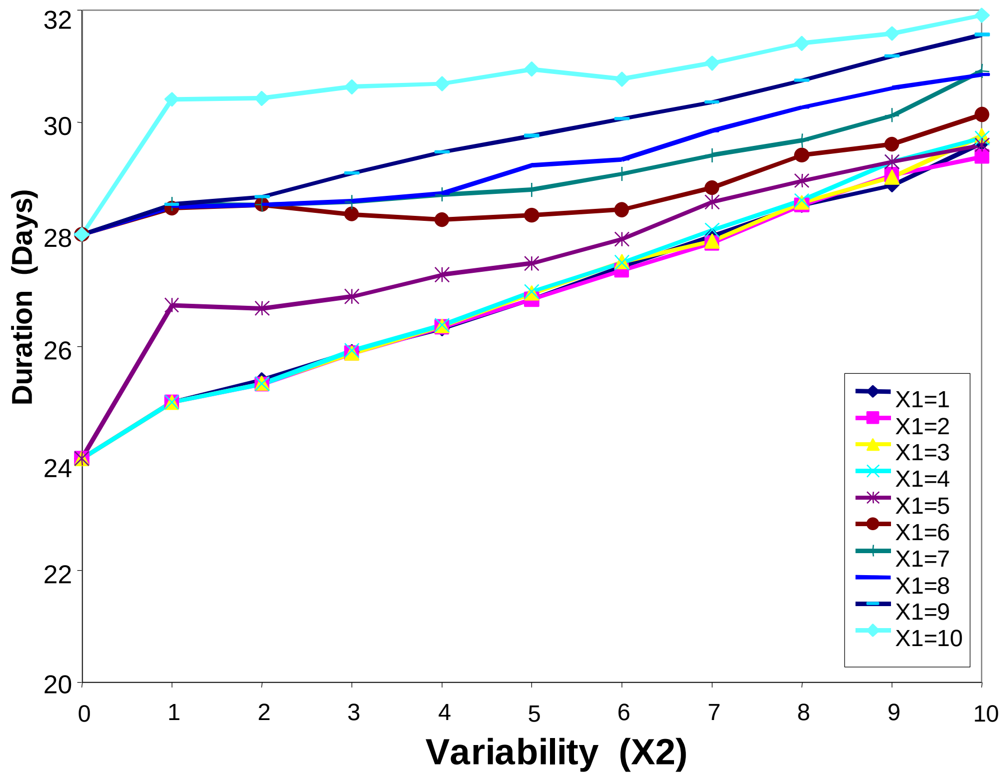

Figure 4: Duration vs. Variability for Different Buffer Sizes (X1)

Figure 5 shows the results from a different perspective, it shows how increased buffer size can affect project duration. For buffer sizes below 5 the buffer size has no impact on project duration for the case with no variability, this result is expected because in those cases the time buffer of one day is equivalent to a buffer size of 5 units (production is 5 units/day). For other cases, the results show that the increase in duration due to an increase in buffer size becomes less significant for projects with larger variability. Even though activities may start earlier in projects with small buffer size, they probably are affected by lower production rates due to interference and impacts from other trades as a result of high production variability.

Another interesting observation is that for a small buffer size project duration is strongly impacted by changes in variability. Note that the range of expected duration is very spread on the left-hand side of Figure 5. On the other hand, for larger buffer sizes the range of expected duration of the project remain within a narrow range. Figure 6 further reinforces this observation showing that for a project with a large buffer there is little increase in project duration when the variability increases.

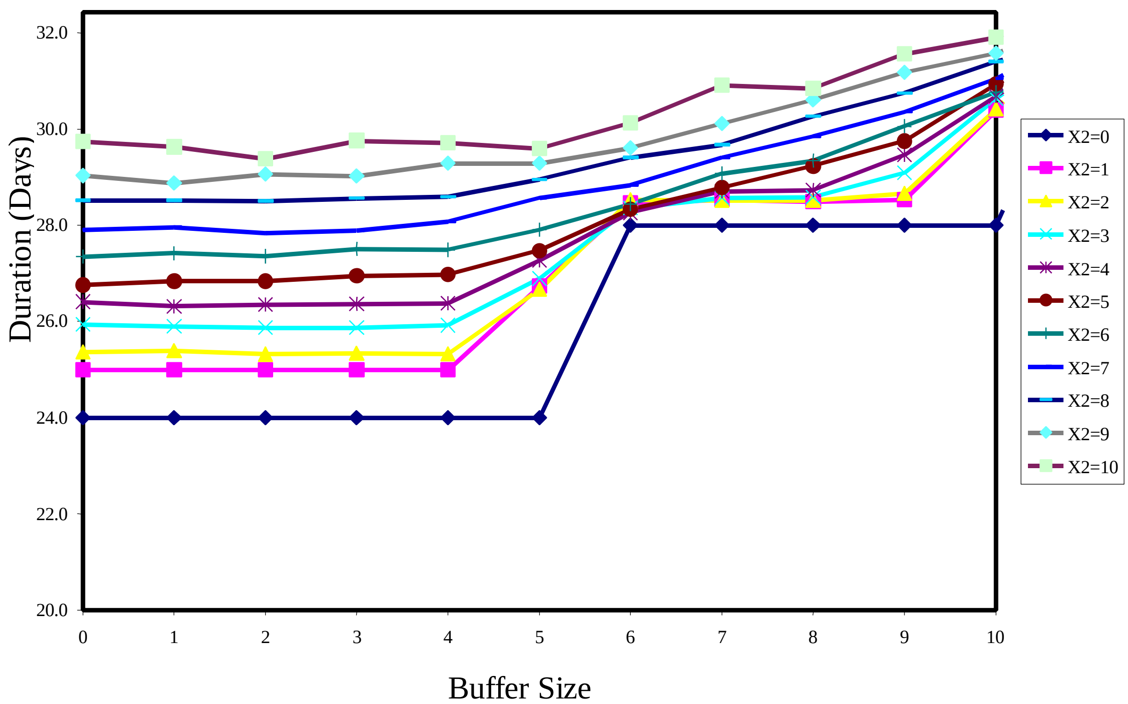

Figure 5: Duration vs. Buffer Size (For Different Variability (X2))

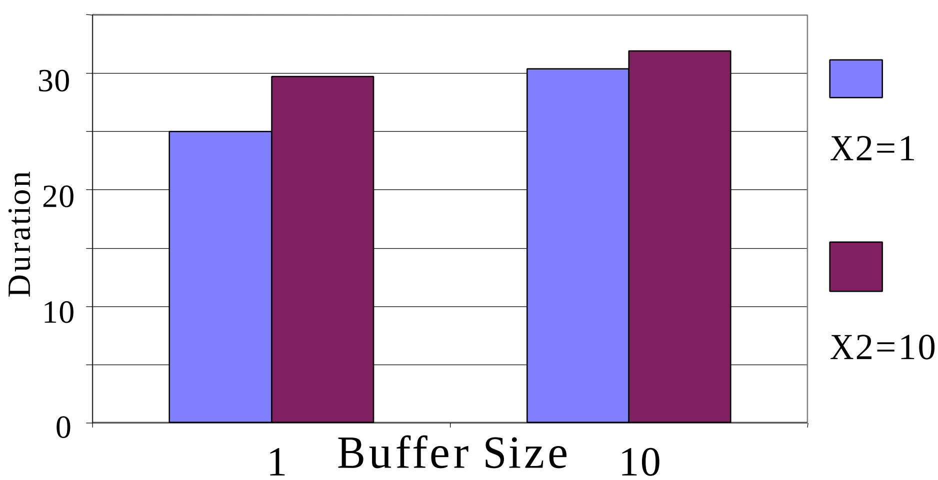

Figure 6: Buffering Effects for Different Variability

These observations illustrate how buffers can help to reduce the uncertainty of project schedule paying only a small price in scheduled time when production rate variability is high. The impact of the resulting increased productivity in individual trades is analyzed in the following section.

COST EFFECTIVE STRATEGIES

The introduction of a cost model allows the extension of the analysis to capture the impact on cost of the changes in productivity and project schedule. Figure 7 shows the Project Costs for different combinations of variability and buffer size. A preliminary observation is that variability can significantly increase project costs, this is particularly important for projects with small buffer size (X1<5) that in the figure show increases of approximately 15-17% when X2 increases from 0 to 10. This is due to a reduction in productivity of the individual activities, due to the lack of protection against variability in production rates. In a real project situation this effect could be higher because uncertainties come from different sources, not only production rates.

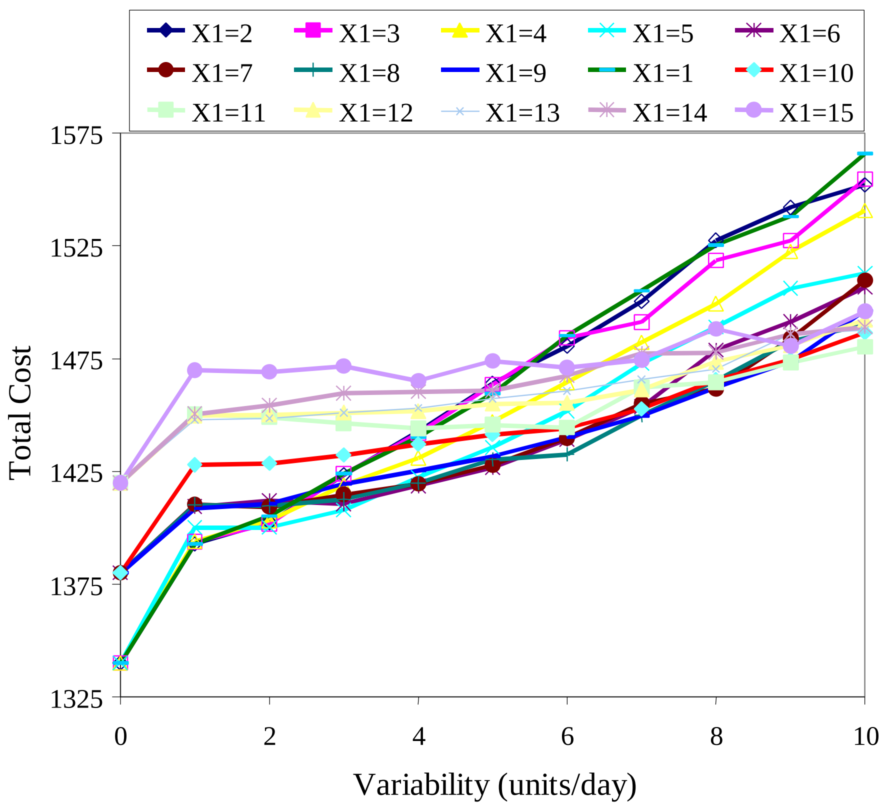

Figure 7: Project Cost vs. Variability (X2) for Different Buffer Size (X1)

Projects with large buffer size are more expensive for small variabilities but their costs are also less sensitive to increases in variability. For instance, for buffer size X1 > 10, the increase in project cost is less than 5 % when X2 increases from 0 to 10. With further analysis of the figure it becomes clear that strategies with smaller buffer sizes, between 0 and 4, are cost effective only for cases with low variability. They obtain the expected minimum cost only for values of X2 < 3. For projects with variability values of X2 > 4, the expected minimum cost is obtained for increased buffer sizes. For instance, for a value of X2 = 9 the minimum cost is obtained for a buffer size X1=11.

Figure 8 further explores this relationship between minimum expected cost and buffer size. It summarizes the relationship between buffer size, variability and minimum cost. The values were obtained for 3000 simulations for each value of X2. It shows in the Y axe the values of buffer size that result in minimum expected cost for the different values of variability under consideration. It shows a clear trend that indicates that buffer size should be directly related to production variability in order to obtain a minimum cost production strategy. The line trend in the figure is approximately X1=X2+1, indicating the buffer size should be larger than the variability parameter X2. This type of analysis could be helpful in project situation to locate and size schedule buffers as suggested by Ballard and Howell (1997).

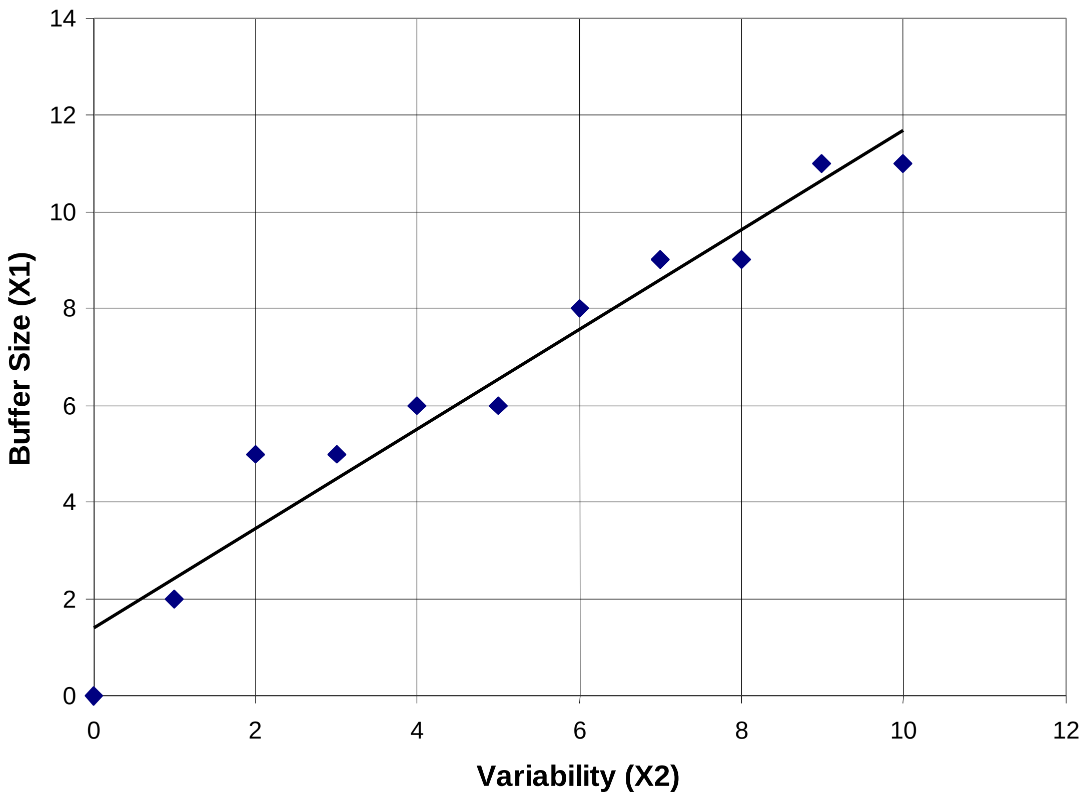

Figure 8: Buffer Size for Minimum Expected Cost

CONCLUSIONS

This implementation extends the educational value of a management game through the analytical power of simulation but maintaining the simplicity of the models and the simulation environment. This paper has shown how a simple production model, implemented in a simulation model, can be used to explore lean production strategies.

This approach can be used to further enhance the exploration of lean production concepts by participants of a training session or as a first approximation to more serious exploration of production strategies. Strategies, such as buffering, can be explored regarding the size and location of protective buffers. Other strategies like the Last Planner methodology, suggested by Ballard and Howell (1998) to improve reliability in the work plans, could be shown to be cost effective to convince a doubtful project manager to invest time and money in its implementation. The models can be also used to explore investment decisions in production capacity increase or in reducing production rates uncertainty. The paper provides a preliminary example of this approach, the authors believe that the model can be extended to explore other concepts and practical issues.

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