PARADE GAME:
IMPACT OF WORK FLOW VARIABILITY ON SUCCEEDING TRADE PERFORMANCE

Iris D. Tommelein[1], **David Riley**[2], **and Greg A. Howell**[3]

ABSTRACT

The Parade Game illustrates what impact work-flow variability has on the performance of construction trades and their successors. The game consists of simulating a construction process in which resources produced by one trade are prerequisite to starting work by the next trade. Production-level detail, describing resources being passed from one trade to the next, illustrates that throughput will be reduced, project completion delayed, and waste increased by variations in flow. The game shows that it is possible to reduce waste and shorten project duration by improving the reliability of work flow between trades. Basic production management concepts are thus applied to construction management. They highlight one of the shortcomings of using CPM for field-level planning, which is that CPM does not explicitly represent reliability. The Parade Game can be played in a classroom setting either by hand or using a computer. Computer simulation enables students to experiment with numerous alternatives in order to sharpen their intuition regarding variability, process throughput, buffers, productivity, and crew sizing. Managers interested in schedule compression will benefit from understanding work-flow variability's impact on succeeding trade performance.

KEY WORDS

Productivity improvement, contractor coordination, reliability, performance, lean construction, discrete-event simulation, specialty contracting, project management, production management, process modeling.

---

[1] Associate Professor, Civil and Envir. Engrg. Department, 215-A McLaughlin Hall, Univ. of California, Berkeley, CA 94720-1712, 510/643-8678, FAX 510/643-8919, tommelein@ce.berkeley.edu

[2] Assistant Professor, Dept. of Constr. Mgmt., 116 Architecture Hall, College of Architecture, Univ. of Washington, Seattle, WA, 98195-1610, 206/616-1917, FAX 206/685-1976, driley@u.washington.edu.

[3] Adjunct Professor at Boise State and Virginia Tech. and Executive Director of the Lean Construction Institute, mail: Box 1003, Ketchum, ID 83340 ghowell@micron.net

INTRODUCTION

Lean thinking recognizes variability and the devastating impact it has on the continuous flow of work and the resulting throughput of a system. Accordingly, one of its tenets is to synchronize and physically align all steps in the production process, so there is little wait time for people or machines, and virtually no staging of materials or partially completed products (Womack and Jones 1996). This sounds straightforward enough, except that few people have good intuitive understanding of how variability really affects the flow of work.

Work flow can be characterized in different ways. In manufacturing, it is defined by stationary machines with partially completed products being transported from one to the next. In construction, the products being built tend to be stationary, whereas crews of various trades move from location to location and complete work that is prerequisite to starting work by the following crew. There are obvious similarities and differences between manufacturing and construction, as many have argued before. Nonetheless both can be viewed as production systems including processing stations (machines or crews) and hand-offs of partially completed work. Production principles developed for manufacturing systems will therefore also apply to construction.

In order to enhance intuitive understanding of the impact variability has on work flow, we describe the simplest of all production systems, namely a single line of processing stations where products output by one are input required by the next one. Building construction practice reveals the existence of many such single-line production systems, termed ‘parades of trades.’ Better understanding of these systems can be gained by means of simulation games, to be played manually or using a computer. Such games reveal the general lack of project management understanding and the absence of tools for managing the parade.

PARADE OF TRADES IN BUILDING CONSTRUCTION PRACTICE

Building construction involves a large number of specialty trades that generally work their way in succession of one another floor by floor. Specialty trades typically work as subcontractors to the general contractor and may include those responsible for the building’s foundation, steel erection, decking, form work, concrete reinforcing bars, concrete, drywall, mechanical, electrical, plumbing, roofing, glazing, vertical transportation systems, fire and sprinkler systems, environmental controls, to name but a few. Gus Sestrup, superintendent with Turner Construction, says these contractors’ work sequences are being performed as a ‘parade of trades.’ Example parades are (Riley 1997):

- **Structural Parade:** e.g., erecting structural steel (steel erector); placing and securing decking as well as welding shear studs (decking contractor); and placing rebar, then pouring and finishing concrete (concrete contractor).
- **Overhead Work Parade:** e.g., installing HVAC system (mechanical contractor), sprinkler system (fire protection contractor), emergency lighting (electrical contractor) and pipe (plumbing contractor) (Riley and Sanvido 1997).
- **Interior Finishes Parade:** e.g., installing wall studs, routing electrical conduit, placing insulation materials, hanging drywall, painting.

- **Perimeter Enclosure Parade:** e.g., building perimeter walls, placing windows, installing flashing and applying sealants.

Gravity-supported systems, typified by the structural parade, tend to follow a strict sequence. It is also preferable to install gravity plumbing systems and HVAC duct before pressured piping systems with hot and cold water, in turn followed by electrical conduit. Of course, if installation of one system blocks access for installation of another, then the latter system should go in first. Sequencing tends to be more important in highly congested areas and less so in areas with easy access. Access, enclosure, support, etc. all are important determinants of precedence (Gray 1986). Similarly, reciprocal dependencies must be identified early as they may force one trade to perform only a portion of their work, then leave and return when subsequent trades have completed prerequisite work (Riley and Sanvido 1997).

When assigning work to crews, it is also important to recognize the extent to which the concentration of work varies by trade throughout the building. If a preceding trade enters an area with a lot of work specific to their trade, thereby taking a longer time to complete than the moving parade can tolerate, successors may have to get out of line and perform out-of-sequence work elsewhere. Relocation takes extra time, but it may prevent them from becoming idle altogether. Out-of-sequence installation for one does not necessarily impede other trades' work.

Finally, different parades move through a building in different directions. Riley distinguished work area, prefabrication area, storage area, and product-space patterns to characterize the space behavior of various trades (Riley and Sanvido 1995). This crisscrossing of parades makes managing them an even bigger challenge.

The existence of parades of trades is widely recognized—though probably not under this name—by superintendents who coordinate the work of specialty contractors. Construction work is often scheduled accordingly. However, to expedite project completion, general contractors may compress the project schedule and force succeeding trades to follow on their predecessor's heels. This may jeopardize the succeeding trades' ability to perform—especially when that predecessor's performance is unreliable, that is, when output varies considerably from one day to the next, and when this output is prerequisite to the work done by the successor. To enable the parade to expedite job completion and minimize waste (in terms of crew idle time or remobilization effort), it is essential that work be released reliably between the trades.

The rate of progress of an activity is often quoted by means of a single number, e.g., "We plan to erect 80 steel components per day." Even though all trades may plan to proceed at the same pace, each trade's production rate alone is insufficient to gauge the speed of the parade as a whole. The single number only represents an average and the actual production rate will vary with some standard deviation, e.g., due to variation in weight and size of components, ease of reach and access to their final installation location, fabrication and erection tolerances, etc. This standard deviation represents what we here term 'variability.' No variability means production is 'reliable.' The Parade Game illustrates the impact variability has on the production rates of trades that succeed one another in a linear sequence.

UNDERLYING THEORETICAL ISSUES

Determining which parades are best suited where and when so that the project can be completed expediently is a production management task. It is typically handled by construction superintendents. Nonetheless, while they may be effective at managing the parade, regrettably, their goal is not necessarily to achieve optimal crew productivity for all trades involved.

In addition to superintendents, project managers also need to understand the complexity of this production task together with its various performance characteristics, so that they will impose reasonable demands when selecting and managing those performing the work and recognize the real culprit when problems occur. Project management training, however, tends to focus on managing contracts and projects, not on managing production. Consequently, managers often end up imposing unrealistic expectations on the production process or fail to manage it altogether (Tommelein and Ballard 1997).

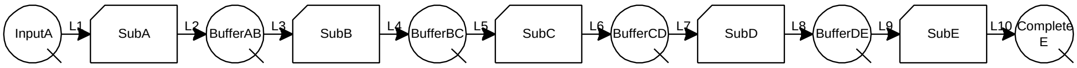
Project management schedules that use the critical-path method (CPM) describe activities with their durations and precedence relationships. The finish-to-start relationship is most often used though it assumes sequential finality, i.e., predecessors must be 100% complete before their successors can start. This assumption certainly does not hold in the parade of trades where regular hand-offs exist between trades and, once the parade has started, all trades have to move in sync for the parade to progress at a steady pace. Other production variables and performance characteristics must therefore be defined to describe the parade of trades. They are defined as follows:

- **Production Capacity:** number of trade-specific work units per unit of time a crew is technically able finish provided their work is unconstrained (i.e., directives, materials, tools, equipment, crew, work space, and prerequisite work are available as needed);
- **Production Rate:** actual number of trade-specific work units per unit of time a crew is able finish given constraints on their work (e.g., lack of prerequisite work completed, non-availability of materials, or impeded work space);
- **Buffer**: work units accumulated ahead of a crew, from which they can draw to perform work.
- **Wasted Time:** time during which crew is not able to realize its production capacity due to constraints that hamper their work;
- **Project Duration:** time it takes from start to completion of a project;
- **Throughput:** number of work units completed divided by the project duration.

PLAYING THE PARADE GAME

The game that is presented in this paper was inspired by Goldratt's' "boy-scout hike" (Goldratt and Cox 1986). By analogy, Greg Howell created a game to be played by construction students in a classroom situation. The game can involve any number of players. The game coordinator will split up large groups in teams of equal size, e.g., of 5 players each. Each team forms a 'parade of trades' with players lining up in sequence. Players are represented by the symbols labeled SubA through SubE in Figure 1. Each team is given a pile of 100 bolts (or any other kind of widget) and their task is to pass them all from the front of the line (the input buffer, InputA) to the end (the output buffer, CompleteE). When this has been accomplished, the project is completed.

Figure 1: Parade of Trades Line-up



Each player in line can pass only a limited number of bolts from one side to the other, e.g., SubA will move them from InputA to Buffer AB. The number moved is determined by rolling a die. At the onset of the game, the coordinator will hand each player one of five possible dies, A, B, C, D, or E. After a player has rolled her die and passed the appropriate number of bolts, she must wait until the player downstream from her in turn has rolled her die and taken bolts from the buffer in-between them, before she may replenish this buffer.

The coordinator can introduce various degrees of variability in the game by writing made-up numbers on each face of each die. This is done prior to handing dice to players. A normal die has faces with values 1, 2, 3, 4, 5, and 6 and therefore an average roll of 3.5. We suggest that the game be played with several different dice as described in Table 1, each however having an average roll of 5. From an 'average production' viewpoint, the dice are therefore identical. When variability is considered, they clearly are not.

Table 2: Variability of Available Dies

Type of Die	Numbers on Faces
A	5, 5, 5, 5, 5, 5
B	4, 4, 4, 6, 6, 6
C	3, 3, 3, 7, 7, 7
D	2, 2, 2, 8, 8, 8
E	1, 1, 1, 9, 9, 9

Instead of allowing each player to choose their own die, the coordinator may wish to equip all players in one team with dice of type A (all-5), another team with dice of type C (3-7 dice) and yet another one with dice of type E (1-9 dice), etc.

Each time a player rolls her die, she should record (1) the number rolled and (2) the number of bolts she was able to draw from the buffer upstream from her. If the upstream buffer is smaller than the number rolled, that smaller number is the number of bolts passed along. When all 100 bolts have been passed to the end of the line, the team has completed its task. Each player then calculates (3) the average of the numbers written on her die, (4) the number of times she rolled a die, (5) the total of all numbers she rolled, (6) the average number she rolled by dividing (5) by (4), (7) the average number of bolts passed along by dividing 100 by (4). The team's project completion time is equal to the number of rolls of the last player in the line plus the total number of players minus one.

ITEMS FOR GROUP DISCUSSION

When all teams have completed their project, the groups should discuss their findings. Some issues to inquire about are:

- Which team completed their project in the shortest amount of time? Could this have been anticipated, given the dice provided to them?

- How come the number in (2) may be less than that of (1)?
  This will be the case when the player upstream rolled a low number and was unable to provide much of a supply. The person downstream then is said to 'starve' due to lack of resources. Similarly, when the player upstream rolls a large number and the player downstream a small one, bolts will accumulate in a buffer between them.
- What is the relationship between (7) the average number passed along and (3) the average of numbers written on the die? How do these numbers compare for the various players relative to their position in the production line?
- What is the relationship between (6) the average number rolled and (3) the average of numbers written on the die?
- If you wanted to be certain to get the project done in 24 time units, what dice would you give to the team?
- Which team may have a chance of getting the project done in less than 20 time units?
- What does it mean when (7) the average number passed along is smaller than (6) the average number rolled? What would you do if you were a subcontractor facing this situation?
- If a team is playing with dice that have a variability plus and minus four relative to their average roll, how can one increase the likelihood that the team will complete its project in as much time as the all-5 team? That is, how can one make an unreliable team speed up?

COMPUTER SIMULATION OF PARADE OF TRADES

The parade game can be played with any type of die. For illustrative purposes, a few combinations were investigated further using computer simulation. Four alternatives are depicted in Figures 2, 3, 4, and 5. In Figure 2, all players have an all-5 die. In Figure 3, all players have a 3-7 die. In Figure 4, all players have a 1-9 die. Finally, in Figure 5, all players have a 'faster' die, with an average roll of 7 instead of 5. Each figure in this first set illustrates what the outcome may be of playing the game once. Of course, given the randomness in the outcome of the die at each roll, the plots will look different at each repetition of the game.

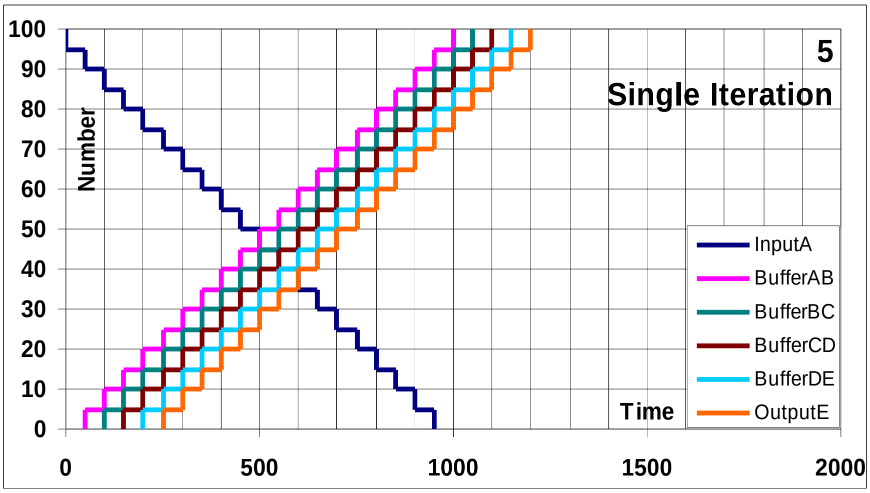


Figure 2: Output from Single-iteration Simulation where all Players have Die A (all 5)

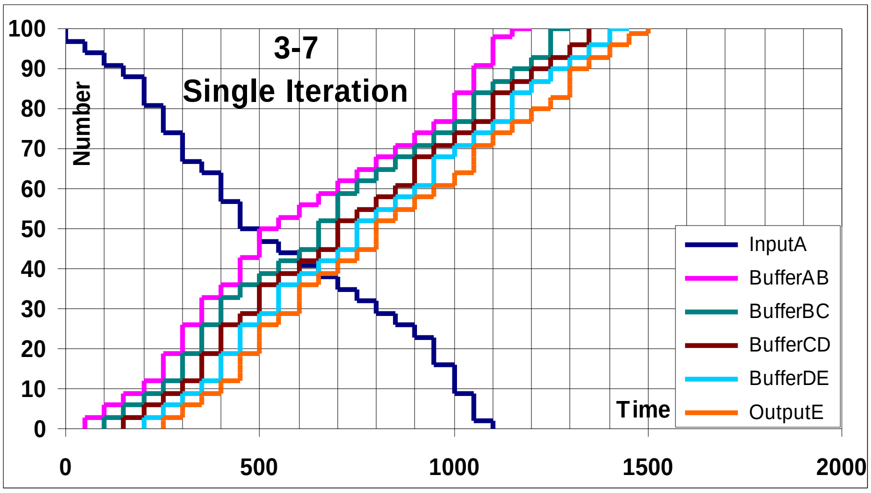


Figure 3: Output from Single-iteration Simulation where all Players have Die C (3-7)

After comparing these plots, the reader can draw their own conclusions regarding the impact of variability on succeeding trade performance, and especially on project completion and system throughput. Additional system characteristics for each of these models are given in Table 2. Actual throws realized are always less than or equal to the actual throw average. This means the subcontractor is wasting time because the maximum production capacity cannot be achieved.

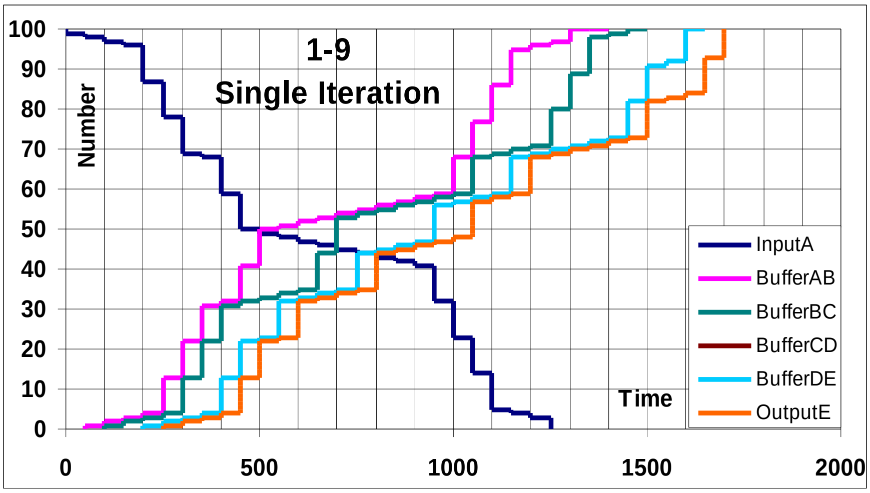


Figure 4: Output from Single-iteration Simulation where all Players have Die E (1-9)

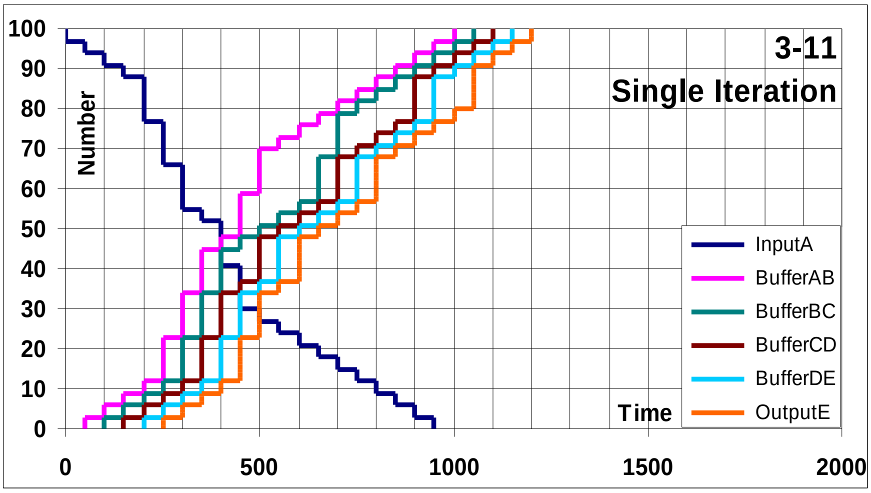


Figure 5: Output from Single-iteration Simulation where all Players have Die with Increased Average Roll (3-11)

The next set of figures illustrates average value plus-and-minus one standard deviation, calculated after the games have been played 1,000 times (it takes the computer only a few minutes to do this!). Figures 6, 7, and 8 plot the percent complete vs. time, whereas figures 9, 10, and 11 plot the buffer size vs. time.

It is clear that playing with dice with increasing variability increases the chance of finishing early, but also that of finishing late! Note that the slopes of the average percent complete diminishes in each model. Unfortunately, those further down the line are subjected to the variability in output provided by those upstream from them. The slope also decreases from one model to the next when variability increases. Lower slopes mean lower production rates and thus wasted capacity. With increased variability, intermediate buffers (work in progress) also grow larger.

Table 2: Output Values for Single-iteration Simulations

Activity	First Start	Last Start	Actual Number of Throws	Average Actual Throw	Avg. Actual Throw Realized
All 5					
SubA	0	950	20	5	= actual
SubB	50	1000	20	5	= actual
SubC	100	1050	20	5	= actual
SubD	150	1100	20	5	= actual
SubE	200	1150	20	5	= actual
Project Complete		1200			
1-7					
SubA	0	1100	23	4.57	4.35 (+)
SubB	50	1200	24	4.33	4.17
SubC	100	1300	25	5.08	4.00
SubD	150	1350	25	6.02	4.00
SubE	200	1450	26	5.46	3.85
Project Complete		1500			
1-9					
SubA	0	1250	26	4.08	3.85
SubB	50	1400	28	3.86	3.57
SubC	100	1500	29	5.14	3.45
SubD	150	1550	29	6.79	3.45
SubE	200	1650	30	6.60	3.33
Project Complete		1700			
3-11					
SubA	0	950	20	5.40	5.00 (*)
SubB	50	1000	20	5.80	5.00
SubC	100	1050	20	7.80	5.00
SubD	150	1100	20	9.40	5.00
SubE	200	1150	20	8.60	5.00
Project Complete		1200			

(+) Even the first person in line may have an average actual throw realized less than its average actual throw, because starvation may occur when the input buffer is near depletion.

(*) It was just by coincidence that this iteration yielded a 5 for the actual throw realized. These 5 bolts, which are passed along by the first person in line, get passed along downstream as well, as each station has excess capacity: the actual throw average is larger than the buffer size ahead.

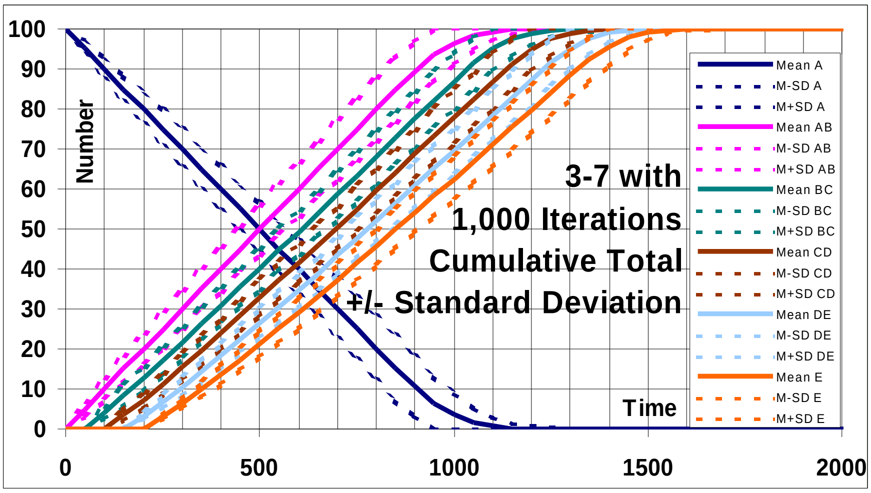


Figure 6: Output from 1,000-iteration Simulation where all Players have Die C (3-7)

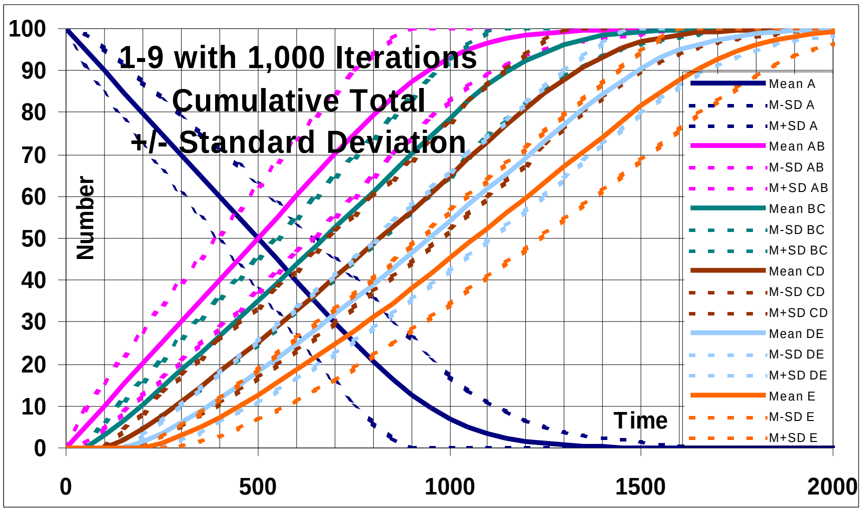


Figure 7: Output from 1,000-iteration Simulation where all Players have Die E (1-9)

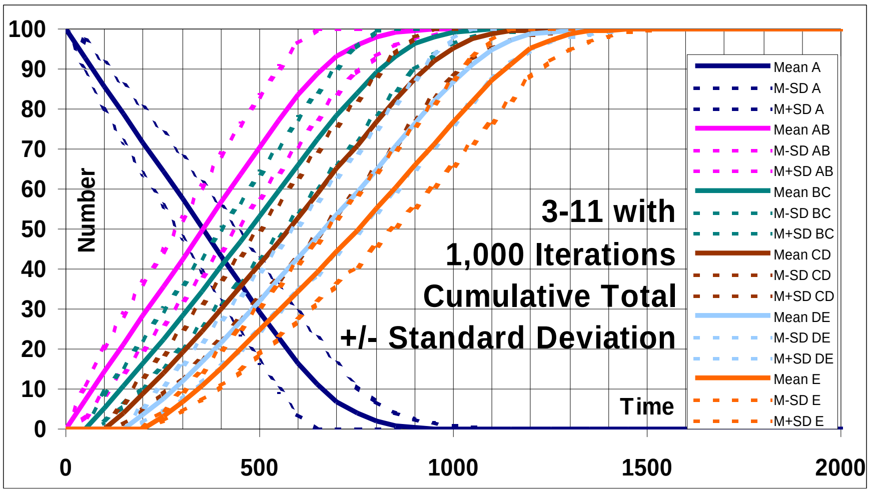


Figure 8: Output from 1,000-iteration Simulation where all Players have a fast Die (3-11)

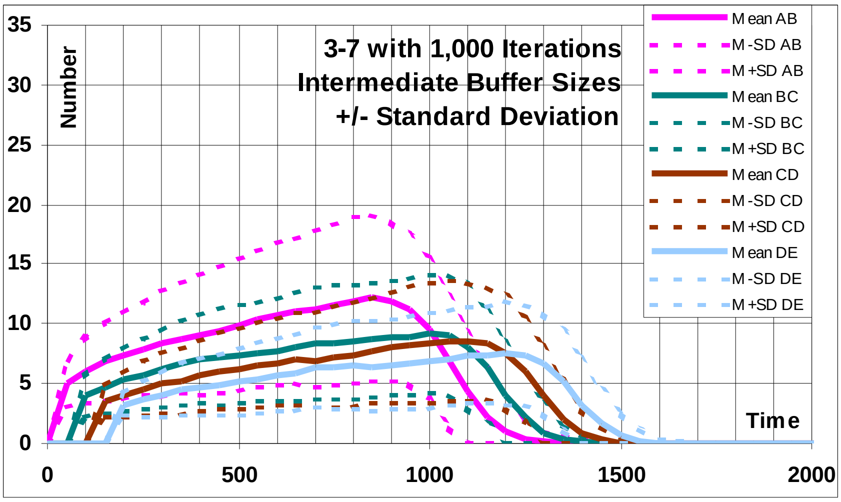


Figure 9: Buffer Size from 1,000-iteration Simulation where all Players have Die C (3-7)

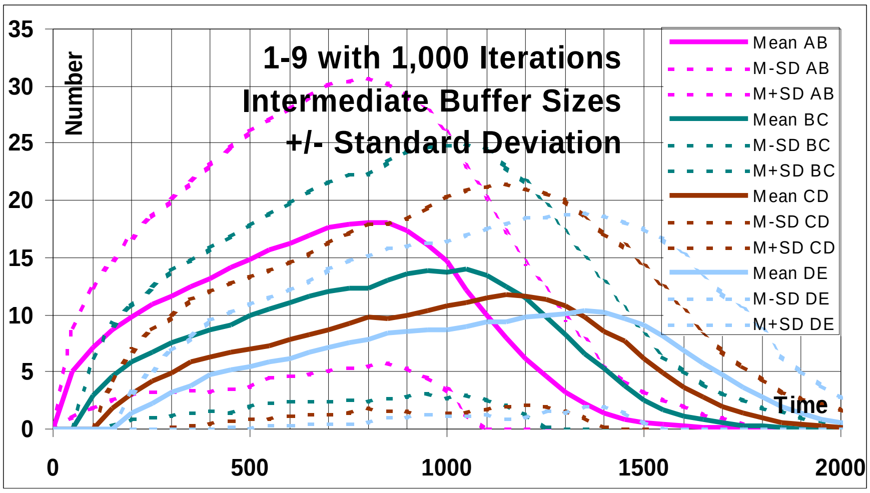


Figure 10: Buffer Size from 1,000-iteration Simulation where all Players have Die E (1-9)

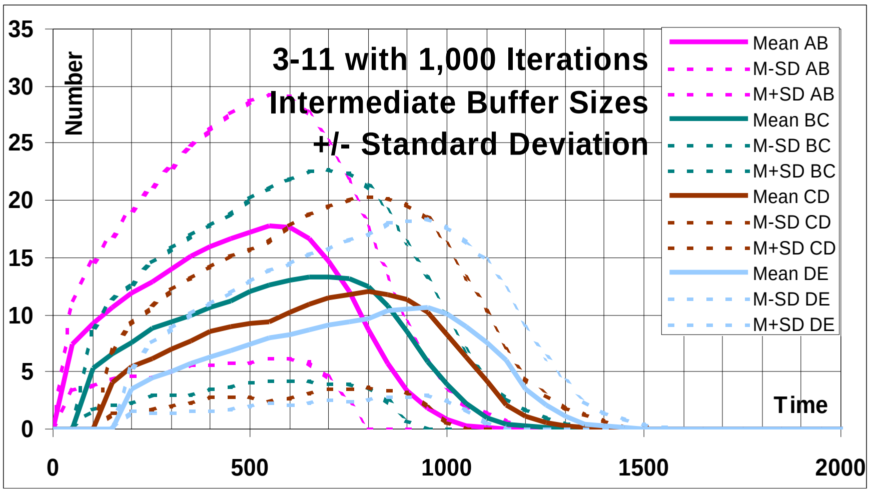


Figure 11: Buffer Size from 1,000-iteration Simulation where all Players have a fast Die (3-11)

RELATED WORK AND DISCUSSION

Computer games to help explain construction concepts were developed as early as the late 1960s (e.g., Au and Parti 1969 and Au et al. 1969). Games akin to the one presented here pertain to linear construction work, where construction progress can be represented by means of a line-of-balance or velocity chart. For instance, Harris and Evans (1977) describe a game for players to manage road construction. Their parade includes a fixed-order progression of 7 processes. The player's challenge is to step-wise control production rates and buffer sizes by deciding on the size of labor crews, rates of supply of materials, numbers of machines, and hours to be worked, while random variations affect the outcome of each step.

Worthy of mention is that Harris and Evans dictate that a minimum buffer of 1 km of roadway be maintained between processes to move resources, store equipment, and handle materials. When players attempt production within the minimum buffer, operations are said to interfere and resources are wasted. Harris and Evans also observe that 'the effect of variability in early processes is diminished successively as each process is performed, due to the imposition of the minimum buffer' (p. 414). Indeed, construction field practitioners use buffers to shield work from up-stream uncertainty (Howell et al. 1993).

The cost of repetitive-type construction certainly depends upon the way the project is executed; it is not solely a function of the measured quantity of work it contains (also noted by Harris and Evans p. 413). This is no surprise: the major task of any contractor is to determine means and methods. Nonetheless, means and methods alone are not the only drivers for production. As the Parade Game illustrates, coordination among trades is equally important. Contractors will be able to price their bids more favorably when they know that a skillful manager will coordinate their work with others on site. (e.g., Birrell 1978, 1981, 1985, Tommelein and Ballard 1997).

IMPLEMENTATION

The computer model for the Parade Game has been implemented using the STROBOSCOPE system for discrete-event simulation (Martinez 1996). The same system behavior can, of course, be shown using any other simulation engine, but STROBOSCOPE was chosen for its ability to record intermediate data, such as buffer sizes and throws. Readers interested in obtaining the STROBOSCOPE input file for the Parade of Trades may contact Iris Tommelein. Those wishing to use STROBOSCOPE for non-profit educational purposes can download it for free from http://www/strobos.ce.vt.edu/.

CONCLUSIONS

A very simple game was presented to illustrate what impact variability has on work flow in a single-line production system. The game does not require many resources to be played (e.g., a cut-up 2-by-2 piece of lumber makes for easy-to-see, large dice) but it does allow the players to develop a better, intuitive understanding of several fundamental production concepts, including variability and throughput. It was shown that unreliable work flow results in waste: production stations cannot realize their full production capacity because they starve for resources. Managers interested in schedule compression will benefit from understanding work-flow variability's impact on succeeding trade performance.

ACKNOWLEDGMENTS

Greg Howell created the game in his role as director of the Lean Construction Institute so that he could more easily explain production concepts to construction practitioners and thereby train managers to managing work, not contracts.

The simulation work is part of Iris Tommelein's broader program of research on lean construction and new technologies for materials management. Her research is funded by grant CMS-9622308 from the National Science Foundation, whose support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

Alarcon, L. (editor)(1997). *Lean Construction*. A.A. Balkema, Rotterdam, The Netherlands, 497 pp.

Au, T. and Parti, E. (1969). "Building Construction Games—General Descriptions." ASCE, *J.Construction Division*, 95 (CO1) 1-9.

Au, T., Bostleman, R., and Parti, E. (1969). "Construction Management Game—Deterministic Model." ASCE, *J. Construction Division*, 95 (CO1) 25-38.

Birrell, G.S. (1978). *The Criteria by which Construction Prime and Subcontractors Evaluate the Management Performance of Each Other*. Vols. 1 and 2, Dissertation for Doctor of Architecture degree, Univ. of Michigan, Ann Arbor, MI, 547 pp.

Birrell, G.S. (1981). "The Informal Organization which Manages the Construction Process." *Proc. CIB W-65 3rd Symp. on Organ. and Mgmt. of Construction*, 6-8 July, Dublin, Ireland, B1.201-211.

Birrell, G.S. (1985). "General Contractor's Management: How Subs Evaluate It." ASCE, *J. of Constr. Engrg. and Mgmt.*, 111 (3) 244-259.

Goldratt, E.M. and Cox, J. (1986). *The Goal*. Croton-on-Hudson, NY: North River Press.

Gray, C. (1986). "'Intelligent' Construction and Cost Analysis." *Constr. Mgmt. and Econ.*, E&FN Spon, London, U.K., (4) 135-150.

Harris, F.C. and Evans, J.B. (1977). "Road Construction—Simulation Game for Site Managers." ASCE, *J. Construction Division*, 103 (CO3) 405-414.

Howell, G., Laufer, A., and Ballard, G. (1993). "Interaction between Subcycles: One Key to Improved Methods." *J. Constr. Engrg. and Mgmt.*, ASCE, New York, NY, 119 (4) 714-728.

Martinez, J.C. (1996). *STROBOSCOPE State and Resource Based Simulation of Construction Processes.* Ph.D. Diss., Civil & Envir. Engrg., Univ. of Michigan, Ann Arbor, MI, 518 pp. (available at http://www.strobos.ce.vt.edu/).

Riley, D. (1998). *Extracting Knowledge from the Coordination Process*. Department of Building Construction, College of Architecture, Univ. of Washington, in preparation.

Riley, D.R. and Sanvido, V.E. (1995). "Patterns of Construction-Space Use in Multistory Buildings." *J. Constr. Engrg. and Mgmt.*, ASCE, New York, NY, 121 (4) 464-473.

Riley, D. and Sanvido, V. (1997). "Space Planning for Mechanical, Electrical, Plumbing, and Fire Protection Trades in Multi-story Building Construction." in Anderson, S. (ed.) *Proc. Construction Congress V.* Minneapolis, MN, ASCE, pp. 102-109.

Schmenner, R.W. (1993). *Production/Operation Management: From the Inside Out.* Fifth edition, Prentice Hall, 825 pp.

Crichton, C. (1966). *Interdependence and Uncertainty. A Study of the Building Industry*. Tavistock Institute, Tavistock Pubs., London, U.K., 83 pp.

Tommelein, I.D. (1998). "Pull-driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique." ASCE, *J. Constr. Engrg. and Mgmt*., 124 (4) 279-288.

Tommelein, I.D. and Ballard, G. (1997). "Coordinating Specialists." *Technical Report No. 97-8*, Construction Engineering and Management Program, Civil and Environmental Engineering Department, University of California, Berkeley, CA.

Womack, J.P. and Jones, D.T. (1996). *Lean* Thinking*: Banish Waste and Create Wealth in Your Corporation.* Simon & Schuster, New York, NY, 350 pp.