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FRAMEWORK LINKING LEAN SIMULATIONS TO THEIR APPLICATIONS ON CONSTRUCTION PROJECTS

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ABSTRACT

The QUESTION this paper seeks to address is: Can the principles illustrated by Lean simulations be systematically linked to applications of those principles on actual projects? The PURPOSE of this research has been to ease the transition between theory and practice by aggregating published case studies as well as lean simulations and making links between them.

The RESEARCH METHOD adopted for this study included: (1) prepare a systematic literature review sourced from LCI and IGLC databases; (2) collaborate with the Lean Construction Institute to construct an inventory of existing lean simulations and the principles they illustrate; (3) analyze published case studies and simulations for the lean principles they embody; and (4) develop a matrix to establish logic connections between simulations and case studies from actual projects. FINDINGS were assembled onto a Simulation/Case-study matrix. This research involved locating, translating, and organizing 23 years of published, organically developed, construction case studies from IGLC and LCI databases. Therefore one LIMITATION of this this research is that it included only those simulations and case studies that have been published.

One IMPLICATION and VALUE of this research is that it offers a framework to assist lean educators and facilitators when teaching Lean Construction. This matrix can also serve as a "seed" for various international communities to extend and share how specific lean principles can be incorporated into their own cultural traditions within project delivery processes.

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KEYWORDS

Lean simulations, case studies, Lean Construction teaching, Simulation/Case-Study matrix, Lean principles

INTRODUCTION

Simulations and lean project case studies have appeared in academic publications for over two decades. Yet novices to Lean Construction (LC) have expressed frustration over an inability to make mental connections between the principles illustrated by simulations and potential applications of those principles on actual construction projects. Structured literature reviews indicate that implementation of lean principles on a construction site are often incomplete or incorrect because the workers do not have a comprehensive understanding of lean construction principles and are therefore hesitant to apply lean methods and tools (Heyl 2015).

Although several books such as *Toyota Production System: Beyond Large-Scale Production* (Ohno 1988), *The Toyota Way* (Liker 2005), *Factory Physics* (Hopp and Spearman 2008), and *Modern Construction: Lean Project Delivery and Integrated Practices* (Forbes and Ahmed 2011) have been published, a single comprehensive source does not exist that conveys a definitive interpretation of how to implement lean principles on a construction site (Tsao et al. 2012).

A typical course on Lean Construction requires accumulation of diverse publications that can facilitate a broad understanding of its application to construction contracts, design and office activities, field operations and supply chain relationships of capital projects (Tsao et al. 2012). There is a gradual shift from traditional course delivery methods that primarily emphasize textbooks as lean educators are evaluating other interactive approaches that encourage analytical thinking and conversation between students and educators (Tsao et al. 2013). A simulation can offer a better learning environment to demonstrate the impact of decisions on a process because it can be easier to understand the functionality of an actual system under real time conditions (Caňizares and Faur 1997; Walters et al.1997).

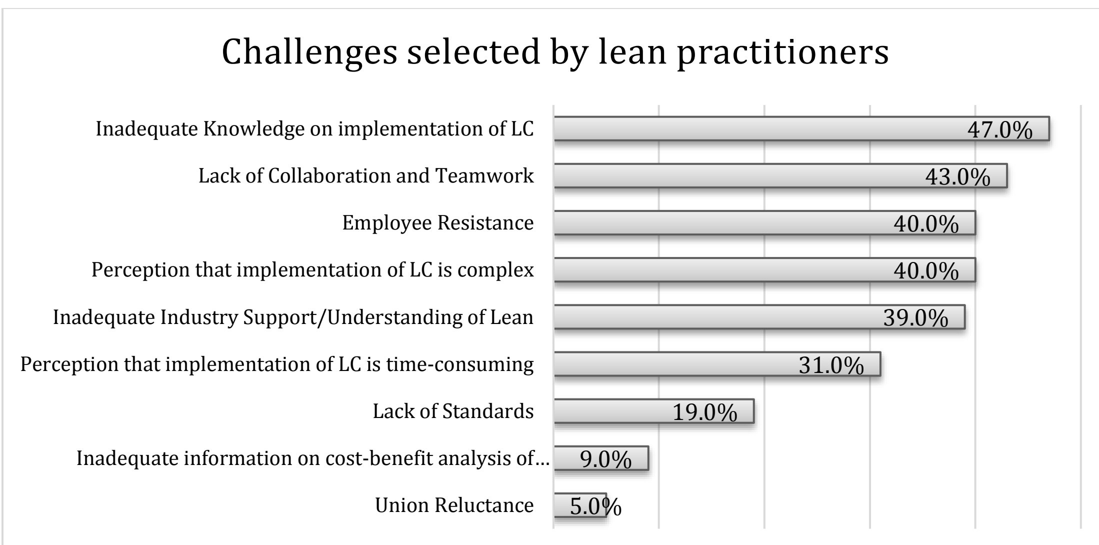
Izquierdo et al. (2011) recommended that the development of case studies is an ideal approach to impart knowledge about Lean Construction (LC) after analyzing feedback from a Basic Management Functions Workshop (BMFW). This workshop was developed to train construction industry employees in the application of LC principles in order to maximize value and minimize waste for customers.

NEED FOR A "SIMULATION-CASE STUDY" FRAMEWORK

Successful implementation of Lean Construction (LC) requires a determined approach and committed project participants (Heyl 2015; Hirota and Formoso 1998). Figure 1 shows that 47% of lean practitioners selected "inadequate knowledge on implementation of lean construction" among project stakeholders as a major challenge (McGraw Hill Construction 2013).

Benefits achieved through Lean can be difficult to grasp when that knowledge is transmitted only through textbooks (Rybkowski et al. 2008). Although simulations are often played at lean construction workshops and there are numerous published case study articles describing productivity gains gleaned from lean methods implemented on construction sites, novices still express frustration about their inability to connect principles illustrated by lean simulations to their actual applications in construction. Clarifying lessons illustrated by the lean simulations is an important first step to supporting the research question: Can the principles illustrated by Lean simulations be systematically linked to applications of those principles on actual construction projects?

The effectiveness of a simulation as an appropriate teaching methodology depends on the applicability of its associated learning outcomes to a real-time scenario (Ashwin and Pitts 2007; Rolfe 1991). Teaching the complex concepts of Lean philosophy to students and employees who have no experience with Lean can be challenging. When teaching students using lean simulations, it is imperative to develop a creative context so that they can observe and understand the importance and inner workings of Lean philosophy. However, when teaching employees/practitioners, it is also important to translate Lean thinking into an applied context using case study analysis so the lessons become relevant to those working in the construction industry.



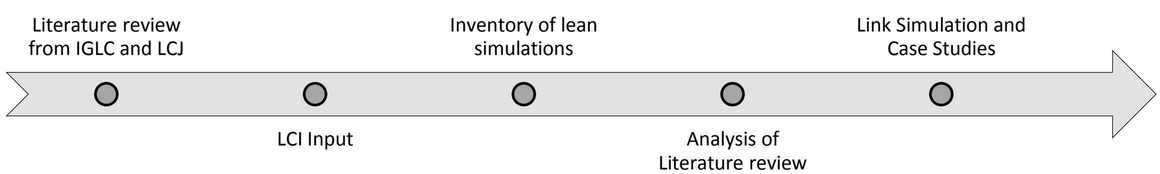
- Figure 1*:* Major challenges encountered in the application of a Lean approach to construction sites (according to lean practitioners).
- Adapted from (McGraw Hill Construction 2013, page 39)

The objective of this research is to offer a framework to assist lean educators and facilitators when teaching Lean Construction. This matrix can also serve as a “seed” for various international communities to extend and share how specific lean principles can be incorporated into their own cultural traditions within project delivery processes.

RESEARCH METHOD

The Lean Construction Institute conducted a study with the Knowledge Transfer Laboratory Team from May 18-21, 2015 in Dallas, TX to identify frequently used lean simulations. Thirty-three lean simulations were identified during the study and were published in August of the same year on the Lean Construction Institute website as a matrix entitled "LCI Simulation Matrix." The simulations identified in the "LCI Simulation Matrix" illustrate fundamental aspects of lean processes that are applicable to the construction industry. "Simulation/Case-study matrix" provides an elaborate model approach that can be implemented on any construction project.

The method adopted for this study was a structured literature review. Various lean construction case studies were reviewed to identify how lean principles are being adapted to the construction delivery process. Although the authors acknowledge there is not yet a clear consensus with respect to lean principles, this research references the 14 principles of Liker's *The Toyota Way* (2005) because the book offers a recognizable and relatively comprehensive framework for lean. Figure 2 illustrates the method adopted for this research. A systematic literature review sourced from IGLC and LCI database was conducted using keywords such as "Lean Simulations," "Case Study," Lean Principles," "Teaching Lean" and "Application/Adaption to construction site." The names of authors who regularly write about simulations and lean case studies were also searched. Construction project case studies were selected based on their relevance to the 14 principles illustrated by Liker (2005) in *The Toyota Way*.



- Figure 2*:* Research methodology adopted to identify the link between lean simulation principles and their application to the construction industry

LIMITATIONS

This research involved locating, translating, and organizing 23 years of organically developed construction case studies from IGLC and LCI Databases. However this research is limited to only those simulations and case studies that have been published.

DELIMITATIONS

The scope of this study was limited to simulations in lean that are being applied to the construction industry as well as to case studies from the construction industry. The research does not include simulations or case studies from any other industry.

RESULTS

Research by Neeraj (2016) focused on seven lean concepts to establish links between lean principles and their application on construction projects. These concepts provided a means to categorize specific simulations, and included:

1. Pull Planning, Small Batch Sizes and Multi-skilling
2. Supply chain problems in construction
3. Collaboration and Communication
4. Continuous Improvement
5. 5S
6. Last Planner System
7. Target Value Design

This paper builds on work by Neeraj (2016). Table 1 illustrates a link between lean simulations that represent collaboration and communication and their application to construction projects. Similarly Table 2 illustrates applications of the Last Planner System principles and Table 3 illustrates applications of Target Value Design principles to construction projects. While many simulations and case studies illustrate more than one principle, the tables are intended to help highlight generally dominating principles.

CONCLUSION

This research explored 8 of the 33 simulations currently listed in the "LCI Simulation Matrix" published by the Lean Construction Institute. The paper provides a framework to link lean principles to their application on construction projects as represented in published case studies. The case studies document impacts on the success of a project where time, cost and quality have been improved.

This research represents an important first step in systematically connecting principles of Lean game simulations to their practical applications on building projects. The objective of this research is to assist lean educators to make memorable links between the lean principles illustrated by simulations and their actual applications, thereby also benefiting practicing stakeholders. The intent is that future researchers will expand on this framework, facilitating among construction stakeholders a better understanding of lean principles and their potential applications to actual projects.

Table 1: Collaboration and Communication

Lean Simulation	**Lean principles illustrated in *The Toyota Way*** (Liker 2005)	**Lean Construction Tools**	**Case Studies that implement these lean principles**
1. Magic Stick Simulation (provided by Alan P. Mossman) **2.** Silent Squares Simulation (Building Dynamics Group, Ohio State University Extension) **3.** Maroon – White Simulation (Smith and Rybkowski 2013) **4.** Win as much as you can Simulation (Gellerman 2003)	• Principle #13 – *"Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly."* *Simulations 3 and 4 illustrate Principle #1 as well as Principle #13*: • Principle #1 – *"Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals."*	• Big Room meetings • A3s	• Alarcón et al. 2011***** • Chin et al. 2004 • Elsborg et al. 2004 • Fundli and Drevland 2014 • Kulkarni et al. 2012***** • Riley and Horman 2001***** • Tribelsky and Sacks 2010

*****Case Study providing exceptional understanding of the learning objectives

Table 2: Last Planner System

Lean Simulation	**Lean principles illustrated in *The Toyota Way*** (Liker 2005)	**Lean Construction Tools**	**Case Studies that implement these lean principles**
5. Colored Blocks Simulation (DPR Construction) **6.** Parade of trades Simulation (Tommelein et al. 1998) **7.** Villego Simulation (http://www.villego.com)	• Principle #3 – *"Use 'pull' systems to avoid overproduction."* • Principle #4 – "*Level out the workload (work like the tortoise, not the hare)."* • Principle #11 – *"Respect your extended network of partners and suppliers by challenging them and helping them improve."* • Principle #14 *"Become a learning organization through relentless reflection and continuous improvement."*	• Pull Planning • Percent Planned Complete for reduced Variability and workload levelling (Heijunka) • Root Cause Analysis (5 Whys) and Go to the Gemba for learning • Kaizen (Continuous improvement) • Last Planner System (LPS) of Production Control	• Ahiakwo et al. 2013***** • Al Sehaimi et al. 2009***** • Bortolazza et al. 2005 • Fiallo and Revelo 2002 • Formoso and Moura 2009 • Junior et al. 1998***** • Kalsaas et al. 2009 • Kim and Jang 2005 • Porwal et al. 2012***** • Soares et.al. 2002 • Tommelein and Beeche 2001 • Valente et al. 2013

*****Case Study providing exceptional understanding of the learning objectives

Table 3: Target Value Design

Lean Simulation	Lean principles illustrated in ***The Toyota Way*** (Liker 2005)	Lean Construction Tools	Case Studies that implement these lean principles
8. Target Value Design Simulation (Munankami 2012)	• Principle #3 – *"Use 'pull' systems to avoid overproduction."* • Principle #13 – *"Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly."*	• Target Value Design	• Ballard et al. 2015 • Do et al. 2014***** • Kim and Lee 2010 • Melo et al. 2014***** • Oliva and Granja 2013 • Rybkowski 2009*****

*****Case study providing exceptional understanding of the learning objectives

REFERENCES

Al Sehaimi, A. O., Tzortzopoulos, P., and Koskela, L. (2009). "Last planner system: Experiences from pilot implementation in the Middle East," *Proceedings of 17th Annual Conference of the International Group for Lean Construction,* Taipei, Taiwan, July 15-17, 53-66.

Ahiakwo, O., Oloke, D., Suresh, S., and Khatib, J. (2013). "A Case Study of Last Planner System Implementation in Nigeria," *Proceed. of 21st Ann. Conf. of the Internl. Group for Lean Construction,* Fortaleza, Brazil, July 31-August 2, 699-707.

Alarcón, I., Christian, D., and Tommelein, I. D. (2011). "Collaborating with a permitting agency to deliver a healthcare project: Case study of the Sutter Medical Center Castro Valley (SMCCV)," *Proceedings of 19th Annual Conference of the International Group for Lean Construction*, Lima, Peru, July 13-15, 402-415.

Ashwin, A., and Pitts, K. (2007). "Developing learning materials for the unknown online learner," Ch. 13 of *The Challenges of Educating People to Lead in a Challenging World,* edited by M. K. McCuddley, H. van den Bosch, W. B. Martz, Jr., A. V. Matveev, K. O. Morse, Volume 10 of the series *Educational Innovation in Economics and Business,* Springer, Netherlands, 273-290.

Ballard, G., Dilsworth, B., Do, D., Low, W., Mobley, J., Phillips, P. and Wood, N. (2015). "How to Make Shared Risk and Reward Sustainable," *Proceedings of 23rd Annual Conference of the International Group for Lean Construction.* Perth, Australia, July 29-31, 257-266.

Bortolazza, R. C., Costa, D. B., and Formoso, C. T. (2005). "A quantitative analysis of the implementation of the Last Planner System in Brazil," *Proceedings of 13th Annual Conference of the International Group for Lean Construction*, Sydney, Australia, July 19-21, 413-420.

Caňizares, C. A., and Faur, Z. T. (1997). "Advantages and disadvantages of using various computer tools in electrical engineering courses," *Education, IEEE Transactions on Education,* 40(3), 166-171.

Chin, S., Yoon, S.W. , Jung, S.0. , Kim, Y.S. , Kim, C.D. , Choi, Y.K. , Chun, J.Y. and Lim, H.C. (2004). "An Analysis of the Life-Cycle Curtain Wall Process Through Supply Chain Management," *Proceedings of 12th Annual Conference of the International Group for Lean Construction,* Helsingør, Denmark, August 3-5.

Do, D., Chen, C., Ballard, G., and Tommelein, I. (2014). "Target value design as a method for controlling project cost overruns," *Proceedings of 22nd Annual Conference of the International Group for Lean Construction,* Oslo, Norway, June 25-27, 171-181.

Elsborg, S., Bertelsen, S., and Dam, A. (2004). "BygLOK–A Danish experiment on cooperation in construction," *Proceedings of 12th Annual Conference of the International Group for Lean Construction,* Helsingør, Denmark, Aug 3-5, 11 pp.

Forbes, L. H., and Ahmed, S. M. (2011). "Modern construction: Lean project delivery and integrated practices," CRC Press (Taylor & Francis Group), Boca Raton.

Fiallo, M., and Revelo, V. (2002). "Applying the last planner control system to a construction project: A case study in Quito, Ecuador," *Proceedings of 10th Annual Conference of the International Group for Lean Construction*, Gramado, Brazil, August 6-8.

Formoso, C. T., and Moura, C. B. (2009). "Evaluation of the impact of the Last Planner System on the performance of construction projects," *Proceedings of 17th Annual Conference of the International Group for Lean Construction,* Taipei, Taiwan, July 15-17, 153-164.

Fundli, I. S., and Drevland, F. (2014). "Collaborative Design Management–A Case Study," *Proceedings of 22nd Annual Conference of the International Group for Lean Construction,* Oslo, Norway, June 25-27, 627-638.

Gellerman,W. (2003). "Win as much as you can : An intergroup competition," Part 2, Section 3 of *Pfeiffer's Classic Activities: Managing Conflict at work*, John Wiley & Sons, Inc.

Heyl, J. V. (2015). "Lean Simulation in Road Construction: Teaching of Basic Lean Principals," *Proceedings of 23rd Annual Conference of the International Group for Lean Construction*, Perth, Australia, July 29-31, 2015, 403-412.

Hirota, E. H., and Formoso, C. T. (1998). "Some directions for developing construction management training programs on lean construction," *Proceedings of 6th Annual Conference of the International Group for Lean Construction,* Guarujá, Brazil, August 13-15.

Hopp, W. J., and Spearman, M. L. (2008). *Factory physics,* Waveland Press, Inc., Long Grove, Ill.

Izquierdo, J., Cerf, M., and Gomez, S. (2011). "Lean Construction Education: Basic management functions workshop," *Proceedings of 19th Annual Conference of the International Group for Lean Construction*, Lima, Peru, July 13-15.

Junior, J., Scola, A., and Conte, A. (1998). "Last planner as a site operations tool," *Proceedings of 6th Annual Conference of the International Group for Lean Construction,* Guarujá, Brazil, Aug 13-15.

Kalsaas, B. T., Skaar, J., and Thorstensen, R. T. (2009). "Implementation of Last Planner in a medium-sized construction site," *Proceedings of 17th Annual Conference of the International Group for Lean Construction,* Taipei, July 15-17, 15-30.

Kim, Y.-W., and Jang, J.-W. (2005). "Case study: An application of last planner to heavy civil construction in Korea," *Proceedings of 13th Annual Conference of the International Group for Lean Construction,* Sydney, July 19-21, 405-411.

Kim, Y., and Lee, H. W. (2010). "Analyzing user costs in a hospital: methodological implication of space syntax to support whole-life target value design," *Proceedings of 18th Annual Conference of the International Group for Lean Construction,* Haifa, Israel, July 14-16, 93-102.

Kulkarni, A. S., Rybkowski, Z. K., Fernández-Solís, J., and Shepley, M. (2012). "Cost comparison of collaborative and IPD-like project delivery methods versus competitive non-collaborative project delivery methods,*" Proceedings of the 20th Annual Conference for the International Group for Lean Construction,* San Diego, CA, July 17-22, 781-790.

Lean Construction Institute (2015). "LCI Simulation Matrix." <http://www.leanconstruction.org/simulation/> (March 23,2016).

Liker, J. K. (2005). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer,* McGraw-Hill, New York.

McGrawHill Construction. (2013). "Lean Construction: Leveraging collaboration and advanced practices to increase project efficiency," *SmartMarket Report.*

Munankami, M. (2012). "Development and Testing of Simulation (Game) to Illustrate Basic Principles of Integrated Project Delivery and Target Value Design: A First Run Study*,"* Master's thesis, Construction Science, Texas A&M University, College Station, TX

Melo, R. S. S. D., Kaushik, A., Koskela, L., Granja, A. D., Keraminiyage, K., and Tzortzopoulos, P. (2014). "Target costing in construction: a comparative study," *Proceedings of 22nd Annual Conference of the International Group for Lean Construction*, Oslo, Norway, June 25-27, 183-194.

Oliva, C. A., and Granja, A. D. (2013). "An Investigation Into Collaborative Practices in Social Housing Projects as a Precondition for Target Value Design Adoption," *Proceedings of 21st Annual Conference of the International Group for Lean Construction*, Fortaleza, Brazil, July 31-August 2, 429-437.

Ohno, T. (1988). *Toyota production system: beyond large-scale production*, Productivity Press, Cambridge, MA.

Porwal, V., Dave, B., Fernandez-Solis, J., Koskela, L. J., and Mehta, H. S. (2012). "State of production plan reliability–a case study from India," *Proceedings of 20th Annual Conference International Group for Lean Construction,* San Diego, CA, USA, July 18-20.

Riley, D., and Horman, M. (2001). "Effects of design coordination on project uncertainty," *Proceedings of 9th Annual Conference of the International Group for Lean Construction,* Singapore, August 6-8.

Rolfe, J. (1991) "SAGSET 1990 – The Proof of the Pudding: The Effectiveness of Games and Simulations," *Simulations/Games for Learning*, 21(2), June, 99–117.

Rybkowski, Z. K., Wong, J. M., Ballard, G., and Tommelein, I. D. (2008). "Using controlled experiments to calibrate computer models: the Airplane Game as a lean simulation exercise," *Proceedings of 16th Annual Conference of the International Group for Lean Construction,* Manchester, UK, July 16-18, 309-319.

Rybkowski, Z. K. (2009). “The application of root cause analysis and target value design to evidence-based design in the capital planning of healthcare facilities,” *Doctoral dissertation*, University of California, Berkeley.

Soares, A. C., Bernardes, M. M. and Formoso, C.T. (2002). "Improving the Production Planning and Control System in a Building Company - Contributions After Stabilization,” *Proceedings of 10th Annual Conference of the International Group for Lean Construction*, Gramado, Brazil, Aug 6-8.

Smith, J. P., and Rybkowski, Z. K. (2013). "The Maroon and White Game: A simulation of trust and long-term gains and losses," *Proceedings of 21st Annual Conference of the International Group for Lean Construction,* Fortaleza, Brazil, July 31-August 2, 987-996.

Tommelein, I. D., and Beeche, G. (2001). "De-Coupling Cladding Installation From Other High-Rise Building Trades: A Case Study,” *Proceed. of 9th Annual Conf. of the International Group for Lean Construction*, Singapore, August 6-8.

Tommelein, I. D., Riley, D. R., and Howell, G. A. (1998). "Parade game: Impact of workflow variability on trade performance," *Proceedings of 6th Annual Conference of the International Group for Lean Construction,* Guarujá, Brazil, August 13-15.Tribelsky, E., and Sacks, R. (2010). "The relationship between information flow and project success in multi-disciplinary civil engineering design," *Proceedings of 18th Annual Conference of the International Group for Lean Construction,* Haifa, Israel, July 14-16, 140-150.

Tsao, C., Alves, T., and Mitropoulos, P. (2012). "Different perspectives on teaching lean construction," *Proceedings of 20th Annual Conference of the International Group for Lean Construction,* San Diego, CA, Jul 18-20.

Tsao, C., Azambuja, M., Hamzeh, F. R., Menches, C., and Rybkowski, Z. K. (2013). "Teaching lean construction—Perspectives on theory and practice," *Proceedings of 21st Annual Conference of the International Group for Lean Construction,* Fortaleza, Brazil, July 31-Aug 2, 977-986.

Valente, C. P., Montenegro, G. A., Brito, F. L., Biotto, C. N., Mota, B. P., and Schramm, F. K. (2013)."Benefits of Batch Size Reduction: A Case Study in a Residential Project," *Proceedings of 21st Annual Conference of the International Group for Lean Construction,* Fortaleza, Brazil, July 31-August 2, 1029-1038.

Walters, B. A., Coalter, T. M., and Rasheed, A. M. (1997). "Simulation games in business policy courses: Is there value for students?" *Journal of Education for Business*, *72*(3), 170-174.