Proceedings of the 2005 Winter Simulation Conference
M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

A SIMULATION MODEL FOR FACILITATORS OF TONY RIZZO'S BEAD GAME

David B. Roggenkamp

Department of Mechanical Engineering
22043 Harsdale Dr.
University of Detroit Mercy
Farmington Hills, MI 48335-5438, U.S.A.

Dave Park

Ford Customer Service Division
16800 Executive Plaza Drive
Ford Motor Company
Dearborn, MI 48121, U.S.A.

Omer Tsimhoni

Department of Industrial and Operations Engineering
1205 Beal Avenue
The University of Michigan
Ann Arbor, MI 48109, U.S.A.

ABSTRACT

As the culmination of a simulation course at the University of Michigan, we simulated the physical structure and outcomes of Tony Rizzo's Bead Game. The game is a pedagogic tool to teach the effects of multitasking in a multi-project environment. During the game, time constraints limit the scope of the activity. Since the outcomes are fairly dramatic, many participants have a difficult time believing that the results they witnessed are truly representative of "typical" outcomes. The simulation model of the game was conceived as an opportunity to provide a more robust example of outcomes including the ability to demonstrate probabilistic distributions as well as potential extensions to the parameters of the game. In practice, the simulation model was effective in duplicating the observed game outcomes. Additionally, the model provides a starting point for potential further research in organizational throughput in a multi-project environment such as research or new product development.

1 INTRODUCTION

1.1 Background

The Bead Game was originally developed as a demonstration of the principles put forth in Eliyahu Goldratt's book Critical Chain (Goldratt 1997). Dr. Goldratt is best known for the development and promotion of a manufacturing management strategy known as Theory of Constraints or TOC as presented in his book The Goal (Goldratt 1984). When he tried to apply some of the same principles to new product development, he identified the key constraint of a product development (PD) organization to be the project management methods used. Critical Chain is a project management technique that addresses inefficiencies in more traditional approaches primarily by taking better account of resource availability and the variation in duration of tasks than in a more traditional project work-plan. One of the key "truths" underlying Critical Chain is an acknowledgement of the negative effects of multitasking in organizational performance.

In the early to mid 1990's, Tony Rizzo (then an employee of Lucent Technologies, now President, Product Development Institute) developed a helpful pedagogic tool to teach this core principle to managers attending face-to-face seminars. Rizzo's Bead Game (Chonko 1999) is a physical simulation with minor role-playing, in which participants play the part of "resources" working on serial phases of two projects simultaneously. Each player's task involves sorting, processing or remixing glass beads of various colors, subject to a small number of rules. Two scenarios are used in the game: one scenario in which two projects (which will be called the Red Project and the Blue Project) are "multitasked" or executed in parallel, and one in which they are "prioritized" or executed in series. The key learning point, which is surprisingly counter-intuitive to most managers, is that a multi-tasking approach by employees delays delivery of *all* projects by a significant margin. Thus, executing multiple projects in sequence by delaying the start of most of the projects, even when some resources are significantly underutilized, will improve the completion dates of all projects over running them in parallel with shared resources.

1.2 Problem Description

The Bead Game's purpose is to provide an opportunity for participants to experience the negative effects of multi-tasking in a simple, inexpensive and highly visceral way. However, most of these training exercises are scheduled to be complete in a two-hour training session – many even in less time. The ability of a group of people to be taught the basic concepts, the rules of the game, practice the physical skills necessary to execute the game, and run the game twice (once under each set of conditions) in this length of time is often quite challenging. The magnitude of the paradigm shift necessary during the debriefing process is often too great of a challenge for many participants who leave the session with a belief that the results they witnessed were somehow abnormal. While additional time for practice, planning and multiple iterations of the game itself would help alleviate some of these concerns; the time is generally not available.

This class project was viewed as an opportunity to provide a computer model of the game that could be demonstrated to game participants during the de-brief time of the exercise to help demonstrate the validity of the results just experienced. The ability to quickly show a modeled iteration of the game and then to show a Monte Carlo sequence of multiple iterations with statistical data for the distribution of outcomes is a potential benefit for the game facilitator.

1.3 Assumptions

There are two aspects of this simulation that require a reviewer to accept sets of assumptions. The first aspect is the applicability of the bead game itself to real world project management. This paper does not attempt to address these assumptions. The second aspect is the set of assumptions made in the construction of this simulation model.

The primary model-based assumptions are those related to the data gathering and statistical representation of the game activities. It was not possible to gather meaningful data for each game activity for several reasons. These reasons include:

- Minimal number of test subjects available for the study.
- Very short duration times for individual motions required measuring duration of multiple actions and assuming that time could be equally divided between the individual motions. (i.e. the time to flip over 1 bead is assumed to be 1/20th of the time to flip over 20 beads).
- Difficulty in separating some individual motions from those preceding or following them and still gathering meaningful data (i.e. the time to set down one spoon and pick up another did not appear to be the same when timed as a unique action versus what was observed during the game play while scooping beads. When timed separately, the spoon switch action was more deliberate and longer duration.)

For these reasons, the data tables provided in section 2.3 show distributions as being "Stat:Fit Recommended" for those items where meaningful data was gathered or as being "Estimated" for those activities where meaningful data was unavailable.

Additional assumptions would have to be made if the results of this study were to be extrapolated to other scenarios outside of the two used in the game. It has been suggested that the simulation model be used for evaluating multi-tasking variations other than treating the two projects equally. Since no data currently exists regarding these other scenarios, the applicability of this simulation to those situations would be uncertain.

1.4 Questions

The concrete output of the simulation analysis will allow conclusions about the effect/benefit/penalty of each project management approach compared with the other. We thus compare the two different approaches to project management used in the game: 1) the Critical Chain management approach, and 2) a more traditional Multi-Tasking management approach.

A key attribute of Critical Chain management is that projects are carefully evaluated and prioritized relative to one another. Each project in an organization has a known priority level versus every other project. These priorities are dynamic in the sense that projects that are executing late to their schedule may have their relative priority increased to improve the possibility of recovery. Resources are expected to know the relative priorities of the projects at any given time and always work at 100% effort on the project with higher priority until it is complete. Hence, once all precedent tasks are complete, a resource is expected to focus all of their energy on their assigned task(s) in support of completion of the higher priority project. All lower priority projects must "wait" until the resource is available.

A key attribute of the Multi-Tasking approach is the expectation (by management) of simultaneous job progress across multiple projects. Essentially, adherents to this management style treat each project as independent entities and find it "unacceptable" to not have made discrete progress on each project between review meetings. Hence, once tasks are available for a given resource for any project, they are expected to divide their effort between the various active projects so as to make progress on each project "equally".

This study will use simulation to "go to court" to evaluate whether a clear advantage exists for one management approach versus the other. Is it better to have idle time for projects that are waiting for resources to become available, or is it better to make continuous progress on all projects? In this analysis, the most important evaluation criteria will be represented by the element of elapsed time. Specifically, we look at the time from start of the first project to completion of each project recorded in seconds of elapsed time.

Summarizing, the simulation will address several critical questions inherent in the game:

- What is the impact of the Critical Chain management approach to project completion times of multiple projects?
- What is the impact of the Multi-Tasking management approach to project completion times of multiple projects?
- How can the different styles affect expected outcomes when expanded to other project management venues?

To analyze the global questions above, and to attempt to discover the truth represented by convergence of physical realities and statistical analysis, the following detailed questions will be reviewed:

1. What do simulations reveal about the alternate project management strategies in terms of elapsed time?
2. What is the variability related to elapsed times under both strategies (output variability)?
3. What can we learn from the model creation, verification and validation process that could be applied to the game to make the learning experiences more meaningful or take less time?
4. What can be expected to happen if the variability in task duration is increased (i.e. does revising input variability have a major impact on more complex or 'real' tasks)?

2 METHODS

This section outlines the methods used in creating the simulation models. However, to make sense of the simulation below, it is necessary to have some knowledge of the specific function of Tony Rizzo's Bead Game. Hence, this section begins with a discussion of the key elements of the game, and is followed by a brief discussion of the ProModel software as applied to the game. Then data collection information is provided to close the Methods section.

2.1 Bead Game Description and Structure

A block flow diagram overview of the game structure is shown in Figure 1. Each project follows this sequence of tasks.

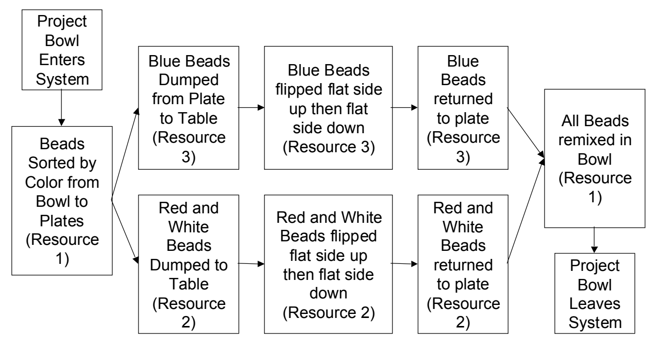

Figure 1: Overview of the Bead Game Structure For a Single Project

The upper left and lower right boxes represent arrival and departure events (no resources). The lower left and upper right boxes represent utilization of the first resource, typically identified as the "Sorter" or "Sorter/Mixer" who is responsible for the first and the final task of each project. The lower row of middle boxes represent utilization of the second resource, referred to as "Inspector A" or "Inspector 1". The upper row of middle boxes represent utilization of the third resource, referred to as "Inspector B" or "Inspector 2". When physically facilitating the Bead Game, there are additional roles that may be assigned to participants. However, since the other participant roles do not come in direct contact with the beads, their effect is not directly included in this simulation model.

In the game, volunteer participants are exposed to the pressures typical in a project management environment – they are monitored to ensure they effectively divide time between projects. The focus is to be consistent with an attempt to include the effects of physical stresses (exhibited as slower task completion times and higher error rates) under the situations of "management scrutiny" in the data gathering effort (second phase described below). This function is provided by both the other role playing participants and the game facilitator.

While the game structure and roles are common across both iterations of the game, some of the details change between iterations.

In the "Multi-tasking" iteration of the game, the two projects are started with only a very brief wait between the first and second. All resources are required to treat the two projects equally by switching back and forth between the projects, performing three actions on one project and then three actions on the other project, as long as both projects are available to them. No resource can do any work on a project until all predecessor work on that project is complete (i.e. the mixing phase cannot begin on a project by resource 1 until both resource 2 and resource 3 have completed their tasks on that project.)

In the "Critical Chain" iteration of the game, one project is given precedence over the other. The second project start is delayed until resource 1 is complete with the first project and work is only done on the second, lower priority, project by ANY resource if they have no work to do on the first, higher priority, project.

2.2 Simulation Model Description

ProModel software allows quick mathematical and visual modeling for the movement of materials (entities) to and from discrete places (locations) with movement and processing determined by the functions "processing" and "resources" designated as such inside the model.

The connection between the first and second phases of data gathering and the application to the ProModel simulation can be quickly understood (particularly for users of the ProModel software) by review of the summary below:

- Entities – represented by the moving beads. There were six types, Red, White and Blue for each of the two projects.
- Locations – represented by places for unique processing steps (Red and Blue bowls, sorting, mixing places). In the detail, there are many subcategories to reflect interim steps (i.e. flip up, flip down for each color, etc.)
- Processing – represented by all moves between locations, and importantly, all of the conditions which must precede a given move (i.e. cannot leave flat side down before all flat side up achieved.)
- Resources – spoons, needed to move (not flip) bead entities.
- Routing – path followed by spoon, and constraining spoon to alternate projects in the Multi-Task scenario.

In the ProModel simulation, the underlying question of multi-tasking versus the sequential task completion providing the backbone to the Critical Chain approach, are driven by the relative priorities and rules established for resource utilization. In the Multi-Tasking scenario, each entity in both projects must compete to "share" the various resources, as opposed to the Critical Chain scenario, where one entity will be designated from inception of production/scheduling, as having a clearly established higher, or dominating, priority. Thus entities and processing will have a hierarchy for the use of all resources.

2.3 Data Collection from Human Subjects

Data collection occurred in two phases. Both phases involved classmate volunteers utilizing the equipment used for the Bead Game and with each one performing some or all of the steps in the physical demonstration. In the first phase, or the Input Evaluation Phase, raw data was gathered from measurement of the durations (as well as variation) of the separate activities and processes that would soon take place with the volunteers, and that would be taking place in simulated time within the model. These detailed data elements included:

- Bead scoop/sort time
- Bead scoop/sort quantity
- Bead flipping time

A number of individuals executed each of the above tasks several times, all of which were recorded along with the durations, quantities (where quantities are variable) and error rates. Prior to obtaining the actual data, a warm-up time was provided to reduce required practice time during the game, under simulation conditions. The goal was to use the data gathered above to approximate standard statistical distributions as input into the ProModel simulation. Therefore, the data obtained was analyzed using Stat:Fit, an effective statistical input modeling feature which is a feature of ProModel. Table 1 shows the results of this stage of data gathering as well as other model input variables that were estimated due to difficulties in gathering "real" data as discussed in Section 1.3 ("Assumptions") of this paper.

Table 1: Data Elements and Distributions Used

Data Element	Distribution Used	Logic
Bead Scoop/Sort Time	Beta(3.05,13.5,1, 15.5)	Stat:Fit recommended
Bead Scoop/Sort Quantity	Bi(6,.547)	Stat:Fit recommended
Project-to-project sorting transfer time	e(1)	Estimated
Dump plate to table time	3+e(3)	Estimated
Bead flip time	N(.65,.125)	Based upon time for 20 flips
Project-to-project flip transfer time	e(2)	Estimated

The second phase of data gathering was the actual "playing" of the game. In this phase a subset of volunteers participated in both project management styles and data on elapsed time for both processes was procured. Table 2 shows the elapsed time ("absolute" clock time) results from the Multi-Tasking iteration of the game and the results from the Critical Chain iteration of the game. Data was gathered and is shown for several key points within the game in order to facilitate the validation process of the model construction.

Table 2: Elapsed Clock Times for Multi-Tasking and Critical Chain by Human Subjects

	Elapsed Time [s]			
	Multi-Tasking		Critical Chain	
Event	**Red Project**	**Blue Project**	**Red Project**	**Blue Project**
Project Start	0	10	0	50
Sorting Complete (Resource 1)	138	150	50	111
Inspecting Complete (Resource 2)	395	405	135	215
Inspecting Complete (Resource 3)	258	261	95	212
Project Complete (Resource 1)	451	459	166	237

3 RESULTS

This section presents the results from running the simulation model as well as a discussion of the model validation.

3.1 Model Results

Table 3 shows the results in tabular form obtained from running ten repetitions of the simulation model for the Multi-Tasking version of the game and for the Critical Chain version. Figure 2 shows the same mean elapsed time values in graphical form.

A comparison of the elapsed times for the blue and red projects in the Multi-Tasking versus Critical Chain models shows that the two models produce different results (Table 3). The red project event times for the Multi-Tasking model were always worse (longer times) than for the Critical Chain model. For the blue project, the start times were better for the Multi-Tasking model (since both confidence interval bounds are less than zero). This is logical because during multitasking, the blue project is started after the third action on the red project whereas for the Critical Chain model, it doesn't start until after the red project sorting is complete. Blue project sorting completion times are non-conclusive between the two models. But the final two events for the blue project (Inspect complete and Project completion) again show the Critical Chain model to have better (faster) times.

So, we can conclude that project completion times are faster under the Critical Chain model with 95% confidence.

3.2 Model Validation

The model was constructed using the individual data distributions recommended from the data collection exercise (as depicted in Table 1). Those elements included Bead Scoop/Sort Time, Bead Scoop/Sort Quantity, and Bead Flip Time. The remaining elements shown in Table 1 were estimated and modified during model construction and verification in order to achieve resulting times that appear to be close to the times gathered during data collection for the entire game (i.e. comparison of values between the simulation model data points as shown in Table 3 vs. the data collected and shown in Table 2.)

As we were only able to obtain a single replication of the physical game with human subjects, the validation is somewhat less robust than we would have preferred. However, the values obtained in the simulation appear to be consistent with the single replicate of "real" data and anecdotally match prior experiences with facilitating the game for other participant groups (no facilitators contacted during the execution of this project had data available from prior game sessions.)

Table 3: ProModel Results for Elapsed Time in Multi-Tasking and Critical Chain Models

	Elapsed Time (mean±SD) [seconds]					
	Multi-Tasking		Critical Chain		Mean Difference (Multi-Tasking minus Critical Chain) [95% CI of difference]	
Event	**Red Project**	**Blue Project**	**Red Project**	**Blue Project**	**Red Project**	**Blue Project**
Project Start	0±0	12±2	0±0	72±8	0 [0,0]	-60 [-66,-53]
Sorting Complete	145±10	152±10	72±8	146±14	73 [64,82]	6 [-6,18]
Inspecting Complete (last resource)	357±101	374±102	134±10	204±15	223 [147,300]	170 [92,248]
Project Complete	513±111	525±108	206±10	274±18	308 [224,391]	251 [168,333]

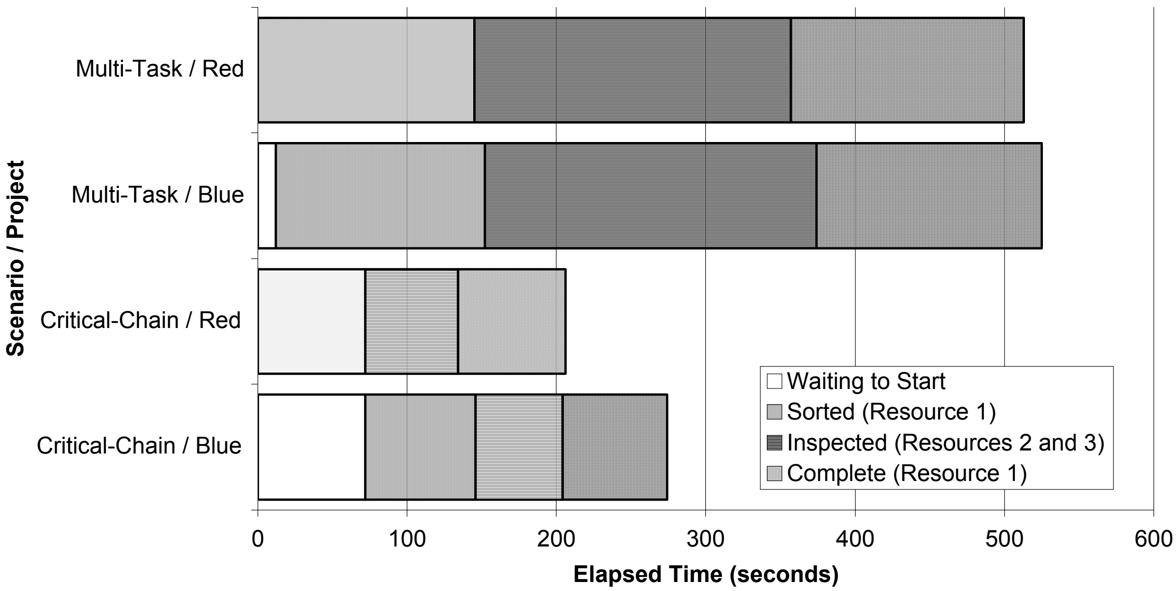

Figure 2: Simulated Project Completion Times by Scenario

It is also appropriate to note at this point that while the initial goal had been to build a single model that would be able to simulate both iterations of the game, we followed a more expedient path and wrote two independent models that are unique to each scenario. We wrote the Critical Chain model first and then used that functioning model as the basis for our Multi-Tasking model. We found that the Multi-Tasking model required a number of additional variables and counters that were not necessary in the Critical Chain version in order to account for the switching between projects and the dependence on completion of predecessor tasks which is more complicated under the Multi-Tasking scenario.

4 CONCLUSION

The first question we had set about to answer was, "What do simulations reveal about the alternate project management strategies in terms of elapsed time?" This answer was given in section 3.1. We are better than 95% confident that the elapsed time performance of both projects was better under the Critical Chain scenario than under the Multi-Tasking scenario. This, in itself is an important conclusion since most organizations obtain their profit from the completion of projects. The sooner projects are complete, the sooner revenue streams are realized bringing cash into the firm.

The second question we posed was, "What is the variability related to elapsed times under both strategies (output variability)?" A simple review of the data shown in Table 3 shows that variability is much greater under the Multi-tasking scenario than with Critical Chain. One standard deviation under the Multi-tasking scenario represents approximately 20% of the project durations for both projects. Under Critical Chain, one standard deviation represents just over 5% of the project duration. Once again, while data is not available to support the application of these results to real world situations, anecdotally these results are consistent with implementations of Critical Chain in real organizations. It is also interesting to note that this result is counter-intuitive to business/project management wisdom that has, to an extent, been inspired by the finance community. In the traditional risk-return tradeoff thinking that is foundational to investment finance, it is assumed that one must take on a higher risk to have an opportunity to obtain the higher payoff (where variability of project duration is the surrogate of risk and shorter project duration is the surrogate of reward.) Data appears to support a claim that the Critical Chain scenario provides higher payoff with simultaneous lower risk.

Our third question was, "What can we learn from the model creation, verification and validation process that could be applied to the game to make the learning experiences more meaningful or take less time?" We can not honestly say that anything was learned from the modeling process to make the game facilitation better other than more intimate knowledge of the inner workings of the game. It is possible that a person with more game facilitation experience might have learned more from the model construction process than we did. However, the intent of this class exercise was for us to learn about the model construction process and we definitely achieved that objective.

The final question posed was, "What can be expected to happen if the variability in task duration is increased (i.e. does revising input variability have a major impact on more complex or "real" tasks)?" This question was our only attempt at "stretching" the boundaries of the existing bead game structure. We tried to increase the variability in our input distributions to try to represent the effects of increased complexity of tasks in some projects. Unfortunately, our model was apparently not robust enough to give consistent results (i.e. the model began to fail completing all tasks prior to ending as the variability was increased.) We ran out of time during the course completion to fix the model or generate additional data with corresponding analysis to adequately answer this question. However, the data we did obtain showed directionally that increasing variability is likely to create a non-linear increase in project duration (i.e. a 2% increase in variability will result in greater than a 2% increase in project duration.)

The original intent of the authors was to create a simulation model that could be used in conjunction with the physical bead game to help teach the potential and principles of Critical Chain project management. Although we have not yet had the chance to use the model in this way, we hope to do so in the future.

5 SUGGESTIONS FOR FURTHER RESEARCH

There are a number of enhancements and additions that have been suggested to us through the completion of this project and authoring of this paper. Many of them were included in our initial project proposal but removed in order to maintain an appropriate scope for a course final project. Most directly, the model should be expanded to handle several situations:

- Multiple Projects – Make the model more flexible so the effect of more than two projects operating simultaneously could be reviewed.
- New Multi-Tasking Rules – Add the ability to change the multi-tasking rules so that projects could be treated unequally but still with multi-tasking (i.e. change the alternating three actions with some other set like three actions on the Red Project and one action on the Blue Project.)
- More/Better Input Data – Collect additional game data to better understand variation of the game in order to improve model validation. Also come up with ways to measure some of the more abbreviated actions under real conditions (i.e. project switching times) so that input distributions are 'real' vs. the current estimates for those actions.
- Improve Model Implementation – Modify the model to allow running to completion under situations of greater variability. Modify the model so that common random numbers can be used to better compare and contrast the two scenarios. While the same seed was used to start both models, the Multi-tasking model has more variables in it and we ran out of time to isolate those additional variables to use different random number streams.

REFERENCES

Chonko, L., M. Cooper, and C. Budd. 1999. Critical Chain Project Management. Available via <http://business.baylor.edu/Larry_Chonko//bus1301/projectmgt.pdf> [accessed November 30, 2004].

Goldratt, E. 1984. *The Goal.* Great Barrington, MA: North River Press.

Goldratt, E. 1997. *Critical Chain.* Great Barrington, MA: North River Press.

AUTHOR BIOGRAPHIES

DAVID ROGGENKAMP is currently a doctoral student at the University of Detroit Mercy studying Product Development. He is on an educational leave from Ford Motor Company where he has worked for 16 years in various capacities in product development. Much of that time was spent as a design engineer designing or creating design standards for vehicle interior systems. In the late 90's, he worked on developing and launching the Ford Product Development System. He also spent time managing a team of people who used system dynamics models to analyze the effects of product scope change to program outcomes as well as investigating new approaches to managing a "PD Factory". His e-mail address is <droggenk@umich.edu>.

DAVE PARK is a policy planning supervisor in the Controllers' Office of Ford Motor Company. His educational discipline is primarily finance and he has fulfilled a variety of roles involving fiscal/analytical responsibility in powertrain analysis, capacity planning, and various customer satisfaction and vehicle quality improvement initiatives. He is frequently sought to serve on cross-functional special problem teams with marketing, quality, and vehicle engineering personnel. His e-mail address is <dpark@ford.com>.

OMER TSIMHONI is an Adjunct Assistant Professor at the Department of Industrial Engineering of the University of Michigan and an Assistant Research Scientist at the University of Michigan Transportation Research Institute (UMTRI). He received his Ph.D. from the University of Michigan in 2004. His primary research interest is in the application of simulation to cognitive modeling and human factors. His e-mail address is <omert@umich.edu>.