Proceedings of the 1993 Winter Simulation Conference
G.W. Evans, M. Mollaghasemi, E.C. Russell, W.E. Biles (eds.)

ANIMATION: WHAT'S ESSENTIAL FOR EFFECTIVE COMMUNICATION OF MILITARY SIMULATION MODEL OPERATION?

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ABSTRACT

This research was sponsored by the Logistics Studies and Analysis Division of Headquarters Air Force Operational Test and Evaluation Center (HQ AFOTEC/SAL), Kirtland AFB, New Mexico. They desired to see how animation could be used in the model validation process and in communicating a model to senior leadership. In order to address their question, we initiated this research in the overall context of using animation to establish a model's face validity. However, we concluded that the research should begin with a more basic issue: what aspects of animation best communicate the operation of a simulation model. Three aspects of animation (movement, color, and detail of icons) were looked at individually and in combination. The ability to communicate was measured both subjectively and objectively. This paper presents the results of the objective measures. There were seven different scenarios containing various problems with the system. The objective measures were subject problem identification accuracy and time delay of problem identification. The results showed that movement was the most important aspect. The subjects performed equally well for all the animations with movement and, when there was no movement, the subjects' performance dropped equally.

1 INTRODUCTION

In this paper we examine the utility of animation in communicating the operation of a simulation model. We limited our investigation to three aspects of animation: movement, color, and detail of icons. These aspects were looked at individually and in combination.

This paper is organized in the following fashion. First, we discuss the use of animation in the validation of simulation models, summarize recent literature pertinent to the problem, and state our assumptions. Next, we relate the methodology and procedures used, our measures of effectiveness, and the results obtained. We close the paper with a summary and provide recommendations for future research.

2 BACKGROUND AND ASSUMPTIONS

First, we present some background information and briefly review current literature concerning validation and animation. Next, we detail our assumptions and discuss limitations regarding this research.

2.1 Background

Although simulation models are used extensively in decision making and problem solving, many decision makers lack confidence in simulation model results (Sargent, 1991). If models are to be legitimate decision aids, it is critical that they be validated. According to Schlesinger, et al. (1979), simulation model validation is "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model". The validation process consists of performing tests and evaluations during the development of a simulation model. These tests range from a review of model assumptions to detailed statistical procedures.

Computer animation is one of many techniques used in the process of simulation model validation (and verification). Through computer animation a "model's operational behavior is displayed graphically as the model moves through time" (Sargent, 1991). Animation is becoming more popular because animation software has dropped in price and increased in quality. Increased computer graphics capability allows the modeler to see the simulated operation of the system in addition to statistical summaries. In addition, animation can be used to enhance a model's credibility. A credible model is a model that decision makers are willing to use because they have confidence in the model's results (Sargent, 1991). According to Law and Kelton (1991), the ability to increase a model's credibility is the main reason for animation's expanding use. Thus, the graphical display of a model through animation can add credence to a model and increase the confidence in a model.

There are many proponents for using animation, not only for model validation, but also for the whole model building process. Those who tout animation the most are those who sell animation software (Brunner, Earle, and Henriksen, 1991; Kalasky and Davis, 1991; Hollocks, 1984; Standridge, 1986). Users of animation are the second most enthusiastic proponents of animation (Aiken, et al., 1990; Johnson and Poorte, 1988; Carson and Atala, 1990). Academia, although acknowledging value in animation, generally stresses other methods of validation or does not explicitly mention animation at all. (Law and Kelton, 1991; Balci, 1989; Banks, 1989).

According to Johnson and Poorte (1988), animation can be useful for debugging and verification, validation, analysis, and communication and presentation. They offer a hierarchical approach for using animation in all of these areas. Kalasky and Davis (1991) state that in the past few years animation has become essential during the simulation process. Summary statistics some times do not show the active interactions of processes of a system. "Although summary statistics are a crucial part of evaluating the performance of a simulated system, it is only through animation that the analyst can easily identify the system status under which, for example, bottlenecks occur" (Kalasky and Davis, 1991). Therefore, animation can be an important tool in communicating the operation of a simulation model.

2.2 Assumptions and Limitations

The experiment consisted of subjects viewing a simulation model animation in a controlled setting with the subjects looking at different scenarios and different types of animations. We performed the experiment within the context of face validity. Face validity involves asking people knowledgeable about the system being modeled whether the simulation model is reasonable. Thus, the subjects were to be "system experts" and judge how well the animations contributed to the model's face validity. In reality, though, the subjects measured how well the animations communicated the operation of the simulation model, which is only a step towards face validity. However, improving communication of the operation of a simulation model is useful for model verification and model validation using techniques other than face validity.

Three aspects of animation were considered:

- Movement
- Detail of Icons
- Color

Each of the above was looked at individually and in combination. Other factors that were not considered include graphs, perspective (as in two-dimensional or three-dimensional), concurrent animation versus playback, and speed of animation.

3 METHODOLOGY

In this section we discuss the preparation and conduct of the experiment. The following sections describe our approach: 1) a description of the simulation model used; 2) a discussion of the animation software used and the animations developed; 3) scenarios used and the resulting experimental design; and, 4) a description of the experimental apparatus and the procedures followed.

3.1 Simulation Model

The simulation model used for this research was taken from a SLAM (Simulation Language for Alternative Modeling) textbook (Pritsker, 1986). A simple model was chosen so that some of the basics of animation could be examined without the problems associated with a complex model. This model (which we call the Loader model) is a simple SLAM network simulation that models a loading and hauling operation for 480 minutes (8 hours). The system modeled consists of one bulldozer, four trucks, and two loaders. The bulldozer stockpiles material for the loaders. Two piles of material must be stocked prior to the initiation of any load operation. In addition to the two loads of material, a loader and an unloaded truck must be available before the loading operation can begin. The time to bulldoze a load is Erlang distributed and is the sum of two exponentials each with a mean of 4 minutes. The loaders are modeled as servers with loading time for server 1 exponentially distributed with a mean of 14 minutes and loading time for server 2 exponentially distributed with a mean of 12 minutes. After loading, a truck hauls the material to the dumping area, dumps its load, then returns for more material. Hauling time is normally distributed with a mean of 22 minutes and standard deviation of 3 minutes. The time to dump is uniformly distributed between 2 and 8 minutes, and return time is normally distributed with a mean of 18 minutes and standard deviation of 3 minutes. The loader must rest 5 minutes after loading a truck. Figure 1 is a diagram of the simulation.

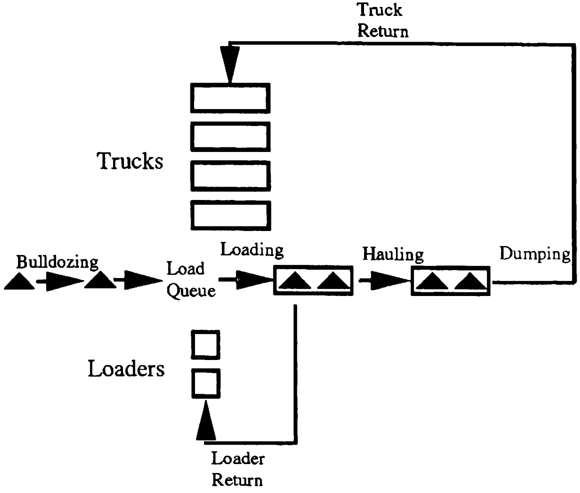

Figure 1: Loader Model Diagram

The Loader model was changed slightly from Pritsker's text to ease the process of animation. In the original model there was no way to retain the identities of the truck and loader entities, and that information was needed for the animations. Also, the original model allowed two trucks to be loaded at the same time and more than one truck to dump at the same time. Finally, the loader with the longest idle time was selected when a loading operation could begin. The first problem was solved by using attributes to track the truck and loader entities. The problem of two trucks being loaded at once was alleviated by using resources for the loading area and the dumping area. The selection of loader based on longest idle time was changed to simply alternating loaders.

3.2 Animations

In this subsection we describe the animation software used and the animations created. First, we briefly discuss the capabilities of the animation software. Next, we list the animations created and describe the animating process. Finally, the layout of the animations with movement and the layout of the animations without movement are shown.

PROOF Animation©(hereafter referred to as Proof) was used to animate the model. Proof is a PC-based, "post-processing" animation software package. Post-processing (or playback) means the animation is seen after the simulation is run. The events or state changes were recorded in a file using a customized SLAM trace during the simulation run and then "played back" by Proof.

Seven different animations were created to examine movement, color, and detail of icons:

- M - Movement. Simple icons that move but do not change level of detail or color.
- I - Icon. Icons exhibit differing levels of detail but do not move or change color.
- C - Color. Simple icons that change color but do not move or change level of detail.
- MI - Movement and Icon. Icons move and change level of detail but do not change color.
- MC - Movement and Color. Simple icons that move and change color but do not change level of detail.
- CI - Color and Icon. Icons change color and level of detail but do not move.
- MCI - Movement, Color, and Icon. Icons move and change color and level of detail.

Hereafter, we will use the above abbreviations to identify the various animation types.

Two files are required to run a Proof animation: a layout file and a trace file. The layout file contains the objects seen on the screen, and the trace file determines the status and movement of the objects. With regard to the layouts, the only background object created was an object representing a pile of material at the dumping area. This object only appeared in **MI** and **MCI**. Any object on the screen that could move or change status in some way required a unique number. That is why it was necessary to keep track of the trucks and loaders in the simulation model. Object classes were created that represented loaded and unloaded trucks and loaders. When a particular object was needed, a class was assigned by the trace file to the object's number. The object that appeared on the screen was based on the class assigned to the object's number. An object's color, speed, or travel time could also be changed by assigning a different color or speed to the object's number. Figure 2 shows the different object classes used.

For the animations with movement, paths were created for the objects to follow. Allowing two trucks to load or dump at the same time greatly complicated the path structure and the logic for path usage. This is why the trucks were limited to loading and dumping one at a time. A snapshot of an animation with movement is in Figure 3. The icons shown are the ones for **MI** and **MCI**. The two loads "fell" out of the truck onto the pile when dumping. **M** and **MC** did not show the pile of material, and the icons were the

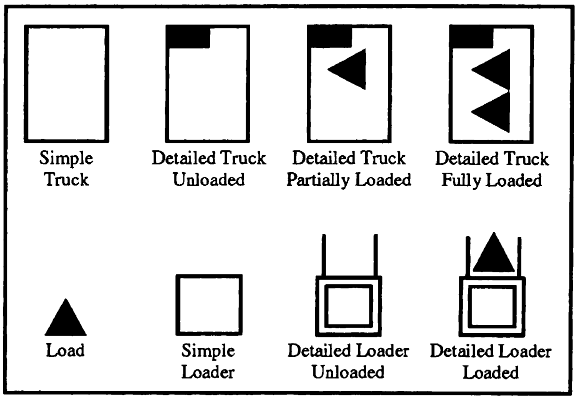

Figure 2: Animation Object Classes

ones labeled "Simple Truck" and "Simple Loader" in Figure 2; however, they did have the same movement as **MI** and **MCI**. For **MC**, the icons were white when idle, green when traveling empty, red when traveling loaded, pink when partially loaded (trucks only), and yellow when dumping (trucks only). **MCI** had the same color scheme with the icons as described above. The icons remained red for **M** and **MI**. No bulldozer icon was used. The bulldozer was represented by the loads arriving.

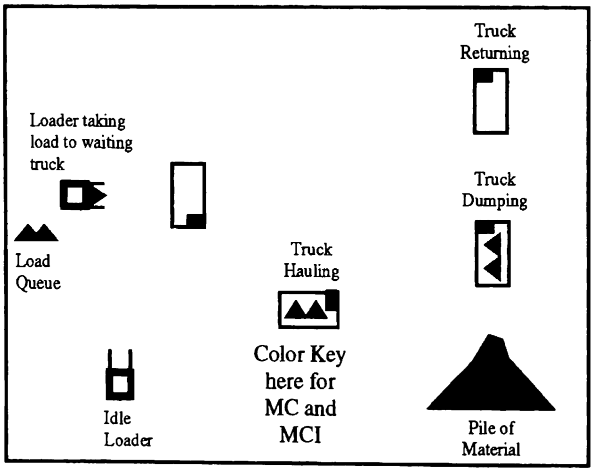

Figure 3: Sample Animation With Movement

The animations without movement used larger stationary icons. The four trucks were displayed at the top of the screen and the loaders at the bottom of the screen. Figure 4 gives a representation of the animations without movement (**C**, **I**, and **CI**). The figure shows the icons for **I** and **CI**. As with **M** and **MC**, the icons for **C** were the ones labeled "Simple Truck" and "Simple Loader" in Figure 2. For **C** and **CI**, the color changes were the same as for **MC** and **MCI**, and the icon changes for **I** and **CI** were the same as for **MI** and **MCI**. The icons in **I** remained red. There was no representation of the load queue in the stationary animations.

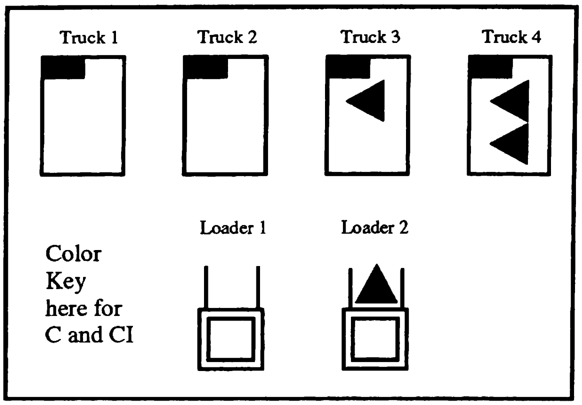

Figure 4: Sample Animation Without Movement

3.3 Scenarios and Experimental Design

Seven different problem scenarios were incorporated into the experiment to motivate the subjects to concentrate on the animations and to measure the subjects' performance while viewing the different animations. The subjects were considered to be the owners, operators, or managers of the loading operation; thus, they were looking for efficiency problems with their system. The order in which the animations were viewed was randomized as well as the scenario associated with each animation. The following is the scenario abbreviation, the simulation model modification, and the associated system problems for each scenario.

- LDER - Load interarrival time, loading time, hauling time, dumping time, and return time unchanged (Original Model with Modifications). All resources are used adequately with a slight buildup of loads.

- SLTK - Hauling time, dumping time, and return time doubled for the third truck (Slow Truck). One truck is much slower than the others, and there is a buildup of loads.

- SLLD - Loading time doubled for the first loader (Slow Loader). One loader is too slow, which creates a buildup of loads and idle time for the trucks.

- FT - Hauling time, dumping time, and return time cut in half for all trucks (Fast Trucks). There are too many trucks for the number of loaders and bulldozers or not enough loaders and bulldozers for the number of trucks.
- FL - Loading times halved for both loaders (Fast Loaders). There are too many loaders for the number of trucks and bulldozers or not enough trucks and bulldozers for the number of loaders.
- SL - Load interarrival time multiplied by 2 (Slow Loads). There are not enough bulldozers, which creates idle time for the trucks and loaders.
- ST - Hauling time, dumping time, and return time doubled for all trucks (Slow Trucks). There are too few trucks, which creates a buildup of loads and loader idle time.

3.4 Setup and Procedure

In this subsection we describe the setup of the room used for the experiment and the procedures followed during the experiment. The experiment was conducted in an isolated room, and a "Do Not Enter" sign was placed on the outside of the door to preclude interruptions. A computer was placed against the wall with pictures of the animation types attached to the wall above the computer. Control of the computer was maintained by the researcher, who was seated next to the subject. The subject was verbally given the purpose of the experiment and then asked to read the description of the model. While the subject was reading, certain subject information was recorded. Once the description was read and questions were answered (if any), the animations were described using the pictures. Each animation was viewed for one minute, which equated to 350 simulated minutes. While viewing the animations the subject performance data was collected. After viewing all the animations, the subject performed a subjective evaluation of the animations. The total time required was 25 to 30 minutes.

4 MEASURES OF EFFECTIVENESS

We established several measures of effectiveness, both subjective and objective, in order to determine which aspect of animation (movement, color, or icon detail) best communicated the operation of the simulation model. However, in this paper we will only present the results from the objective data. Carpenter (1993) presents the complete results. The objective measures included problem identification time and problem identification accuracy. As stated earlier, the subjects viewed each animation for 60 seconds. Thus, the time (in seconds) that it took a subject to identify a problem was recorded, and the problem identified was recorded. If no problem was observed, 60 seconds was noted for the problem identification time and "no problem observed" was noted for the problem observed. So the times of problem identification and the accuracy of the identifications was used as an objective measure of subject performance.

5 RESULTS

A total of 47 individuals volunteered to view the animations. Of the 47, 41 were Air Force Institute of Technology (AFIT) students, five were AFIT faculty, and one was neither. We will present summary results of the problem identification time and accuracy data followed by the results from our Analysis of Variance of the problem identification times.

5.1 Summary Results

Given an animation type, we looked at two items when the problem identification data was analyzed: problem identification time and problem identification accuracy. The problem data measured the subjects' objective performance when viewing the animations. Figure 5 shows the average time (in seconds) that a potential problem was identified. The animations with movement showed consistently lower identification times than those without movement. The percentage of problems correctly identified is shown in Figure 6. A clear difference can be seen between animations without movement and animations with movement. Problems were identified correctly just better than 50% of the time when the animation type was **C**, **I**, or **CI**, whereas the percent correct was 80% or better for **M**, **MC**, **MI**, and **MCI**.

Therefore, when the animations contained movement, the subjects performed better than when the animations did not contain movement.

5.2 Analysis of Variance Results

Our Analysis of Variance assumed a model of the form

$$Y_{ij} = \mu + T_i + B_j + \varepsilon_{ij} \tag{1}$$

where:

- μ is the mean of the responses
- T_i are constants for the treatment effects
- B_j are constants for the block effects
- ε_{ij} are independent $N(0, \sigma^2)$

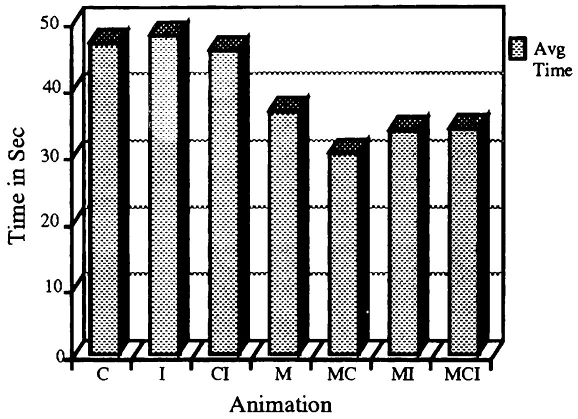

Figure 5: Average Time to Identify Potential Problem

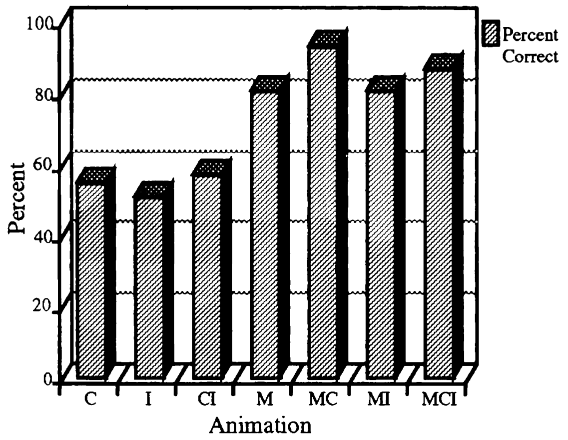

Figure 6: Percentage of Problems Correctly Identified

- $i = 1, \ldots, 7; j = 1, \ldots, 47$

The Y_{ij} represented the problem identification times. Each animation type was a treatment ($i = 1, \ldots, 7$), and each subject was a block ($j = 1, \ldots, 47$). So this model determined if there were differences in subject performance given an animation type and differences in performance between subjects. Table 1 shows the ANOVA table.

The ANOVA table shows that there was a difference in subject performance between animation types, and there was a difference in performance between subjects. That is, there was a block effect. This was expected since there was a variety of subjects, each with a different idea of what constitutes an efficiency problem. Also, some were familiar with simulation modeling and animation and some were not. A Tukey test for additivity was performed to test for interaction effects between animation type and subject. Since the null hypothesis of the test is no interaction effects (treatment and block are additive), the F value of 0.05 and the P value of 0.8308 indicated there was no animation type and subject interaction effects. Table 2 gives the complete results of the test.

Table 1: ANOVA Table for Problem Identification Times

Source	DF	SS	MS	F	P
Treatment	6	15437.2	2572.87	14.92	0.0
Block	46	26524.0	576.61	3.34	0.0
Error	276	47596.4	172.45		
Total	328	89557.7			
Grand Avg	1	504500			

Table 2: Tukey's 1 Degree of Freedom Test For Additivity

Source	DF	SS	F	P
Nonadditivity	1	7.91337	0.05	0.8308
Remainder	275	47588.5		

Model aptness checking revealed that the assumption of normality was valid. Because of the block effect, a formal test of equal variances could not be performed. However, a plot of residuals seemed to show equal variances.

We used the Tukey method of multiple comparisons to determine if the differences between the mean problem identification times of each animation type were statistically significant. The means were tested at a family α level of 0.1. The differences between the mean problem identification times of the animations without movement (**C**, **I**, and **CI**) were determined not to be statistically significant. That is, at the 90% confidence level the means were considered to be the same. Also, the differences between the mean problem identification times for the animation types with movement (**M**, **MC**, **MI**, and **MCI**) were not statistically different from each other; however they were statistically different from the group of animation types without movement. Thus, the test determined that there were two groups: (**MCI**, **MI**, **MC**, **M**) and (**C**, **I**, **CI**). Cluster analysis confirmed these groupings.

6 CONCLUSIONS AND RECOMMENDATIONS

This research looked at three aspects of animation (color, detail of icons, and movement) to determine which ones were the most useful for communicating the operation of a simulation model. This ability to communicate was measured both subjectively and objectively. There were seven different scenarios containing various problems with the system. The objective measures were subject problem identification accuracy and time delay of problem identification.

6.1 Conclusions

The results showed that movement was the most important aspect of animation. The subjects identified problems more accurately in less time when viewing animations with movement than animations without movement.

6.2 Additional Observations

The simulation model used in this experiment was chosen because it was simple and concise. However, the model was not designed with animation in mind. Several modifications and simplifications were made to the model so that is could be animated. Looking back, a couple of the modifications might not have been needed if the we had had more experience with animation and with Proof. Nevertheless, some model modifications would still have been required. The primary addition to the model was the ability to keep track of the trucks and loaders. Creating the animation trace files would have been easier if each separate movement of an entity had been explicitly modeled. For example, the loading times had to be artificially divided to account for the various movements required by the loaders. Therefore, if a modeler anticipates animating a model, this should be kept in mind when designing and coding the model. The modeler should make certain, though, that the system being modeled determines the model design and not animation considerations.

Finally, even though the initial aim of this study was to examine animation's role in establishing face validity, the contribution of animation to face validity was not what was actually measured. The simulation model that was used was assumed to be valid; therefore, the subjects could not judge the model's face validity. In the context of face validity, the research examined which aspects of animation best communicated the operation of the model. So the result that using movement in animations is important applies, not only to face validity, but also to other validation and verification techniques. In addition, this result applies to any other areas in which animation could be used, such as communicating the model to a decision maker.

6.3 Recommendations for Further Study

Several aspects of animation that were not considered in this study (such as graphs and speed of animation) were mentioned in Section 2.1. The aspects of animation that were not examined, plus what we learned during this research suggest the following studies:

- Repeat this research with a larger simulation model of an actual system. That is, investigate movement, color, and detail of icons with a model of a more complex, real world system. The model should have more simultaneous activities and a larger number of entities. Using this type of model would allow real "system experts" to rate the animations. Also, the results from this type of study would assist in determining whether the results of this study hold for a more realistic scenario.

- Investigate the use of graphs alone or in combination with other aspects of animation. This research could address such questions as:

  1. Is a graph showing queue status necessary when the actual entities can be seen waiting?
  2. What information can be displayed with graphs that can not be displayed with the aspects of animation investigated here?
  3. Is the unique information displayed by graphs critical?
  4. Do graphs improve communication or become distractions?

- Examine the impact of the viewing speed of the animations. Many times during the viewing of the animations without movement, the subjects commented that the icons or colors were changing too fast. How would have the subjects performed if the animations without movement had been slower? Is there an optimal viewing speed, and can it be determined?

- Study the usefulness of color in communicating when the colors have well known meanings in the context of the system being modeled. For instance, in this study, the colors were assigned arbitrarily. White represented an idle truck or loader, and red represented a loaded truck or loader. These were subjective color assignments. What if, in the system modeled, red meant stop (as on a traffic light or stop sign), or red meant hot? When there is meaning to the colors, the importance of color as a communication tool might increase.

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