DISCOVERING BEST PRACTICES IN EMERGENCY RESPONSE WITH COMBINED PHYSICAL AND ORGANIZATIONAL SIMULATION

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ABSTRACT

Simulations that incorporate both physical (hard) as well as psycho-social human behaviours (soft) are expected to improve situational awareness during critical events, yet are not readily available. Because of the complex nature of emergency response and, in particular, because of the potential for unforeseen interdependencies in the physical environment, it is difficult to objectively assess the effectiveness of organizational response practices. To overcome this challenge, both the reality of the physical environment and the impact of human organizations must be represented explicitly. We combine two existing simulators to offer a holistic picture that integrates the “hard” and “soft” factors. We discuss the interaction of these simulators for both “as-is” and “what-if” scenarios related to an actual case study. It is expected that this integrated simulation approach will help to discover best practices and policies that would improve the effectiveness of operations for real-world organizations in disaster situations.

Index Terms**—** Hybrid Simulations, Best Practices, Multi-agent Systems, Emergency Response

1. INTRODUCTION

Organizations, especially in emergency response, form key behaviours over time. These “best practices” are learned standards that work in specific situations to reduce failures and improve flow of communications within organizations as well as social structures. They are typically developed over time through experience of individuals within an industry or organization in a “trial and error” fashion that can be expensive, costing both time and money. They may arise as lessons resulting from potentially devastating loss or failure. There are disadvantages to trial and error discovery of practices such as limited scope, i.e., they may not be applicable in a variety of situations. Also, understanding the effectiveness of a particular best practice is challenging as in-vivo analyses are difficult to organize, execute, and assess.

The root difficulty in discovering best practices is simply that reality is often more complicated than any proposed best practice and must be considered appropriately. Both the physical (hard) and human (soft) factors are equally important in understanding this reality. The physical refers to tools, technologies, and structures used by organizations (e.g., critical infrastructure). The human refers to individuals and their interactions within the organizational structure and the resulting social dynamics and cultures.

A simulator that accounts for both advantages of the physical and the human through multi-agent systems programming is a potential best fit for this discovery. However, such capability is not readily available, as physical and human modelling communities have distant goals. This work aims to bridge this gap with the development of a hybrid simulator. We build on previous work involving human modelling and policy analysis of a joint emergency response situation [1] (using the Brahms agent-based framework [2]) and also the modelling of culture [3]. For physical simulation the I2Sim framework has been developed and tested on modeling complex physical infrastructures [4]. This paper targets the convergence of these two simulators towards the goal of improved best practice discovery and testing capability.

The contributions are three-fold: i) an approach for combining physical and agent-based simulators, ii) a holistic simulator for exploring best practices, and iii) a case study using the simulator to model a historical emergency. We begin with a discussion of the historic case study as a backdrop to the integration of simulators.

2. HISTORICAL CASE STUDY

In this work, the case under consideration involves a critical incident at a university steam plant, where a boiler failure resulted in a heat shortage and impacted the winter operations of the university. The scenario is described as follows. During routine steam plant repairs, a combination of factors led to a boiler being restarted while there was still water in its pipes. This led to a large water-hammer explosion that ruptured the boiler releasing steam into the plant and requiring a hasty evacuation of the immediate area. The plant provides steam to the university campus, as well as to the university hospital. At the hospital, the steam is used to both heat the hospital and sterilize the equipment and bedding.

As a result of the explosion, temperatures in buildings on campus and at the hospital decreased, forcing the hospital to consider evacuating patients, and the university emergency operations center (EOC) to meet to monitor and adapt to the crisis. Through a course of events involving a series of meetings of the EOC, as well as the hospital's and city's EOCs, the steam issue was resolved, but not before hospital evacuation procedures were put into place. Even though the hospital was able to cancel the evacuation once normal steam levels were restored, the incident nonetheless affected the immediate hospital's operations for several days as well as the operations of neighbouring hospitals that had to begin preparations for receiving the evacuated patients. The consequences in the end were related only to delayed business operations of the various institutions. However, this is an important factor to consider when exploring best practices in emergency response, especially in a society dominated by economics, as following an incident, business continuity is second in importance only to saving human life.

For the case study, the steam plant, internal boilers, and steam pipes were modelled, in addition to the hospital and a simplified campus. Also the steam technician, hospital representative, and the various members of the university EOC were modelled. It should be noted that meeting transcripts, telecommunication logs, and policy guidelines were used to create the model. However, the validation that the model accurately captures the procedures employed on the day of the incident remains to be performed.

3. DEVELOPING HYBRID PHYSICAL AND ORGANIZATIONAL SIMULATION

Based on the case study, two models were created: one representing the physical reality of the campus and hospital and the critical interdependencies between them; and the other representing the organizational reality of the policies employed. For the physical reality, I2sim, an infrastructure interdependency simulator developed at UBC [4], was utilized to show how various parts of the system are interconnected and how consequences in one area impact on other areas. For the organizational reality, the Brahms multi-agent simulator developed at NASA [2] was utilized. Its particular strength is that it is capable of capturing a "day-in-the-life" of an employee, showing what activities are performed by an employee under particular situations defined in preconditions. The output is a timeline showing the actions of the employee in time as the result of encountering different situations.

In order to combine the simulators, the organizational agents have a built-in model of the physical reality. The details of the physical reality are hidden from most agents. For example, the hospital representative does not need to understand how the steam plant operates. However, as it relates to understanding the situation and enacting a particular policy, the steam technician agent is aware of the components of the steam plant. A shared ontology used to describe the components of the physical layer allows information from the physical simulator to be directly understood by the agents in the organizational simulator and agent actions to be directly understood by the physical simulator.

Furthermore, because both are discrete-event simulators, a specific synchronization interval can be defined in which the latest values from each are exchanged. Once these values have been received, each simulator then resumes its simulation run until the next synchronization point is reached or the simulation ends. Thus, each simulator is able to hide low-level details by exposing only a communication interface. This is sufficient to constrain the physical simulator to the operational directives of the organizational simulator, and the organizational simulator to the physical consequences of the other.

4. EXPLORING POSSIBLE OUTCOMES

Starting from the initial physical and organizational models that capture what took place during the actual incident (i.e., the "as-is" scenario), the various physical points impacted by organizational policy were identified. Three of these points were then selected to develop "what-if" scenarios that correspond directly to two specific organizational policies: (i) the boiler restart procedure used (cautious or aggressive) and (ii) how the steam is distributed between the campus and university hospital. Figure 1 shows the possibility tree that results from considering different combinations of the two policies.

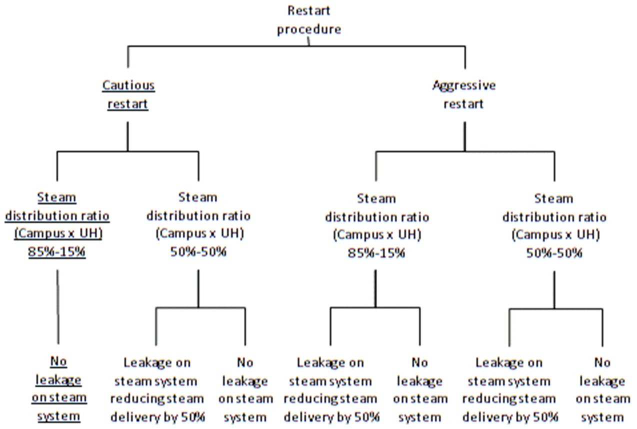

Fig. 1. Decision tree for a steam plant technician in an emergency.

In an aggressive restart procedure, more boilers are brought online sooner with increased steam production. This might negatively impact the system, resulting in further damage which is represented as additional leakage. However, if the system is very sensitive, even a cautious restart might cause additional damage. The probability of further damaging the system, while unknown, is assumed to be much greater under the aggressive restart procedure. In addition to showing the various what-if scenarios, the tree also highlights the branch representing the historic case.

The purpose of the what-if scenarios is to determine if alternative procedures—and, thus, underlying policies—can achieve better results than those procedures used during the historic case.

5. RESULTS

A metric for objectively comparing the results must be decided. The most devastating consequence in the case-study incident is the potential evacuation of the hospital. The earlier the decision to cancel the evacuation is made, the less impact it will have on the university hospital and other hospitals in the vicinity. Therefore, the time of the evacuation cancellation (TEC) is the metric used for comparing the various scenarios.

In the case study, the hospital representative cancels the evacuation when the steam received by the hospital is above the "normal" threshold. Thus, in the figures that follow, the value will either be 1, meaning no evacuation is currently being considered, or 0, meaning an evacuation is being considered. If the state remains in 0 after a particular deadline, then the evacuation will occur. However, in all cases presented in this paper, as in the historic case, the evacuation was cancelled before the deadline was reached.

In the historic case, the steam technician after restarting the boiler and hearing the pipe beginning to burst evacuates the building and waits for confirmation that it is safe to reenter (see Figure 2). Once back inside the heating plant, repairs are performed, and the plant is restarted following approval from the university EOC. Afterwards, the heating system is adjusted over a period of three hours until normal steam levels are achieved for both the campus and the university hospital.

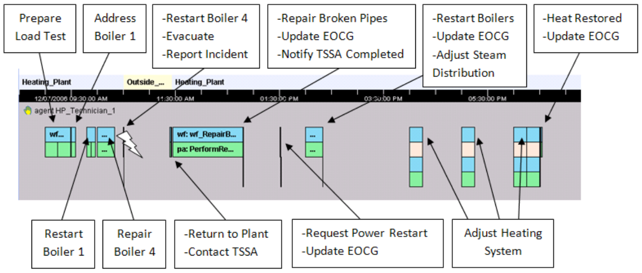

Fig. 2. Annotated timeline showing the activities of a steam technician in the historic case scenario.

The result of the historic case (see Figure 3) is used as a benchmark for the results of the what-if scenarios. During the historic case, the criteria used were as follows: cautious restart procedure, 85/15 split between the campus and hospital, and no additional leakage in the system. The TEC under these conditions is 600 minutes, 480 minutes after the initial incident and 270 minutes after the steam restart was initiated.

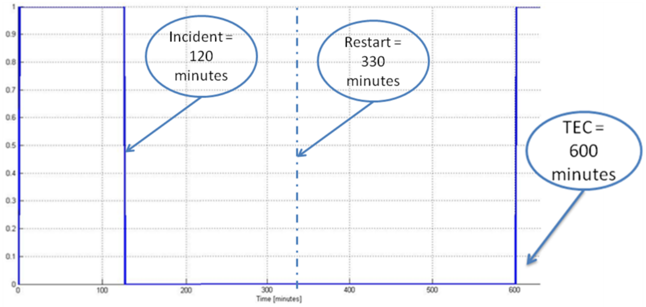

Fig. 3. Result of the historic case scenario.

For the first what-if scenario, the criteria used are as follows: cautious restart procedure, 50/50 split between the campus and hospital, and no additional leakage in the system. By changing only the steam distribution ratios, the TEC is reduced by 150 minutes to 450 minutes, a savings of 2.5 hours (see Figure 4).

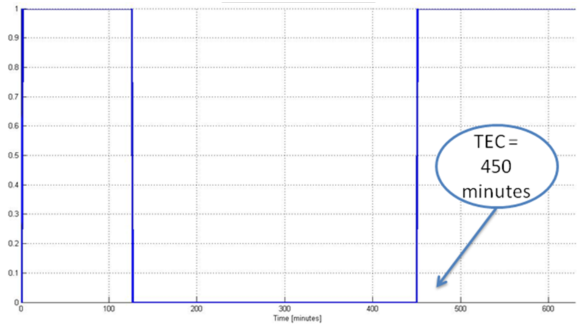

Fig. 4. Result of the first "what-if" scenario.

For the second what-if scenario, the impact of a different restart procedure is examined. As such, the criteria used are the same as in the historic case, except using the aggressive restart procedure. Under these conditions, the TEC is also 600 minutes, suggesting that steam distribution is the dominant factor in the system (see Figure 5).

The final what-if scenario presented is that of combining an aggressive restart procedure with a 50/50 split between the campus and hospital, again with no additional leakage. This particular configuration resulted in a TEC at 320 minutes, the best result achieved across all what-if scenarios (see Figure 6).

The additional steam leakage parameter allows for the exploration of scenarios where, for example, an aggressive restart will further damage the system and result in increased leakage. This parameter results in increased TEC over the various scenarios, and the exact increase will depend on the extent of the additional leakage. It is important that this reality be simulated in the model, i.e., that there be the possibility of negative consequences. Otherwise, the best course of action will always be to use the aggressive restart procedure, with a 50/50 distribution split.

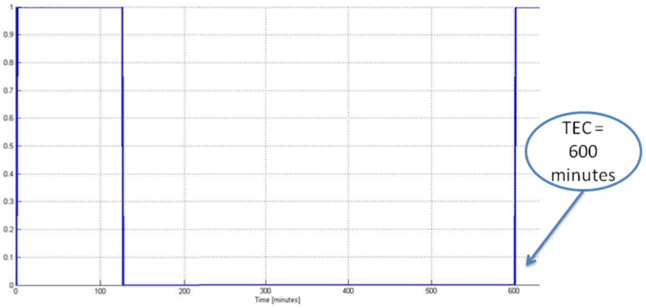

Fig. 5. Result of the second “what-if” scenario.

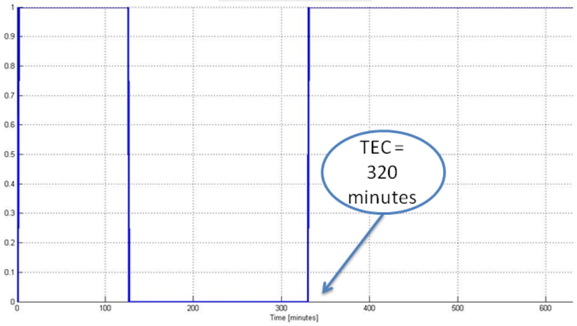

Fig. 6. Result of the third “what-if” scenario.

6. DISCUSSION

In the face of uncertainty, the results of the joint physical and organizational simulators provide responders with information on a wide-range of possible alternatives. These alternatives can be further refined (pruned or elevated in importance) as more information becomes available. Even though none of the alternative solutions may be optimal, they nonetheless provide a fuller picture of the possibility space faced by the responders and allow them to make more informed decisions about the practices and policies used. In the case of the steam plant, for instance, if information about the damage level of the system is not available, the responders will need to weigh the advantage of using an aggressive restart procedure, which could further damage the system, over a cautious one.

In analyzing the results of the joint simulation runs, it becomes clear that the most crucial policies are those related to the steam distribution. Therefore, in addition to supporting emergency responders, the approach of combining realistic physical and organizational simulators can also be used to help inform future capital investment decisions, for example, ensuring that the physical mechanisms necessary to enact the 50/50 distribution policy are in place.

7. CONCLUSION AND FUTURE WORK

In this paper, the results from joining a physical and organizational simulator were shown. For a real-world case, the combined simulators were able to show the impact of different organizational policies on the physical reality of the system. While this is still preliminary work, it was able to show policy configurations that achieved better results than the historic case, pointing to better practices in the face of hospital steam incidents.

In discovering best practices, it is important that the most appropriate policies in one case be suitable over the entire class of similar cases. To achieve this, a database of incidents should be maintained and physical models created to determine if the policies from the organizational simulator are generally applicable. It would be interesting to analyze these cases to see what similarities exist and which policy configurations achieve the best results in general. This we leave for future work, along with expanding the physical model and policy space.

8. ACKNOWLEDGEMENTS

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