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Validation of Crisis Response Simulation within the Design Science Framework

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Research-in-Progress

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Abstract

In design science research in information systems (DSRIS), validation is often neglected in exchange for an emphasis on evaluation. However, rigorous scientific contributions most often explicitly address validation. In order to address the complexity of validation within design science, an explicit recognition of the assumptions and methods used within the DSRIS framework is needed. In this paper we discuss an approach to validation in a research in progress aimed at theory development in coordination of crisis response, through the use of agent-based simulation. This enables validation to be discussed from the point of view of simulation, the agent-based approach and the domain of crisis response, underpinned by a hermeneutical epistemology. Other research endeavors within DSRIS can follow a similar strategy to deal with the issue of validation.

Keywords: Design science, validation, agent-based simulation, crisis response

Introduction

The discussion around rigor vs. relevance in information systems research (ISR) has been around for some time, focusing on the nature of ISR, on the interaction between researchers and practitioners, and on the tension between the design of information technology (IT) artifacts and the development of theory, among others. While some provide recommendations for increasing the relevance of ISR outputs (Benbasat et al. 1999; Gill et al. 2009), others provide suggestions on how to improve the rigor (Boudreau et al. 2001; Lee et al. 2009). The increasingly used and accepted design science research in information systems (DSRIS) would seem to provide an adequate framework for ISR which is both rigorous and relevant (Hevner et al. 2004; Winter 2008). However, the epistemological foundations and the role of theory development and validation in DSRIS are still unsettled, leaving open questions for the actual practice of relevance and rigor.

The agreed upon genesis of design science lies in Herbert Simon's The Sciences of the Artificial (first published in 1969) in which he articulated the difference between natural science, concerned with how things are, and design science, concerned with how things ought to be, based on his understanding of design as problem solving (Simon 1996). Following Simon's tradition, design science was introduced in ISR by March and Smith (1995), who presented it as corresponding to prescriptive research aimed at improving IT performance, as opposed to natural science, corresponding to descriptive research aimed at understanding the nature of IT. An important point was that ISR should actually integrate both perspectives, an argument that came back on the more recent and highly influential paper on DSRIS (Hevner et al. 2004). However, with almost a decade in between there is an interesting revision worth noting. March and Smith (1995) attach the activities of *Discovery* (generating or proposing scientific claims) and *Justification* (testing scientific claims for validity) to natural science and present them as separate from (but parallel to) the activities of *Building* (constructing an artifact for a specific purpose) and *Evaluation* (determining how well the artifact performs) attached to design science. In Hevner et al. (2004) the activities were merged into *Develop/Build* and *Justify/Evaluate*. This helps state the case in favor of having both relevance and rigor in ISR, but may also leave behind lack of clarity with regards to how theory development should be seen in

DSRIS. On one end of the spectrum, March and Smith (1995) explicitly exclude theory and theorizing from design science. On the other end, several authors contend that theory development should be an intricate part of DSRIS (Kuechler et al. 2008; Markus et al. 2002; Walls et al. 1992). Hevner et al. (2004) do not seem to take a stance either way. This paper takes that view that DSRIS could be used for theory development (leaving aside the question of whether it should). However, this still leaves open issues around epistemology and validation.

Epistemological issues may arise when asking what kind of theory can be developed through DSRIS. Walls et al. (1992) speak of design theories, which are prescriptive theories about how to design information systems effectively and feasibly. Venable (2006) claims that design theories should be reduced to utility theories, which are predictive (rather than prescriptive) about the utility of applying a meta-design to solve meta-requirements. Theory can also be related to the kinds of artifacts produced by DSRIS, which according to March and Smith (1995) may be constructs, models, methods and/or instantiations. For Winter (2008) theories should be considered a fifth (intermediate) type of artifact. In contrast, Gregor and Jones (2007) take a broad view of theory which encompasses constructs, models and methods, and where only instantiations correspond to the (material) artifact as such. According to Iivari (2007), it is precisely the difference in the type of knowledge produced which determines the epistemology underlying DSRIS. Gregor (2006), however, has strongly argued that the type of theory produced in ISR should not depend on the underlying paradigm; for her, theory is actually independent from specific ontological or epistemological positions. Nonetheless, the question of how (or if) to validate the resulting theory does depend on an underlying epistemology (Niehaves 2007).

This paper presents different perspectives for validating a research in progress aimed at improving IT-supported coordination in the domain of crisis (emergency) response. The theoretical development is an extension of the information-processing view of coordination – e.g. (Galbraith 1973; Malone et al. 1994) – with notions from emergence, leading to new design principles for developing and using IT to support coordination of multiple response agencies in case of an emergency. An agent-based simulation model is built to enable comparison between different coordination mechanisms and showing how emergent coordination can be achieved. This enables both an improved understanding of coordination in the domain of crisis response, as well as providing a testbed for experimenting with different mechanisms that imply different designs and uses of IT. We follow Gregor and Jones (2007) in placing our theoretical contribution within DSRIS as composed of constructs, models and methods. The concepts of coordination are combined with the concepts from emergence and represented through an agent-based model for which a specific development methodology is used. The resulting simulation model constitutes the instantiated artifact.

The rest of this paper starts by presenting the design science framework as approached in this research. This leads to a discussion of validation in DSRIS, focusing on the relationship between theory validation and artifact evaluation. Depending on epistemological considerations, artifact evaluation can serve as a way to validate the underlying theoretical contribution, so validation of the simulation model itself needs to be considered. Accordingly, we discuss validation fro the point of view of simulation and then within the agent-based context in particular, where epistemological issues also arise. Finally, we briefly discuss validation of agent-based simulations within the context of crisis response. The final section summarizes the approach to validation that results from the discussion and pints to the next steps in the research.

The Design Science Framework in Information Systems Research

Design science, as a problem-solving paradigm for ISR, seeks to create innovations that define the ideas, practices, technical capabilities, and products through which the analysis, design, implementation, management, and use of information systems can be effectively and efficiently accomplished (Hevner et al. 2004). As such, a DSRIS contribution requires identifying a relevant organizational IT problem, demonstrating that no solution exists, developing an IT artifact that addresses this problem, rigorously evaluating the artifact, articulating the contribution to the IT knowledge-base and to practice, and explaining the implications for IT management and practice (March et al. 2008). Let us recall the basic framework for ISR from the perspective of DSRIS in Figure 1.

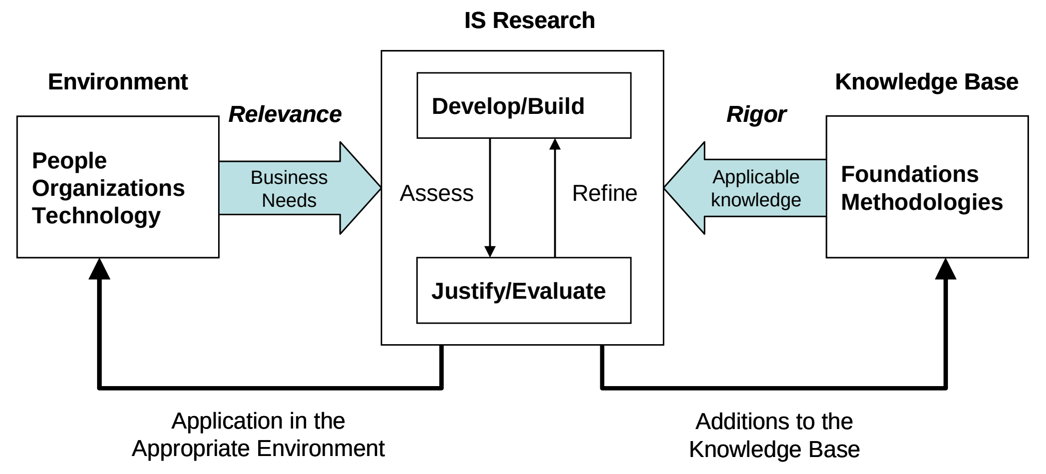

Figure 1. Information Systems Research Framework, adapted from (Hevner et al. 2004)

The dual goal of relevance and rigor in ISR has already been mentioned as key to DSRIS. The framework in Figure 1 suggests that relevance is attained through identification of business needs and application of an artifact within an environment, while rigor is achieved by appropriately applying existing foundations and methodologies to both the construction and evaluation of the artifact (Hevner et al. 2004). Later, Hevner (2007) presented these as the *Relevance Cycle* and the *Rigor Cycle*, respectively. In addition, the central component in Figure 1 (IS Research) is achieved through a *Design Cycle* in which the artifact must be tested thoroughly before "releasing it" to the *Relevance Cycle* and before the knowledge contribution is output into the *Rigor Cycle*.

Since design science is issue-driven, rather than theory-driven, e.g. (Klabbers 2006), the *Relevance Cycle* guided the start of the research in progress that this paper relates to. An initial literature study of coordination in crisis response and of the role of IT in supporting it provided an initial set of open issues. The *Rigor Cycle* then provided a conceptual framework for studying coordination in practice and for identifying the limits of the knowledge-base that constitute the opportunity for theory extension (i.e. the information-processing view of coordination). This led back to the *Relevance Cycle* for a case study in which observation of crisis response exercises provided empirical content to the theoretical concepts and contributed to identifying context-dependent business needs. As a result of the findings from the case study, the *Rigor Cycle* continued, committing to emergence as a source for improving coordination in crisis response and as a potential extension to the theory of coordination in this setting. This included the study of emergent coordination in multi-agent systems and to background notions of emergence in general. With these elements, the *Design Cycle* as such began. Simulation is used as the guiding strategy for this core cycle, for the following reasons: 1) simulation can be used for theory development/extension (Davis et al. 2007) and is inherently suitable for iterative testing before returning to the relevance and rigor cycles, 2) agent-based simulation in particular can be used to study emergent coordination (Macy et al. 2002), and 3) simulation is an adequate research method in crisis response were collecting data or directly implementing artifacts can be prohibitively expensive or risky (Kleiboer 1997). This use of simulation within the DSRIS framework opened up questions regarding validation which we will address in the rest of the paper.

Validation in Design Science Research in Information Systems

Many DSRIS accounts focus on evaluation, rather than validation (Hevner et al. 2004; Kuechler et al. 2008; March et al. 2008; Peffers et al. 2007). Thus, an open question is what validity might entail within DSRIS, as compared to evaluation. On the one hand, any artifact resulting from DSRIS should be assessed against a criteria of value or utility (March et al. 1995). Such criteria depend on the type of artifact produced, e.g. constructs are evaluated against completeness, simplicity, elegance, understandability and ease of use, while implementations are evaluated against efficiency, effectiveness and impact (March et al. 1995). On the other hand, design theories are subject to empirical validation (Walls et al. 1992). Utility theories, for example, are stated in terms of efficacy, effectiveness and perhaps elegance or ethicality (Venable 2006). It would seem then that evaluation corresponds to the artifacts and validation to the theory, but this distinction becomes murky when the theory is expected to be validated through the artifact.

The premise behind using the artifact to validate the theory is that theories are intended to correspond to reality, but reality cannot be directly apprehended (we only have perceptions and representations) so we need to prove the effectiveness of theories through practical applications (March et al. 1995). Furthermore, when it comes to design theories, even if they pass scientific tests of explanatory or predictive power, they must also pass the test of practice (Walls et al. 1992). Since domain-independent design theories cannot be assessed directly, they require domain-dependent knowledge and the creation of a domain-specific design theory used to develop a real system (Käkölä et al. 2008). This understanding of validation corresponds to the pragmatist philosophy according to which truth is utility or "what works in practice" (March et al. 1995). In this view, the evaluation of the artifact corresponds to the validation of the truthfulness of the design or utility theory that it embodies (Venable 2006; Walls et al. 1992). Others take a more radical view by stating that artifacts have no truth, only utility (Iivari 2007; March et al. 1995). In this case, validation is not done against a measure of truth, but rather against a measure of pragmatic value determined by pragmatic success (Moody 2003). This might actually render pragmatism as an inadequate epistemology for DSRIS, because it is not about equating truth with utility, but rather about doing away with truth altogether, which is more akin to constructivism. Thus, the assumption that DSRIS is based on pragmatism, though widely held, does not hold for all kinds of DSRIS, making it open to alternative epistemologies, such as interpretivism (Iivari 2007; Klabbers 2006; Niehaves 2007).

Even assuming a pragmatist/constructivist view of validation through artifact evaluation, it remains problematic for the following reasons. While acceptance of the artifact might be seen as a conventional way to validate prescriptive knowledge, such acceptance is not an inherent aspect of the artifact, because the artifact might be accepted years after its construction and because the artifact is typically weakly linked to the underlying theories (Iivari 2007). In addition, attempts at partly overcoming the validation problem through pragmatic success should still recognize that even if the theoretical propositions survive the empirical test, this status of being valid is always tentative and temporary (Lee et al. 2009). This corresponds to Popper's philosophy of science, according to which theories are only provisionally valid, or rather, corroborated or confirmed until refuted (Lee et al. 2009). Moreover, a plausible but unsuccessful artifact suggests contextual limitations rather than disconfirmation or falsification (Kuechler et al. 2008). Furthermore, even if the theory is falsified, a researcher can still invoke auxiliary hypotheses to defend it (Lakatos 1978).

Despite the above challenges, in DSRIS the relation of a designed artifact to theory is extension and refinement, rather than disconfirmation (Kuechler et al. 2008). This fits with the iterative nature of the *Design Cycle* (and its corresponding simulation strategy) suggesting that validation can still be achieved through the simulation artifact, which is why we need to look at validation and artifact evaluation from the point of view of simulation as well.

Validation through Simulation

A straightforward use of simulation is DSRIS is aimed at supporting the artifact assessment by supplying an artificial setting for testing its potential utility and thus validating the underlying theory. An example of this can be found in Chang (2008). In this example, two theories (prospect theory and mental accounting) are combined into an artifact (a pricing system) and evaluated for perceived utility through simulation (using performance measures). The simulation results reveal that the prices obtained are superior to those obtained through pricing systems based on expected utility theory, thus demonstrating the value of the theory embedded in the artifact. Another example (Muntermann 2009) proposes a simulation-based evaluation approach to determine the (potential) value of an artifact. In this case, the artifact is a prototype of a mobile financial notification decision support system based on underlying forecasting models. Since it is a prototype, market adoption lies potentially in the future and thus *ex ante* evaluation is needed. The simulation provides the setting for empirically testing hypotheses about the value of the DSS on the basis of historical and artificial data. Both examples follow the view that utility ultimately determines the value of the artifact (and of the underlying theory) but since simulation is used to determine this (potential) value, the simulated performance is as valid as the simulation models that are used to test it.

In our case, simulation is not used for assessing a separate artifact, but rather the simulation model is the artifact itself which is built inside the *Design Cycle*. The model operationalizes the theoretical constructs (Davis et al. 2007) and can thus be used to extend and refine the theory. This means that the simulation is used with the dual purpose of instantiating the constructs, methods and models obtained from the *Rigor* Cycle while at the same time enabling experimentation to test and extend those same notions iteratively. This is consistent with Simon's view that simulation can provide new knowledge by working out the implications of premises or assumptions we already know, or by using simplified models in which new aspects arise out of the organization of the parts in poorly understood systems (Simon 1996). According to Kriz and Hense (2006), simulation can be used to bridge the gap between analytical (natural) science and design science, because it has a dual position. First, the simulation model itself is designed as an artifact using knowledge from analytical science and is subsequently translated into concrete context-dependent circumstances and evaluated according to the theory. Second, after having been evaluated, the simulation model itself can be used analytically for theory testing. This follows the DSRIS premise that design is science when the design is aimed at instruments to test theories (Walls et al. 1992). The dual use of simulation does not preclude the validation of the simulation model itself, which is why we need to discuss validation in this context.

Model Validation in Simulation

Simulation model validation is equivalent to substantiating that the model, within its domain of applicability, behaves with satisfactory accuracy consistent with the study objectives (Balci 1994). In terms of DSRIS, the domain of applicability and the study objectives are determined by the *Environment* (see Figure 1). But the "accuracy" is where we encounter problems. The fundamental difficulty in validating both simulation models and scientific theories has to do with the problem of induction; that is, inferring from observations of a real system that the model (or theory) captures essential structures and parameters of said system (Kleindorfer et al. 1998). The simplified assumption is that any deviation from the real world output is a result of errors that diminish the model's validity. However, design should be aimed at changing existing situation into preferred ones (Simon 1996), so deviation from the "real world" is precisely what we are aiming for. This shift from predictive simulation models (where accuracy is fundamental) to simulation for improving understanding and performance implies a shift in epistemological emphasis as well.

Broadly speaking, the epistemological focus in simulation may have an objectivist or relativist character (Kleindorfer et al. 1998). Extreme objectivism purports that model validation is independent from the builder and the context. Extreme relativism believes that all models are equally (in)valid, as this is a matter of opinion. In practice, most modelers adopt an intermediate strategy. This can be understood epistemologically as hermeneutics, which advocates for enough constraint to guarantee stability and meaning, yet no so much as to stifle autonomous and creative action. The "hermeneutical circle" in simulation holds that there is a continual play back and forth whereby our understanding of general principles is increased as we interpret the particulars in a given application. Furthermore, there is a recognition that this "playing" with a simulation model – or a theory – is a way of effecting its validation (Kleindorfer et al. 1998). One can see the parallel between this "play" and the *Design Cycle* in DSRIS. First, construction of the simulation model is a fundamental step in the validity of the simulation results (Becker et al. 2005). Second, validation (along with verification of the model) is not a phase or step in the lifecycle, but a continuous activity throughout the simulation lifecycle (Balci 1994).

Accordingly, we depart from the use of simulation solely as lab experiment, as in (Kriz et al. 2006; Muntermann 2009), which is objectivist and thus tied to natural/analytical science, despite the pragmatist criteria of value. A view of simulation which is more adequate for design science has been proposed by Klabbers, e.g. (2006), using non-trivial machines and concepts from complex adaptive systems. This changes the emphasis from being variable-centric, to being process-centric, as well as shifting the focus from the "community of observers" to the "community of practice". This shift implies two things: first, the artifact's meaning is constructed by the community of practice in its context of use; second, the representation shifts from a trivial machine to an actor system. The first consequence is dealt with by recognizing the underlying epistemology of heremeneutics and points towards expert validation, the second consequence is dealt with by adopting an agent-based approach to simulation which fits with the actor system perspective. Thus, we go on to discuss validation in the context of agent-based simulation.

Validation in Agent-Based Simulation

Agent-based simulations address the "what-if" question as do other simulation approaches, but also deals with the interaction between local and global, micro and macro, individual and emergent behavior, and structure vs. chaos (Davis et al. 2007; Louie et al. 2008; Macy et al. 2002). The consequence, in terms of validation, is that model validity can no longer simply be understood as how close the computed behavior is to the "real" answer, because there is no "real" answer" when we are dealing with "what-if" analysis. In this case, face-value expert validation often takes the place of quantitative or statistical validation techniques (Dooley 2002).

This distinction between quantitative/statistical validation and face-value expert validation is crucial in agent-based simulations. In general, multi-agent models of social systems represent a new approach to simulation for which traditional validation methods are not always applicable (Louie et al. 2008). This creates a challenge for validation of agent-based simulation and is the source of much of the criticisms that it receives as a research method. Such criticism, however, arises from a different perspective on the use of simulation, as the following summary of (Louie et al. 2008) shows. When the criticism surrounds the lack of real-world data for grounding the simulation model, the reply should be that the purpose of the simulation may not require data (in fact, this might be precisely why simulation is needed, to see how data might look like) or that the lack of data does not preclude systematic and formal attempts to understand how a system behaves. With regards to the criticism that experts may disagree as to the validity of the model, the reply should be that the model is used precisely to try out, guide and refine diverging assumptions and mental models (not to determine their correctness). Against the prospect of not being able to use traditional validation techniques, the use of agent-based models is not disqualified because it enables theory development about social processes that other simulation approaches are not amenable of doing and sensitivity analysis can still be employed to determine how individual factors influence emergent system behavior. When the criticism is that agent-based simulations (as well as DSRIS) are derived from the interaction of multiple theories, potentially violating the *ceteris paribus* assumption behind natural science theory validation, this is clearly at odds with the expressiveness obtained precisely from such a multi-disciplinary background and ignores that theory development in this context does not require isolation, but rather encourages development across multiple levels of analysis and using multiple theories to drive the dynamics, while maintaining control over the variables.

Only one dimension remains in our exploration: the domain of crisis response. In the following section we look briefly at what the relationship is between crisis response and simulation and what this implies for validation.

Validation in Crisis Response Simulation

Simulation can be used when the cost of collecting data is prohibitively expensive or there are a large number of conditions to test. In crisis response there is a large number of heterogeneous response agents and a large set of environmental variables. This, along with the unpredictable nature of crises and the difficulty in planning real-life experiments, make simulation an adequate alternative for doing research in crisis response. For example, simulation can be used to rapidly examine previously unexamined alternatives (Louie et al. 2008) or to provide a more economical method of testing contingency plans and practicing coordination between different response agencies (Kleiboer 1997). Agent-based simulation in particular can be used to define behavior down to the individual agent level, which is useful in modeling emergency response to a disaster (Robinson et al. 2005).

However, there are several challenges related to validation of crisis response simulations. Integrating micro-level simulations to observe system level progression of a disaster requires validating a simulation of a potentially chaotic event and this is difficult due to scarcity and inconsistencies in actual data for comparison (Robinson et al. 2005). Other challenges include: interoperability between emergency response modeling and simulation applications; availability of good reference models or historical data; and interpretability of the simulation data (Jain et al. 2003).

Conclusion

This paper reviewed some of the literature on DSRIS to reveal diverging positions or ambiguity with respect to validation, theory development and epistemology. More specifically, it has shown that evaluating the pragmatic success of an IT artifact, as a way to validate the theoretical contribution of the DSRIS project which produced it, is problematic and epistemologically contingent. As a result, validation is framed according to the underlying epistemology (hermeneutics), the use of simulation (agent-based) and the domain (crisis response). This creates a consistent basis for validation of the research contribution in which the limitations are recognized, the understanding of validation is made explicit, and the choice of validation techniques is better informed, pointing at the use of sensitivity analysis and face validity, as well as incorporating additional rigor in using simulation and experimentation methods transparently.

The next steps in the research will be to carry out experiments and validation of the simulation model, through sensitivity analysis and expert face validation. Only after this has been completed, can the *Design Cycle* be completed and the contribution ready for going back into the *Rigor Cycle* as an addition to the knowledge-base. On the other hand, the simulation itself can also be ready for actual use inside the *Relevance Cycle*. Specifically, it can contribute to training in new forms of coordination and to designing new artifacts that support emergent coordination in crisis response.

In general, other researchers using design science should be careful and explicit regarding their epistemological assumptions, the role of theory development, the methods employed and the implications in terms of validation (and its associated techniques). When the cost or risk of implementing or evaluating the artifact in the real world is too high, simulation can provide an appropriate way of theory development and validation, as opposed to waiting for the artifact to be adopted in practice before publishing results that can still be presented rigorously for a relevant problem. In addition, a recognition of epistemological and theory-development choices will deeply influence the way in which validation is approached. If we agree that validation is an intrinsic part of science, then such an effort could help strengthen the science of design.

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