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David Paradice
Harbert College of Business
Auburn University
dparadice@auburn.edu

James Parrish
College of Business
University of North Texas

Sandra Richardson
Fogelman College of Business & Economics
University of Memphis

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David Paradice
Harbert College of Business
Auburn University
dparadice@auburn.edu

James Parrish
College of Business
University of North Texas

Sandra Richardson
Fogelman College of Business & Economics
University of Memphis

Abstract:

We review a 30-year period of systems design efforts focused primarily on the design, implementation, and validation of a DSS to support managerial problem formulation. We do so with intimate knowledge of the projects, having either been (1) directly involved in the projects ourselves, (2) directly involved as mentors to the principal researchers, or (3) indirectly involved as colleagues of the principal researchers and in near proximity of the studies when they occurred. We identify prelude projects that lead to the definition of a broadly defined objective: the grand challenge. Foundation projects refine the capabilities and concepts needed to achieve the grand challenge. Realization projects follow in which the grand challenge is achieved. We argue that a grand challenge perspective allows us to see more clearly how individual DSR efforts contribute to a cumulative body of knowledge while simultaneously providing a context for the evaluation of individual projects. A grand challenge perspective can also guide design science research.

Keywords: Design Science, Cumulative Research, Decision Support Systems, Problem Formulation.

1 Introduction

In this paper, we examine a series of IS projects that occurred over a 30-year period. We do so with intimate knowledge of the projects, having either been (1) directly involved in the projects ourselves as principal researchers, (2) directly involved as mentors to the principal researchers, or (3) indirectly involved as colleagues of the principal researchers and in near proximity of the studies when they occurred. This frame of reference gives us insight into specific project results as well as insight into the overall stream of research. Our review covers 12 doctoral dissertations, 23 peer-reviewed journal articles, and 16 conference proceedings and other works that document the studies. The research stream addresses the grand challenge of developing a DSS for managerial problem formulation. By examining these projects as a grand challenge, we can better understand the nature of grand challenges in general.

As Winter and Butler (2011) explain, the effort to attain a grand challenge "seeks to drastically alter the boundaries of existing knowledge, established disciplines, and available capabilities" (page 100). A grand challenge requires collaboration among researchers across projects that may occur over many years (perhaps decades). These researchers bring different perspectives to the pursuit of the grand challenge. They develop new practices, processes, and norms and they build on each other's successes. Researchers make a large investment of time and effort because they perceive succeeding in the grand challenge will significantly impact not only their academic field but also other academic fields and the world at large. According to Winter and Butler (2011), the IS community has not yet adopted the grand challenge terminology or tradition. The closest they come to identifying an IS-oriented grand challenge is the research in AI to develop a chess-playing computer. Several IS researchers have suggested the design science research community would benefit by looking to grand challenges in research programs (Larsen et al., 2010; Hovorka et al., 2012; Grover et al.; 2015).

Recognizing that some of the projects we review were executed years before the term design science research became established, we nevertheless refer to these as design science projects because they share the same goal and many of the same processes as their post-establishment counterparts. We propose that individual projects in pursuit of a grand challenge reflect theorizing rather than theory development. Runkel and Runkel (1984) note "theory belongs to the family of words that includes guess, speculation, supposition, conjecture, proposition, hypothesis, conception, explanation, model." Weick (1995) uses this insight to observe that theorizing, while not the same as theory, is still valuable because it captures the "interim struggles in which people intentionally inch toward stronger theories." When we evaluate individual projects from a perspective of theorizing, rather than a perspective of theory, then the value of these projects can be more accurately assessed. In this way, the standard changes from evaluating good theory to evaluating good progress toward a theory.

In our analysis, we find a pattern of activity in pursuit of a grand challenge. This activity involves prelude projects in which the grand challenge begins to take shape, foundation projects aimed at establishing building blocks needed to achieve the grand challenge, and realization projects that realize the goal implicit in the challenge. Prelude projects are early projects that explore an idea. If a grand challenge has been identified, prelude projects may focus on the design and development of system capabilities believed to be important to realizing the grand challenge. In some cases, however, prelude projects may be executed before a grand challenge is identified. In this case, the prelude projects typically bring insights to researchers that lead to the grand challenge. Once a system design and system capabilities are in place, foundation projects are undertaken. If the grand challenge was stated to initiate the research stream, these projects begin to fulfill the grand challenge. In the absence of an explicit grand challenge, these projects are the ones that make the grand challenge explicit. Foundation projects reflect increasing sophistication and complexity in meeting the challenge. Eventually, the research projects become realization projects, in which the realization of meeting the challenge is demonstrated by applying the systems that have been developed in new settings.

The boundaries of the project categories are not rigid and it may not be clear exactly when the projects being executed have moved from one category into another, especially since the statement of the grand challenge may not exist when the prelude and foundation projects occur. When a grand challenge emerges organically, the prelude projects may be recognizable only in hindsight. Even when the grand challenge is stated to initiate a research stream, the projects undertaken may not fit neatly into a specific category at the time they are executed. For example, a research team may believe it has all of the system capabilities needed to create a more sophisticated system only to learn that a new capability is needed. In this case, the research may have been perceived as a foundation project only to find it is more accurately categorized as a prelude project in hindsight. Still, these categories are useful for describing and discussing how the grand challenge emerges and how a grand challenge may be structured to guide a research program. In identifying these project categories, we address the lack of concepts necessary to understand the nature of a grand challenge. Further, we can use these concepts to develop an approach to a grand challenge effort.

2 Prelude – The Grand Challenge Emerges

In the early 1970s, business schools were beginning to teach management strategy using computer-based business simulations. At a time when teaching programming, hardware, and software concepts was the de facto method of introducing MIS in business schools, there was little in the way of generally accepted methods for teaching MIS design and development concepts. This situation changed when a new approach to teaching MIS concepts called the "gaming method" was developed (Courtney, Bierer, Luckew, & Kabbes, 1978). The gaming method approach used business simulation games and encouraged business students to identify decision processes, gather and organize data, and generate reports that they could use to make business strategy decisions. Students learned to use technology to repeat the process as necessary to improve performance. Students who were engaged in the gaming method approach spent less time making calculations and more time thinking about business strategy (Courtney et al., 1978).

Around this time, some researchers began to question the approach to DSS use that was commonly pursued. When DSS use was considered in light of Simon's (1960) intelligence – design – choice model of decision-making behavior, there appeared to be little attention being given to the intelligence portion of the model. In other words, DSS were being used to construct models to guide decision making, but few DSS resources were focused on formulating the structure of the model. The normal DSS use at that time involved developing one or more models and varying the inputs to them to produce a range of possible outcomes (i.e., scenario analysis), followed by choosing a course of action that reflected the set of inputs that led to the most desirable outcome. Several researchers suggested that a critical weakness in the DSS movement at this time was the assumption that the models embedded in the DSS include the correct variables combined in the proper manner (Elam, Henderson, & Miller, 1980; Wang and Courtney, 1982).

Experience with the gaming environment to teach MIS concepts led to more consideration about the type of features needed in a DSS to create a tool that managers could use to help them better understand their general business environment (Courtney, DeSanctis, & Kasper, 1983). The MIS research literature contained conceptual descriptions of DSS (Sprague, 1980; Bonczek, Holsapple & Whinston, 1981) and a number of DSS-like software packages were in the market in the early 1980s, but few systems (if any) met the criteria for a DSS generator as described by Sprague and Panko (1981). However, an ability to easily create and use computer-based models was considered critical to supporting managerial decision-making and prototype systems were being built to do this (Wang, 1981; Wang and Courtney, 1982). It is during this period that the first mention of support for general business problem structuring or general business problem formulation occurs.

A general gaming environment for teaching and studying MIS concepts, known as the Business Management Laboratory / Systems Laboratory for Information Management (BML / SLIM), was developed around this time. BML was the business game; SLIM was the DSS. While DSS generators were being used with the gaming method approach to teach MIS, other MIS researchers were building streams of research based on common laboratory environments. For example, the Minnesota Experiments (Dickson, Senn, & Chervany, 1977) and work led by Benbasat (Benbasat and Schroeder, 1977; Benbasat and Dexter, 1979; Benbasat, Dexter, & Masulis, 1981) reflected this idea of a common laboratory environment. These research streams contributed conceptually to the idea of a generalized DSS for managerial problem formulation.

The BML/SLIM environment supported studies of the utility of a DSS to facilitate decision-making processes, decision maker cognitive style, and locus of control. It also provided a platform to investigate Simon's general model of intelligence, design, and choice and the extent to which user behavior reflected Simon's concepts. Moderate confirmation of expectancy theory -- those who expected the DSS to help used it more than those who did not expect it to help – was found (DeSanctis, 1982). Students who modeled problems performed better than those who did not, and those who used their models performed better than those who built a model but did not use it (Kasper, 1983).

An insight that occurred over the course of these studies was that the effectiveness of DSS for managerial support is highly dependent on the underlying model of knowledge creation and knowledge management embedded in the DSS. Notably, these studies did not begin with this thought in mind, although research calling for support of problem formulation had been published (Leavitt, 1975; Lyles and Mitroff, 1980). A significant advantage of the BML/SLIM environment is that it allowed researchers to compare models made by subjects in the experiments with the code in the business simulation, providing an objective way of determining model correctness. These early studies showed users might develop bad models. They might also develop good models and not use them.

Traditional behavioral research had ignored these points. In the search for the dependent variable in information systems research (Delone and McLean, 1992), studies of user satisfaction, user confidence, amount of information considered, information recall, and so forth far exceeded studies of decision accuracy or precision. The researchers involved in the gaming method studies recognized the decision maker as an imperfect part of the system. Such a user could be very satisfied with decisions based on a flawed decision making model. This realization changed the focus of the research. Rather than focusing on an outcome such as user satisfaction, the focus was on an outcome such as guiding the user to a better decision making model. With these results in mind, the grand challenge of a DSS to support managerial problem formulation began to emerge. It was not yet specified explicitly, but the idea was taking shape and the feasibility of such a system was beginning to be discussed.

3 Foundation – The Grand Challenge Takes Shape

Although there was still no definitive statement that a DSS for general managerial problem formulation was the goal, the idea was being discussed among researchers. The goal of building a DSS for general managerial problem formulation required the researchers involved to deal with messy, complex issues inherent in the task of grasping the structure of managerial problems in dynamic business environments. Early discussions of the idea sought examples of work in other fields that might serve to guide the work. Many efforts in other fields were deep and narrow efforts. That is, the fields could be characterized by series of if / then statements that could lead to reasonable explanations. Narrow areas of medical diagnosis, in which specific symptoms characterized certain illnesses with high likelihood, were also being studied. A review of these efforts led to a proposition that perhaps business data could be analyzed in a similar way. That is, if a business data point (e.g., price) changes in some way, then the change in a related business data point (e.g., demand) could be predicted. The basic concept that was leveraged was a cause-and-effect construct. The cause-and-effect approach was thought to have an additional promising feature in that reversing the causality could lead to a method of explanation. That is, if a business data point changed (e.g., demand increased), then the reason for the change could be identified by looking at other data points causally related to it (e.g., price decreased or advertising expense increased).

These discussions led to a series of studies using the BML/SLIM environment to determine whether these cause-and-effect relationships could be modeled and used effectively. Chief among the design requirements discussed was the ability to represent causality in a business environment. These foundation projects began with the development of a DSS (Mohammed, Courtney, & Paradice, 1988) based on how people determine causality in events (Einhorn and Hogarth, 1982). The system also drew on research in general diagnosis (Bouwman, 1983) and directed graphs (Burns and Winstead, 1982). This work was extended by integrating a graphical capability into the construction and use of causal models drawing on a branch of systems engineering known as structural modeling (Pracht, 1984; Pracht, 1986; Pracht and Courtney, 1988). This new system also drew on work that integrated theoretical concepts related to human memory, mental imagery, and problem solving (Greeno, 1973). This research determined that a graphical capability would not help those who struggle with manipulating mental images, thus this capability did not help all subjects to better understand the business problem environment that confronted them. However, the system was quite useful in a group setting (Loy 1986), which is how much decision making occurs in organizations. Groups using the system not only understood their decision situation better than those without the graphical capability, they had higher performance as well (Loy, Pracht, & Courtney, 1987). These studies inspired an investigation into a way to consolidate individual cognitive maps into a collective map (Lee, Courtney, & O'Keefe, 1992).

In hindsight, we can see that BML/SLIM becomes a critical boundary object in this research stream. Boundary objects support repositories of related ideas that facilitate communication and cooperation across different yet related projects that share a common referent, resulting in the resolution of different goals and an increased understanding of a research stream (Star and Griesemer, 1989). According to Winter and Butler (2011), boundary objects play a pivotal role in grand challenges by supporting shared representations, cooperative development, legitimation, and transfer of knowledge, collaborative design, sharing of resources, and mobilization for action. BML/SLIM becomes an object used in the teaching community for teaching MIS and DSS concepts and in the design community focused on research into DSS design. It is an object used by multiple research teams, eventually over a span of many years and at different institutions, to support research into managerial problem formulation support. BML/SLIM becomes a shared object that is structured enough to provide a common basis for researchers to build upon, yet flexible enough to accommodate very different perspectives on exploring the design, development, and validation of the capabilities required in a DSS for general managerial problem formulation. Successive projects will build new capabilities into BML/SLIM based on the lessons learned in prior studies and drawing on the perspectives of various researchers who become interested in this grand challenge. It becomes a common simulation environment that supports a network of otherwise independent researchers.

Figure 1 illustrates these “prelude” and “foundation” stages of projects. The researchers who pursued the foundation projects were familiar with all of the prelude projects. The arrows in the figure indicate which projects or groups of projects directly influenced other projects, either through generating a new question to be examined or by providing results that were extended. After these foundation projects were completed, the grand challenge of a DSS to support general managerial problem formulation became defined. This is when the specific research question, “Can a DSS to support general managerial problem formulation be designed?” became explicit. Figure 1 also contains the projects that were executed to answer that question. They are discussed next.

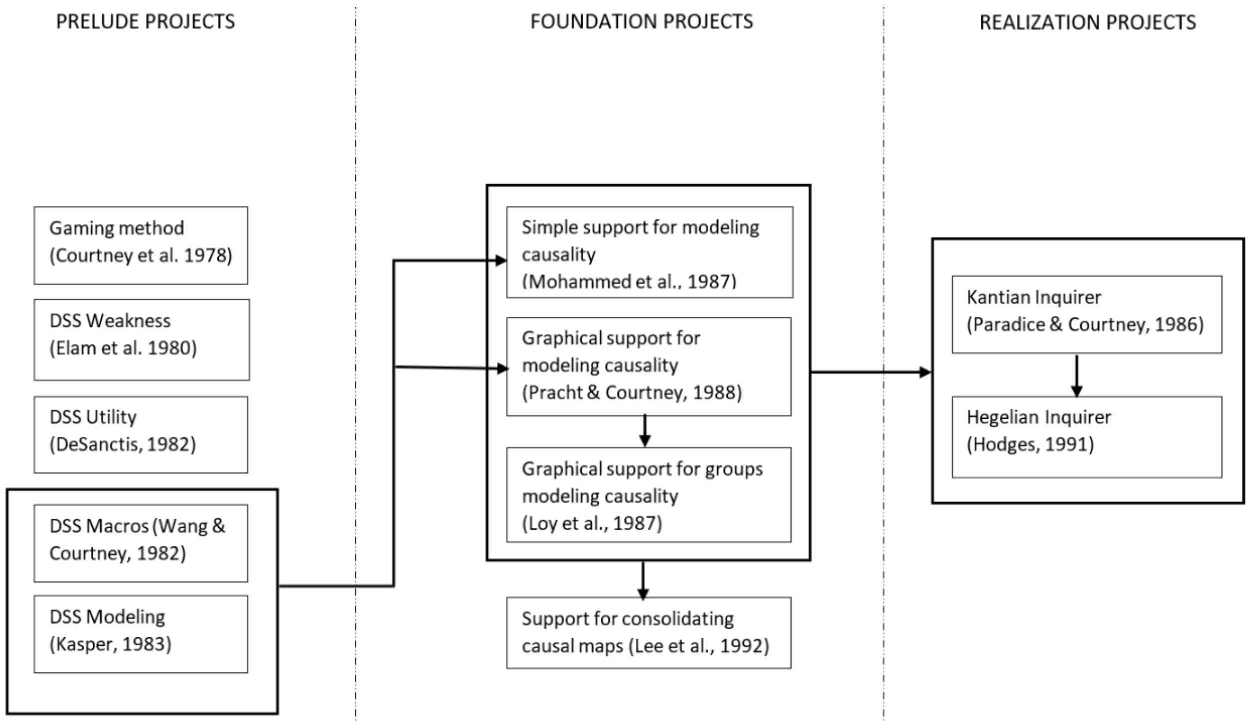

Figure 1. First Iteration of Grand Challenge Effort

4 Realization – The Grand Challenge is Attained

Once the foundation projects showed merit, realization projects could be initiated to demonstrate the grand challenge was being attained. The deep and narrow approach that spawned the cause-and-effect constructs that had been tested had proved to be too rigid for general managerial problem formulation (Courtney, Paradice, & Mohammed, 1987). The general business domain is better characterized as shallow and broad. The envisioned DSS was a knowledge management system, and philosophers have examined knowledge for centuries. Thus, turning to philosophy to identify kernel theory for the design of a knowledge management system seemed logical. The philosophical basis was found in C. West Churchman’s *Design of Inquiring Systems* (Churchman 1971). In this book, Churchman discusses the act of inquiry and the creation of new knowledge. Churchman describes the design of five inquiring systems, in systems terms, which are based on the philosophical approaches of five philosophers: Leibnitz, Locke, Kant, Hegel, and Singer. These inquirers, in the order just listed, reflect increasing capability to handle complex inquiry. These inquiring designs became the blueprint for the design of a DSS for managerial problem formulation.

This book would also become an important boundary object in the research stream. The next paragraphs describe how teams of researchers at multiple institutions used the descriptions of specific philosophical bases to explore the development of a general DSS for problem formulation. Each of the five philosophies is used by a different research team to push the concept of DSS for problem formulation to a new level of complexity. Additionally, the book provides a common language for discussing Churchman's concepts with former students of Churchman as well as IS researchers who are interested in philosophical issues in IS. The underlying theme of the book, that philosophy can inform the design of inquiring systems, also becomes a seed for exploring philosophical bases that are not included in Churchman's work. Thus, we see the book's content and structure are robust enough to support a common language of DSS design, yet flexible enough to support the discussion when it goes beyond the book's content into new philosophical areas. These are characteristics of boundary objects described by Winter and Butler (2011).

The Leibnitzian inquirer, grounded in formal logic, was deemed to be too rigid to handle the wicked nature of business problem formulation. The limited applicability of approaches based on causal mapping that were studied in the foundational projects suggested bypassing the Leibnitzian inquirer as kernel theory. The Lockean inquirer, focused on a single model of a problem, was deemed unrepresentative of the way complex managerial problems are typically addressed in organizations (i.e., by groups or at least after considering multiple perspectives). Thus, a design of a multi-model system based on the Kantian inquirer was the first attempt at this explicitly philosophy-based approach (Paradice, 1986; Paradice and Courtney, 1986). This design was tested using the BML / SLIM testing environment (Paradice and Courtney, 1987). The system performed as well as the training models provided by student subjects and in a few cases properly identified environmental relationships that the students typically specified incorrectly. In this way, the Kantian approach showed some promise of guiding users to a better understanding of their decision environment.

Having seen the implementation of the Kantian inquirer, the design and development of a system based on Hegel's philosophy was undertaken. The Hegelian inquirer is grounded in dialectic processes. A system combining a number of perspectives of dialectic, devil's advocacy, and assumption surfacing techniques – all of which were being discussed in the general debate around dialectic approaches – was developed. The prototype system was capable of "concurrently representing and synthesizing two conflicting cause-and-effect models of a typical strategic planning situation, and to show how one such tool could be used as an aid in various knowledge manipulation procedures involving conflicting problem models" (Hodges, 1991).

These projects established that the grand challenge can be attained in some fashion. A truly grand challenge may be too difficult to fully realize, but the success of these two efforts established the feasibility of the grand challenge and generated interest in refining the approaches. Earlier work examining users' models against the known relationships in the business simulation, combined with the performance of the Kantian system test, provided further evidence that a DSS for managerial problem formulation is highly reliant on the quality of the knowledge embedded in the system (Courtney and Paradice, 1993). Consequently, knowledge acquisition techniques in managerial problem domains became a focus of research (Kim, 1990; Kim and Courtney, 1988). Additionally, business environments were recognized as growing increasingly volatile and dynamic. Managers would need assistance identifying important data in the environment to process. Expecting managers to manually process the volume of data expected was unreasonable. Thus, attention turned to automated knowledge acquisition, believing it would be required for managers to have any chance of staying informed in dynamic business information environments. Given the increasing volume of data being created, some type of automated sensing of relationships in the corporate business environment was also expected to be required. Consequently, three approaches to discovering important information and relationships between data items automatically were examined (Billman, 1989; Billman and Courtney, 1993). Recognizing that people often work with qualitative descriptions of the business environment, work with qualitative descriptions of relationships (i.e., increases and decreases) that commonly surfaced when discussing the systems with participants in the studies began. The feasibility of adapting qualitative physics to model business problems qualitatively is reflected in the SIMON system which mapped a simple accounting flow process into a completely qualitative representation (Paradice, 1992).

In hindsight, we see three phases (prelude, foundation, and realization) of projects that constitute a stream of research (see Figure 2). Today, we would undertake the projects as design science research, but at the time of these studies, that concept was not yet widespread. The grand challenge of building and testing a DSS for general managerial problem formulation was not known when the studies in the prelude phase of the stream were undertaken. These earliest projects were pursued for reasons that have nothing to do with the grand challenge, but an insight emerged from these projects that spawned interest in investigating the feasibility of an early statement of the grand challenge. This early statement was, “What would be needed if one were to really try to build a DSS for general managerial problem formulation?” Seeking answers to this question led to a set of related projects in the foundation phase. These projects became more complex and continued to developed capabilities, but they did not provide a blueprint for how to build the system. Philosophical concepts of knowledge creation provided the blueprint needed to move into the realization phase.

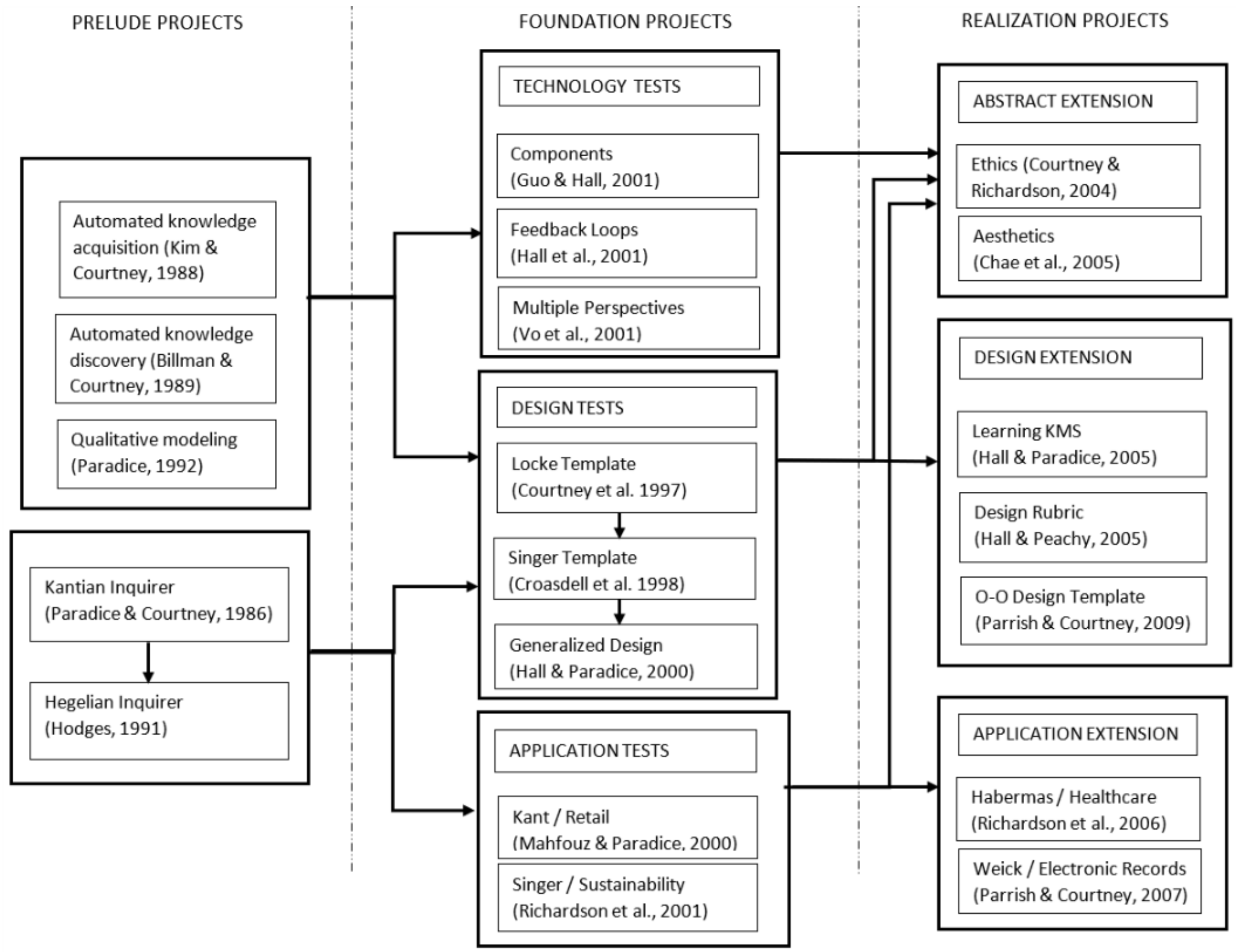

Figure 2. Second Iteration of Grand Challenge Effort

5 Expansion – The Process Repeats

The success of these projects was encouraging, but a way to move from these proof-of-concept studies was needed. Notably, the end of this first stream of projects (early 1990’s) is around the time that design science-type concepts were being raised in the IS research community (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Within a few years, these activities would be codified into an approach termed design science research (Hevner et al., 2004). Indeed, much of the work we have discussed in this paper would have been termed design science research had that term been recognized in the literature. The next series of projects repeats the prelude-foundation-realization sequence of phases, but is also influenced by DSR concepts. In particular, greater attention would be given to making the architecture and system design explicit (Nunamaker, Chen, and Purden, 1991), identifying meta-requirements and kernel theories (Walls, Widmeyer, & El Sawy, 1992 & 2004), and executing the activities outlined by Peffers and his colleagues (Peffers et al., 2007). DSS has always been grounded in real decision-making contexts, so the effort in this research community unsurprisingly began to move toward projects that explore the relevance of the research. This move was consistent with another design science research focus on important and relevant problems (Hevner et al., 2004). These projects are attempts to move the prototypes and proofs-of-concept into actual domains. In hindsight, we can see that these are prelude projects to a new grand challenge: implementing general business problem support in practice.

As designing, implementing, and testing these systems progressed in the BML / SLIM environment, researchers began to consider whether the approaches developed would be successful in realistic settings. The Kantian inquirer approach was considered in a retail domain with conjectures on how Wal-Mart might use the approach to make better operational decisions (Mahfouz and Paradice, 2000). The Singerian inquirer was applied to sustainable development to show how an urban infrastructure project that combined the Singerian approach with unbounded systems thinking and the generalized DSS model that was emerging provided a holistic perspective and a structure for dealing with messy problems (Courtney, Richardson, & Paradice, 2000). The Singerian inquirer's ability to deal with complexity made the approach effective at introducing structure in dynamic, unknown, and ill-defined environments. Research illustrated that the use of collaboration and decision support technology in a young subsidiary organization, operating in the dynamic and ill-defined environment of the newly deregulated utility industry, resulted in the effective development and use of meaningful success metrics and introduced much needed structure in the organization (Richardson, Courtney, & Paradice, 2001).

A series of foundation projects occurred to investigate improvements to the fundamental design that was emerging. Software technology components that would be needed to collect organizational information (Guo and Hall, 2001) and the role of feedback loops in these systems (Hall, Paradice, & Courtney, 2001; Hall, 2002) were emerging as research focus areas. Feedback is required to update the knowledge base in a dynamic business environment so that the DSS can provide accurate information to decision makers. The feedback mechanism must be designed in a way that filters information from the environment so that the DSS is updated only as necessary. That is, noise from the environment that would not produce significant changes would need to be filtered. Finally, an investigation of how multiple perspectives of problems (Mitroff and Linstone, 1993) could be maintained was pursued to create a conceptual design of a system consisting of multiple inquirers. The system was designed to accommodate not only multiple individual cognitive maps that could have different perspectives, but also to maintain the integration of the individual maps with an organizational map (Vo, Paradice, & Courtney, 2001). Others would later continue development of approaches to properly integrate multiple perspectives of complex problems into the decision support capabilities (Hall and Davis, 2007; Paradice and Davis, 2008).The design science research stream that was now over two decades in the making began to turn toward applying the concepts learned to a larger and more general organizational setting. Additional research projects were conceived to explore applications of the design. Research investigated the Lockean (Courtney, Croasdell, & Paradice, 1997), Singerian (Croasdell, Paradice, & Courtney, 1998) and generalized (Hall and Paradice, 2000; Chae, Hall, & Guo, 2001; Hall, 2002; Hall and Paradice, 2005) inquiring system as templates for organizational design.

At this time, the researchers involved were beginning to think in terms of a more general approach to these development efforts. The theorizing involved the requirement for DSS such as these to be grounded in a philosophical basis. Note that the theorizing that occurred was not that the system needed to be grounded in one of Churchman's inquirers. Rather, there was need for some appropriate philosophical basis as a kernel theory. With this in mind, a project to manage knowledge in a pediatric bipolar disorder setting was executed that used philosophy developed by Habermas (Richardson, Courtney, & Haynes, 2006). This study explored the complexities of designing knowledge management systems for the healthcare context in a way that emphasizes ethical design and the promotion human dignity. Habermas' theory of communicative action and discourse ethics are combined with Churchman's inquiring systems theory to derive a set of design principles for knowledge management systems that emphasize ethics and the emancipation of humankind. Integrating Habermas' philosophy related to individual emancipation and autonomy with medical ethics theory to design an end-of-life patient decision support system was also explored (Richardson, 2006). The goal of the system was to enhance patient autonomy by facilitating informed decision-making and the communication of each individual patient's end-of-life treatment preferences to the medical team as a patient transitioned into hospice care. The system was tested in the hospice branch of a large hospital system and resulted in improved patient decision-making, improved patient autonomy, and improved treatment decisions by the hospice medical team. Ethical considerations were now feasibly within the purview of general managerial problem formulation.

New knowledge creation is also an act of sense-making, so Weick's notion of sense-making was examined to employ a second philosophical perspective. Sense-making is a retrospective process that enables action in uncertain or ambiguous situations through the development of plausible images to rationalize what is occurring (Weick, Sutcliff, & Obstfeld, 2005). This philosophy was applied to the examination of electronic records management in a municipal court setting (Parrish, 2008; Parrish and Courtney, 2007). Sense-making was used in conjunction with environmental scanning to generate knowledge used in a strategic planning process. In these efforts, we begin to see how the project stream ultimately builds to generalizable results.

The research moved from theorizing to theory when a theoretical foundation for the design of a learning-oriented knowledge management system was published (Hall, Paradice, & Courtney, 2003). Following the approach described by Walls and his coauthors (Walls et al., 1992), open systems theory, Churchman's (1971) inquirers, and Simon's intelligence-design-choice model (Simon, 1960) were combined to form a kernel theory for the learning-oriented knowledge management system. The conceptualization of learning-oriented knowledge management systems in the context of an inquiring organization (Hall and Paradice, 2005) extended the idea of considering inquirers as design templates (Parrish and Courtney, 2009). By viewing the inquirers from an object-oriented programming perspective, one could identify the various attributes and methods for each of the inquirers. The resulting perspective allows designers to utilize the templates as a foundation of a knowledge management system. The concepts developed in the project stream were used to evaluate knowledge management systems (Peachy and Hall, 2005) and to determine that the characteristics and capabilities of Churchman's inquiring systems were evident in the knowledge management research of the time.

The last projects in this effort apply abstract notions developed at the earlier levels on a larger scale, at times in a more abstract manner. Researchers began to consider applying the problem formulation support concepts in organizational settings and looking for wider applications of the lessons learned. In these final projects, attention turned to applying what had been learned to ethics, aesthetics, extension of the inquirers, and evaluation of knowledge management. Churchman's inquirers emphasize ethical issues (Richardson and Courtney, 2004), so earlier work (Courtney, 2001) was reconsidered to include ethics and aesthetics and specifically to consider social consensus and concentration of effect, two aspects of moral intensity, as means for managing the process of sweeping in more information as required by the Singerian inquirer (Chae, Paradice, Courtney, & Cagle, 2005). The adherence to the requirements of the Singerian inquirer was continued by a later reconsideration of the model and power was swept in to be considered along with other perspectives (Parrish, 2006). Now, these projects may already be prelude projects to new grand challenges.

6 Discussion

This review described a grand challenge by looking back at a series of projects that were focused on a common goal, but a grand challenge can also be used to initiate and guide a research program. We will discuss each perspective: seeing a grand challenge in retrospect and using one to guide research.

We looked backward through a 30-year stream of research to identify prelude projects, foundation projects, and realization projects. In this case, where no grand challenge had yet been established, the prelude projects fall into two categories. The first category contains independent projects executed in different disciplines without regard to each other. Some were focused on teaching IS while others were focused on DSS design. Some were in non-IS disciplines. The earliest notions of a grand challenge began to emerge when researchers began to combine the insights from these studies. Once researchers began to think about how to teach DSS concepts to business students and how a DSS should be designed to support managerial decision-making processes, the first researchers working on what would become the grand challenge began working on a second category of prelude projects to develop specific capabilities that were believed to be needed. This second category of projects differs from the first category in that the projects have a general purpose of investigating a common question.

We found prelude projects lead to a second type of project which we call foundation projects. Foundation projects differ from prelude projects by having greater scope. They attempt to achieve success in applying the capabilities created in the prelude projects in scenarios that have characteristics of the grand challenge environment. While a prelude project may investigate the development of a system capability, the foundation project investigates the application of the capability. For example, a prelude project in the research stream that we reviewed developed a graphical means of representing business problems. A subsequent foundation project investigated whether the use of the graphical capability actually led to better decisions.

Foundation projects lead to a third project type which we call a realization project. The realization project differs from the foundation project by again increasing the scope of the investigation. Prelude project capabilities and foundation project achievements are brought together in the realization project in an attempt to show success in terms of the grand challenge. A realization project is an attempt to demonstrate that the grand challenge has been achieved. We see that there may be more than one realization project, as researchers with different perspectives seek to realize the grand challenge in different ways.

Our final insight in looking backward at a grand challenge is to recognize that realization projects become prelude projects for a new grand challenge. In our review, researchers sought to generalize the applicability of the systems that emerged from the original grand challenge. This new grand challenge would require greater capabilities, which were developed through another round of prelude projects.

These insights describe what we learned in looking back at a long period of research. What we have learned could certainly be used to make a grand challenge a template for a research program. Indeed, computer science and other disciplines have identified grand challenges in the past and used the mere statement of the challenge to guide research activity. With this review, we can use the prelude, foundation, and realization project concepts to identify gaps in knowledge that need to be addressed in order to achieve a (new) grand challenge.

In this approach, a research community could ask, "What capabilities do we believe are needed to achieve the grand challenge?" Prelude projects could be conceived to develop capabilities that are nonexistent or under-developed. Once adequate capabilities exist, the research activity in the field could move to foundation projects that demonstrate how the capabilities successfully fulfil the needs that they should fill. When adequate, successful capabilities exist, then realization projects could begin to make the final achievement of the grand challenge a reality.

Although the nature of a grand challenge is that multiple research communities will ultimately be involved, one or a few researchers could potentially recognize the conditions in which a grand challenge might be declared. For this to happen, we believe the researchers must be working on or interested in a difficult problem and either be members of different research communities or familiar with the work occurring in different research communities. We believe some amount of familiarity with a problem is needed in order to discern the current state of solutions to the problem. The researchers must acknowledge the problem can be viewed from multiple perspectives, or that it might be stated in different ways, in order to recognize prelude projects in different fields that are potentially relatable to a grand challenge. A researcher who can see a common thread among different research tracks at ICIS or AMCIS could be in the initial stage of identifying a grand challenge. The development of a research track in the next conference focused on studies from different perspectives of the problem would be another signal that a grand challenge could be emerging. Still, a true grand challenge requires recognition by multiple researchers in multiple disciplines.

The complexity of a grand challenge should attract research communities from different areas to work on the challenge. This is when boundary objects become so important. In this review, the BML/SLIM environment and Churchman's development of inquiring systems as a blueprint for design were critical to achieving the grand challenge. BML/SLIM provided a common technical environment for the studies executed by various researchers. Churchman's work provided a common philosophical design language for research teams separated in space and time. Each boundary object served to connect studies by different researchers over several decades.

Winter and Butler (2011) describe grand challenges as boundary objects. They observe that grand challenges provide insights into the likely success of solving a problem and a basis for cooperation, but they don't indicate how this happens. Our review helps us see how this happens. By considering a grand challenge as a three-stage process of prelude, foundation, and realization project types and looking more closely at the characteristics of projects within each category, we provide more structure to evaluating the potential of the grand challenge. A grand challenge allows us to draw conclusions from multiple design cycles (Gregor and Hevner, 2013). Different research communities who take up the grand challenge will identify different prelude capabilities that are needed and produce different foundation applications of those capabilities, but the grand challenge will provide a common means of sharing and evaluating progress toward the realization of the ultimate goal. In this way, the grand challenge becomes an overarching design principle for design science research, allowing us to assess the progress of DSR efforts toward enhancing "technology and science knowledge bases via the creation of innovative artifacts that solve problems and improve the environment in which they are instantiated" (Hevner, in Rai, 2017).

7 Summary

A grand challenge may be declared at the beginning of a research effort or recognized in one that is underway. It begins with prelude projects that develop capabilities needed to achieve the grand challenge goal. These projects are followed by design cycles that result in an accumulation of foundation knowledge related to the grand challenge goal. In the end, the goal is realized to some extent in projects that apply the foundation knowledge gained to attain the goal. The last projects in a grand challenge research stream can become the prelude projects for a new grand challenge.

The effort in a grand challenge is not necessarily linear. The effort may move back and forth between the categories, as attempts to realize the grand challenge goal expose new issues in design or system capability. Boundary objects occur in the grand challenge that help various research communities understand and coordinate efforts to advance the design and the capabilities of the systems that are being developed. The grand challenge itself can be a boundary object, providing a structure rigid enough to provide commonality across domains yet flexible enough for work to advance from different perspectives.

A grand challenge perspective allows us to see parallel efforts to develop the design and the technology in pursuit of the grand challenge. These efforts are not necessarily concurrent. It is more likely that effort pushes forward in one stream until it becomes clear that more work is needed in the other. In fact, an important aspect of the grand challenge perspective is that it acts to provide a context which relates these projects to each other, thus providing an impetus to continue the work that contributes to a greater goal. In the grand challenge work reviewed here, some projects focused on technical capabilities. Once technical feasibility was realized, projects began to focus on the design of the envisioned DSS. Over time, we also see the work within the grand challenge progress from solving specific system-related problems to testing general applications. Thus, the grand challenge perspective provides guidance for what types of projects can or should come next.

A grand challenge perspective facilitates identifying the accumulation of results and knowledge over multiple projects. Drawing on research into a better way to teach MIS concepts and the conceptual design of DSS in the late 1970s, a grand challenge effort to develop a way to support managerial problem formulation emerged that continued in some fashion through the first decade of the 2000's, a span of 30 years. Indeed, these studies continue to influence work even today (c.f., Gruetzemacher, 2017).

Gregor and Hevner (2013) point out that "A DSR project has the potential to make different types and levels of research contributions depending on its starting points in terms of problem maturity and solution maturity." The grand challenge perspective allows us to better evaluate the contributions of individual efforts by providing the context needed to assess the maturity of the problem and solution spaces. A grand challenge perspective shows more clearly the interplay of lambda and omega knowledge bases in design science research over time, and how they work together to advance knowledge in a problem domain.

Through a grand challenge lens, we can see the evolution and accumulation of knowledge while simultaneously providing a context for the evaluation of individual projects. We encourage similar reviews of seemingly related research streams to discover other grand challenges that have been pursued in design science research. A process that can be followed is this:

1. Review the research literature on a particular topic to identify studies on that topic.
2. Examine the studies over time, paying attention to the researchers involved and the topics covered in the literature reviews.
3. Look for relationships between researchers. Do they share a common mentor, program, or research community?
4. Look for instances of researchers working in multiple knowledge domains on a common challenge, or on different aspects of a common challenge.
5. Look for boundary objects that have common definitions across domains but are flexible enough to provide utility in different domains.
6. If the research stream is initiated by a grand challenge, one would expect to see studies in different domains that reference each other as the research communities share or leverage knowledge on the achievements being made.
7. If the grand challenge is more organic, the studies are likely to show more variance in the reference domains occurring as new researchers bring their perspectives to the challenge.
8. As the grand challenge is pursued, progress toward success can be seen in the literature reviews over time as they become less focused on capabilities and more focused application.

Individual researchers and communities of researchers can get the attention of journal editors by situating their studies in the context of a grand challenge. Taking this approach, the design science research that occurs becomes research into the grand challenge, not just building a system (McKay and Marshall, 2005). When adopted, a grand challenge perspective provides a context for evaluating theorizing as opposed to theory. Had the research stream to develop a general business problem formulation DSS been embraced by the IS research community as a grand challenge, perhaps greater advances would have been made and at a faster pace. If so, perhaps the research would have contributed to increasing IS legitimacy as suggested in Winter and Butler (2011). For example, the computational basis of several of the inquiring systems developed in the early 1980s would be labeled "business intelligence" today. Grand challenges are another way to push the edges of IS research (Grover and Lyytinen, 2015). Taking a grand challenge perspective provides an opportunity for academic IS research to lead industry developments. Doing so will address the concern that IS scholars must begin actively developing and pursuing grand challenges and that failure to articulate and pursue grand challenges will result in continued undervaluing of IS scholars' work within universities, organizations, and society as a whole (Winter and Butler, 2011).

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About the Authors

David Paradice is Chair of the Department of Systems & Technology and Harbert Eminent Scholar in the Raymond J. Harbert College of Business. He has published over 50 articles and book chapters on the use of information systems in support of managerial problem formulation and has served on over 50 doctoral dissertation committees. Prior to joining Auburn University, Dr. Paradice was Senior Associate Dean at the Florida State University College of Business. He has been a Center Director, a teaching award winner, served on several corporate advisory boards, and worked as a consultant.

James Parrish is an Assistant Professor in the Department of Information Technology and Decision Sciences at the University of North Texas College of Business. His research interests include knowledge management, design science, and socio-technical issues related to cybersecurity.

Sandra Richardson is an associate professor of Business Information and Technology in the Fogelman College of Business and Economics at the University of Memphis. She is also the Associate Director for Healthcare IS at the Center for Innovative Technology Management, and a Cyber Security Research Fellow at the Fed Ex Institute of Technology. Her research explores how organizations integrate information systems into unique organizational and institutional arrangements to create economic or social value. She investigates the relationships between information systems and organizational strategy, the implication of public policy on organizational information systems, healthcare information systems, and cyber ethics.