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Design Science Research Methodology: An Artefact-Centric Creation and Evaluation Approach

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Abstract

Adaptation of the Design Science Research methodology has never been easy. There have always been concerns regarding the validity of design science and the evaluation of the artefacts generated therewith and the subsequent claims of the researchers. To address these problems we propose an artefact-centric creation and evaluation methodology for design science research. This methodology begins with observation which is followed by theory building which in turn is followed by an interwoven artefact creation and artefact evaluation process. The artefact creation process focuses on the creation of key artefacts that include conceptual models, processes, conceptual frameworks, system frameworks, architectures, and implementations. The artefact evaluation process is tightly interwoven with the artefact creation process and evaluates the artefacts independently as well as against prior artefacts that influenced their creation. In this paper we discuss in brief the application of this methodology to the 'Sustainable Business Transformation' design science research project.

Keywords

Design science research, artefact creation, artefact evaluation, research methodology.

INTRODUCTION

Traditional research in the physical sciences is concerned with the *what* whereas fields such as engineering and computer science concentrate on the how. Newell and Simon (1976) argue that the building of artefacts such as computers and programs is empirical inquiry though their unique forms of observation and experience do not fit the experimental method. Rapp (1981) identifies the close relationship between technological constructions and experiments and states that all technological constructions whether successful or unsuccessful can be viewed as experiments leading to particular insights and producing new knowledge in the process. These ideas towards the design of artefacts have been fleshed out and adapted for conducting research in the Information Systems discipline (e.g. Nunamaker et al. 1991; Hevner et al. 2004). The Information Systems discipline was (and still is) uniquely positioned to bring design science to fruition by integrating diverse technological, social, and managerial issues. Proof of concept by design, implementation and evaluation plays a pivotal role in fundamental information systems research (Nunamaker et al. 1991). This has been echoed by Hartmanis (1993) as new ideas and conceptualisations are driven largely by technology and therefore demonstrations (demos) can play the role of experiments. Hevner et al. (2004) formalises the process and advocate for innovative and creative artefacts, which overwhelmingly supports many others (such as Vaishnavi and Kuechler 2007; Burstein and Gregor 1999; Cao et al. 2006; Galliers and Land 1987; Kaplan and Duchon 1988; Keen 1987; Mingers 2001; and Nunamaker et al. 1991). They argue that 'proof of concept by design, implementation and evaluation' is a valid design science research methodology in information systems.

In addition to defining the design science artefact creation methodology, Nunamaker et al. (1991) propose five criteria for the evaluation of design science artefacts. These criteria suggest that design science research: studies an important phenomenon in information systems; makes a significant contribution to the domain; artefacts are testable and realisable; artefacts provide better solutions than existing systems; and the experience gained from the system building process is generalisable. Hevner et al. (2004) also propose seven similar guidelines to evaluate the artefact using empirical methods to determine how well an artefact works. These are: produce a viable artefact in the form of a construct, a model or a method; develop technology-based solutions to important and relevant business problems; rigorously demonstrate the utility, quality, and efficacy of a design artefact via well-grounded evaluation methods; provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies; rely upon the application of rigorous methods in both the construction and evaluation of the design artefact; utilise available means to reach desired ends; and present effectively, both to technology-oriented as well as management-oriented audiences. Due to the inter-disciplinary nature of information systems, Vaishnavi and Kuechler (2007) argue that evaluation and validation in design science research needs much more attention than what Hevner et al. (2004) has envisaged using empirical evaluation. They also propose seven patterns such as demonstration, experimentation, simulation, using metrics, benchmarking, logical reasoning and mathematical proofs for evaluation of the research artefacts. These evaluation techniques concentrate on evaluation of the end outcome rather than inter-weaving evaluation throughout the research process. March and Smith (1995) also argue that design science researchers need to evaluate their artefacts using methods and techniques similar to theory testing. The sophisticated analysis and models demanded by academia is of little relevance to practitioners and industry. Due to absence of rigorous evaluation process, many (such as, Benbasat and Zmud 1999, 2003; Galliers 2004; Weber 2003; and Whinston and Geng 2004) have raised concerns regarding the validity of design science in information systems research and especially the evaluation of the artefacts generated therewith. Benbasat and Zmud (1999) suggest that we need to select topics that are implementable and pragmatic. Therefore, the use and/or adaptation of this methodology have never been easy.

Many of the seminal works (such as Nunamaker et al. 1991; Hevner et al. 2004; Venable 2006; Peffers et al. 2008; Sein et al. 2011; Baskerville et al. 2007, 2009) provide meta-level phases for conducting design science research. However, they do not delve into prescriptive detail nor do they provide exemplar cases of the application of design science, especially evaluation of the research processes and artefacts. Our objective is to address these problems by proposing a detailed prescription to conduct design science research and instantiate with a practical problem. In this paper we explore an artefact-centric creation and evaluation approach to design science that is integrative and complementary to the afore-mentioned methodologies. Furthermore we describe the application of our approach to the universal and perennial problem of Sustainable Business Transformation. We believe that instantiating our implementation oriented design science approach with this pragmatic topic will enable it to be relevant.

ARTEFACT CENTRIC CREATION AND EVALUATION METHODOLOGY

We synthesise the ideas proposed by Nunamaker et al. (1991) and Hevner et al. (2004) to propose an inter-woven artefact-centric creation and evaluation methodology (Figure 1). In particular we leverage and adapt Nunamaker et al. (1991) key design science phases of observation, theory building, systems development, and experimentation. We also rigorously apply the criteria for the design science artefacts proposed by both Nunamaker et al. (1991) and Hevner et al. (2004). This methodology begins with observation which is followed by theory building which in turn is followed by artefact creation and artefact evaluation. The artefact creation process focuses on the creation of key artefacts that include conceptual models, processes, conceptual frameworks, system frameworks, system architectures, and system implementations. The evaluation process is tightly interwoven with the artefact creation process and support evaluation of each and every artefact independently and collectively as well as against prior artefacts that influenced their creation. The methodology has been realised and validated in the context of a number of design science research projects. In this paper, we first explore the artefact creation process (Section 2) followed by the artefact evaluation process (Sections 3 and 4) in the context of a Sustainable Business Transformation (SBT) design science research project.

ARTEFACT CREATION PROCESS

Theories of long-lived artefacts and their manifestation are essential to design science research (Weber, 2003). Such theories would explain how artefacts are created and adapted to their changing environments and underlying technologies (Hevner et al. 2004). This research adapts the system development process proposed by Nunamaker et al. (1991) as the guideline for the creation of research artefacts as illustrated in Figure 1. The adapted steps are: preparation of an overarching procedural solution; design of the framework; design of the architecture; development of the architecture; building of the system; realisation of the proposed procedural solution and artefacts through application of the system; and conclusion. The steps are iterative and follow a cyclical life cycle process. We discuss the steps in the context of a Sustainable Business Transformation scenario in the following subsections.

Sustainable Business Transformation Scenario

A sustainable business aspires towards the delivering of balanced and integrated performances in the three sustainability dimensions: social, economic and environmental. Its management and decision making requires a paradigmatic shift from that of a traditional one. Decisions making in current sustainable business transformation context are still silo-based and uni-dimensional. Decision makers need an overarching procedural solution roadmap and a technological solution that enable them to realise the roadmap for sustainable business transformation and management.

Prepare an Overarching Procedural Solution

Sustainable business transformation is a lengthy cyclical process involving such major activities as understanding sustainability issues and requirements, modelling and simulating a business system for developing sustainability vision and strategies, documenting business scenarios using critical success factors and key performance indicators, redesigning the business processes, restructuring the organisation and reconfiguring information systems, implementation of the new processes and systems, and monitoring, controlling, reporting and continuous improvement. We review a number of existing roadmaps and business engineering processes (such as Business Life Cycle Management Process (Rosemann 2001); Model Driven Business Transformation Framework (Kumaran et al. 2007); MIT90s Framework (Scott-Morton 1991) and identify their problems, issues and requirements. We synthesise ideas and design the SBT roadmap.

Design of the Framework

After reviewing the currently available frameworks relating to sustainability modelling and reporting systems, and relevant enterprise systems, information systems and decision support systems (e.g. Schekkerman 2006), we identify the problems, issues, requirements and opportunities of information systems frameworks. We synthesise ideas from these frameworks and design the Sustainability Modelling and Reporting (SMART) framework.

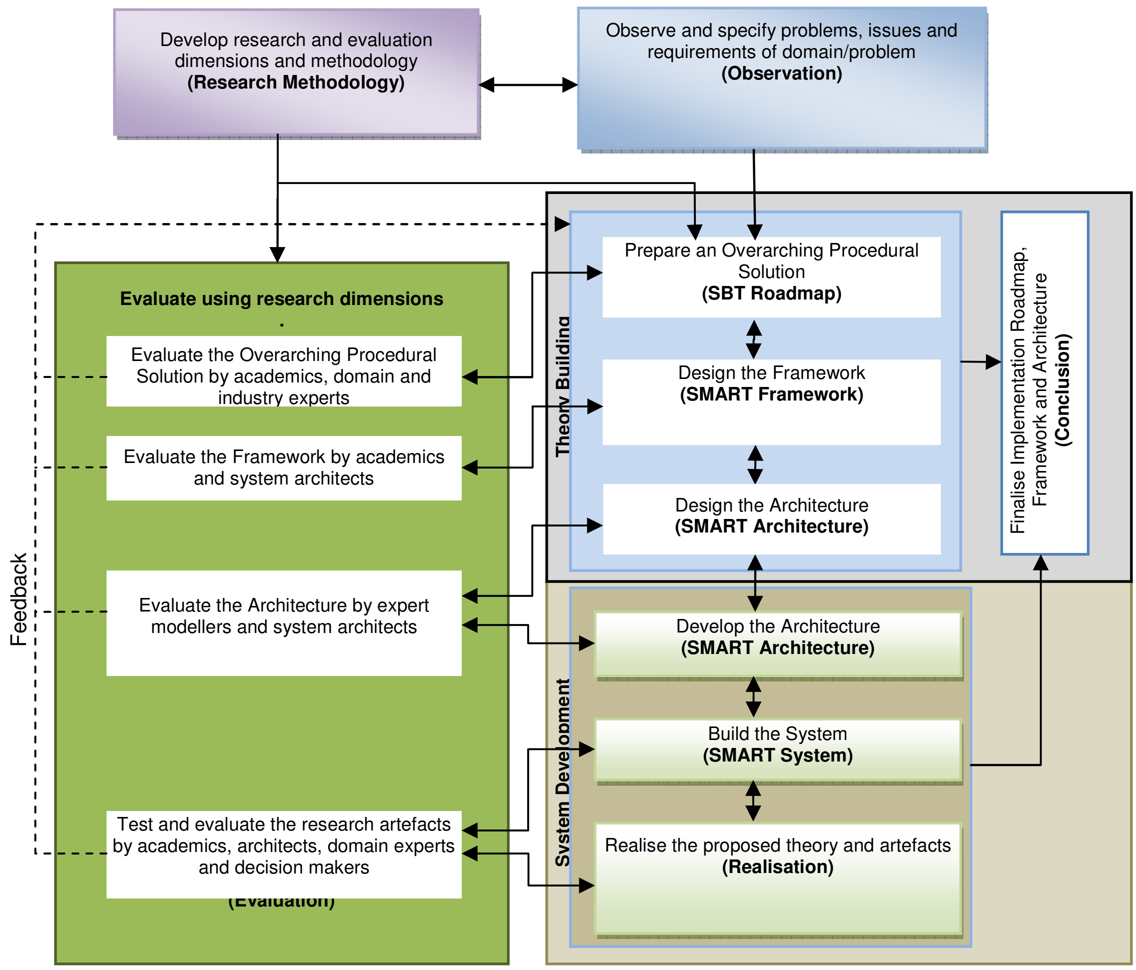

Figure 1. Artefact Centric Creation and Evaluation Methodology

Design of the Architecture

We review architecture design and development methodologies and investigate currently available architectures and systems for identifying opportunities for designing a sustainability modelling and reporting architecture. We synthesise these ideas in the design of the SMART architecture.

Development of the Architecture

The designed SMART architecture is developed further using object-orientation and componentisation. System dynamics, workflow, balanced scorecard, scenario, document, report and data modelling concepts are used for sustainability modelling, process modelling and report modelling. The .Net Framework, Visual Basic.NET, C#, XML, HTML, SQL Server 2005, Crystal Reporting System, etc. are used for the programming of architectural components and information management.

Implementation of the System

We implement the SMART system using business scenarios and analyse how it supports the SBT roadmap. We then discuss the detailed design and development of the SMART system components.

Realisation of the Roadmap, Framework, Architecture and System

We customise the SBT roadmap and the SMART system and present a realisation of the roadmap in the context of a real life business scenario using the SMART system. We then experiment and evaluate the system using simulation of various models and polish the roadmap, framework and architecture, based on observation and experimentation of the system. Finally, we consolidate experiences learned from the system development process. The evaluation process is briefly discussed below.

ARTEFACT EVALUATION PROCESS

Evaluation is key tool for learning about how well design artefacts fit the purpose. It establishes whether or not research has contributed to addressing the problem it set out to resolve. Evaluation is facilitated by a clear statement of measurable outcomes right at the start of the research design and the collection of relevant data throughout its life. *Evaluation refers to a process that seeks to determine as systematically and objectively as possible the relevance, efficiency and effectiveness of an activity in terms of its objectives, including the analysis and the implementation and administrative management of such activity* (Papaconstantinou & Polt, 1997). Process emphasises that evaluation is not a one-off activity as traditionally undertaken at the end of a research project rather it is an integral and continual element of a research process.

Peffers et al. (2008) proposes a 6-step evaluation approach heavily focusing on the evaluation of design science research process but it lacks rigour in the research outputs evaluation process. Pries-Heje et al. (2008) also provide strategies for evaluating artefact design processes and evaluation of the research output using case study and lab experiments. This process focuses on several intermediate steps rather than the entire research process and outcomes. Systematic evaluation ensures demonstration of the rigour and independent process, and objective evaluation implicitly emphasises on the clarity of research objectives as well as usage of a transparent technique that increases reliability and acceptance of the research outcome.

Evaluation methodology must follow an appropriate and sophisticated technique such as qualitative or quantitative or both for evaluation at various states of the research process which can be done by the researchers or outsiders. Quantitative evaluation may involve assessment of the impact of artefacts through a comparison of outcomes between the group and the control group. Qualitative evaluation or approaches are much more likely to rely upon the options evaluators' opinions about the functioning and impact of the design artefacts that includes surveys, case studies and peer reviews. Qualitative evaluation, as involves mainly face to face discussions, provides information beyond that associated with quantitative evaluations.

This section presents the evaluation process that we adopt in our research design, theory building, artefacts design, development and implementation of the SBT roadmap, and SMART framework, architecture and system. In addition to the evaluation approach, it also discusses about the expert evaluators, evaluation criteria, and evaluation of procedural and technological artefacts.

Evaluation Process

Evaluation of the research artefacts is a continuous process. We propose to evaluate each stage of the research artefacts creation process by a group of experts using a number of testing and assessment methodologies. The evaluation process, including the evaluators' responsibility for each step and iteration of the research artefacts creation methodology, is illustrated in Figure 1.

The proposed research methodology as illustrated in Figure 1 follows a process incorporating all four stages namely, observation, theory building, system development and evaluation, and presents relationships and interactions about who evaluate what and when. We make our initial observations from the literature review and continue to improve our observations during design, development, realisation and evaluation of the research artefacts. The theory building stage includes development of the adapted research methodology, design of the SBT roadmap, design of the SMART framework, and design of the SMART architecture. The system development stage is comprised of development of the SMART architecture, implementation of the SMART system, and realisation of the research artefacts using a selected business case. We analyse each of the artefacts during their design and development processes, test them using business scenarios, and use the evaluation results to improve and refine the design artefacts. Finally, we conclude and comprehensively claim the research findings and contribution of the research as an outcome.

Evaluators

Demonstration were given on one-on-one basis to experts of different disciplines as listed in Figure 2 and

Table *1*, who evaluate the SBT roadmap, and SMART framework, architecture and system. In addition to the peers, the researchers also evaluate and test the artefacts as the design and development of the artefacts are in progress. A number of research articles are written to journals and conferences, compiling and evaluating the review comments and feedback. The research findings and artefacts are presented to a number of research consortiums, symposiums, seminars and conferences. This process helps us to receive feedback continuously from academics and domain experts, and to improve the conceptual roadmap, framework and architecture.

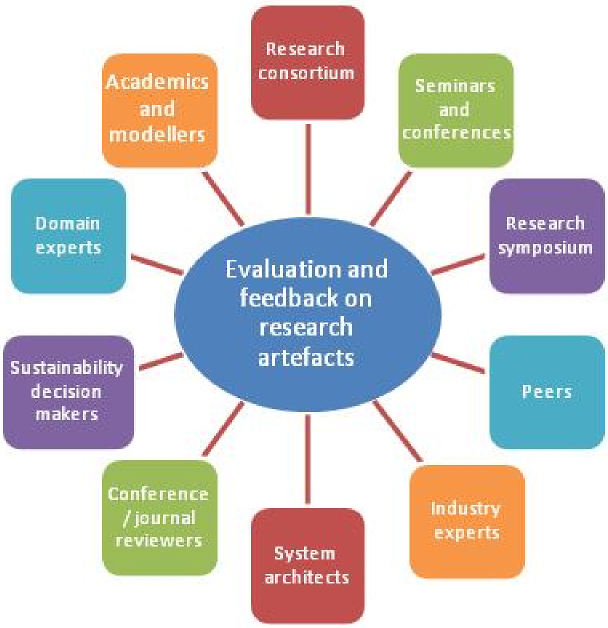

Figure 2: Expert Groups for Evaluation

Evaluation Criteria

This research creates the SBT roadmap as a procedural artefact and the SMART framework, architecture and system as technological artefacts for supporting the procedural and technological aspects of the research problems and issues. As proposed in

Table *1*, industry and domain experts, decision makers and academics are proposed to evaluate the SBT roadmap and the SMART system's support for it; and the system architects, system analysts and academics evaluate the technological artefacts that include the SMART framework, architecture and system.

Table 1: Artefact Evaluation Criteria and Evaluators

Evaluation Items	Evaluators
Suitability and correctness of the SBT roadmap macro-level and micro-level steps	• Industry and domain experts • Business analyst • Decision makers • Academics
SMART system's support for the SBT roadmap	• Industry and domain experts • Decision makers • Academics
Supportability features of the SMART framework, architecture, and system	• System architects • System analysts • Academics
Usability, performance, and reliability features of the SMART system	• System architects • System analysts • Academics

APPLICATION OF THE ARTEFACT EVALUATION PROCESS

In the following sections, we apply the generic artefact evaluation process to the SBT design science research project. In particular we discuss the evaluation of procedural artefacts (Section 5.1) and technological artefacts (Section 5.2).

Evaluation of Procedural Artefacts

The procedural artefacts relate to the end-to-end support for the SBT roadmap steps that addresses macro-level and micro-level life cycle management, decision making during the life cycle processes and paradigmatic integration processes. The SBT roadmap is comprised of 41 micro-level steps, which are categorised into five macro-level steps. The experts evaluate relevance of these SBT roadmap (both macro-level and micro-level) steps using a five-point scale: Very Unimportant, Unimportant, Neutral, Important, and Very Important. The feedback is computed using Likert's 5-point scale: Very Unimportant = 1, Unimportant = 2, Neutral = 3, Important = 4, and Very Important = 5 and presented in both tabular and spider graphical (for example, Figure 3) formats. The spider graph visually presents the level of support as well as indicates the gaps between expected and real supports for each of the 41 roadmap steps.

In addition to the ratings of the roadmap steps, the evaluators also provided comments for improvements of the macro-level and micro-level steps in terms of: 1) sufficiency of the macro-level steps - addition, modification and removal of any macro-level step, 2) sufficiency of the micro-level steps - addition, modification and removal of any micro-level step, and 3) logical sequencing of the steps. The evaluators' comments and observations are carefully scrutinised and addressed to improve the procedural artefacts of the research.

Evaluation of Technological Artefacts

The functionality, usability, reliability, performance and supportability (FURPS) features of the technological artefacts are fulfilled using the SMART framework, architecture and system. The FURPS model (Grady 1992) is used for evaluation of these technological artefacts, which are presented in following three sub sections: 1) evaluation process of the functionality feature; 2) evaluation process of usability, reliability and performance features; and 3) evaluation process of the supportability feature.

Evaluation of Functionality Feature

According to the FURPS model, functional requirements represent the main features, capabilities, generality and security. In this research, functionality refers to the SMART System's conformance and support for the SBT Roadmap Steps. The main function of the SMART system is to support the decision makers in each step of the Roadmap. Therefore, functional evaluation process concentrates on how closely the SMART system supports the decision makers to undertake activities and making decisions that are required to follow each and every steps of the Roadmap.
During this evaluation, various features of the SMART system and its application to a business case are presented to each of the selected experts separately, as mentioned in the second row of

Table *1*, and explain how the SMART system supports and realises the SBT roadmap steps. Each expert then provides feedback using a five-point scale: Very Poor, Poor, Average, Good, and Very Good using a formatted feedback form. They also provide comment about the SMART system's support for each step. The feedback is

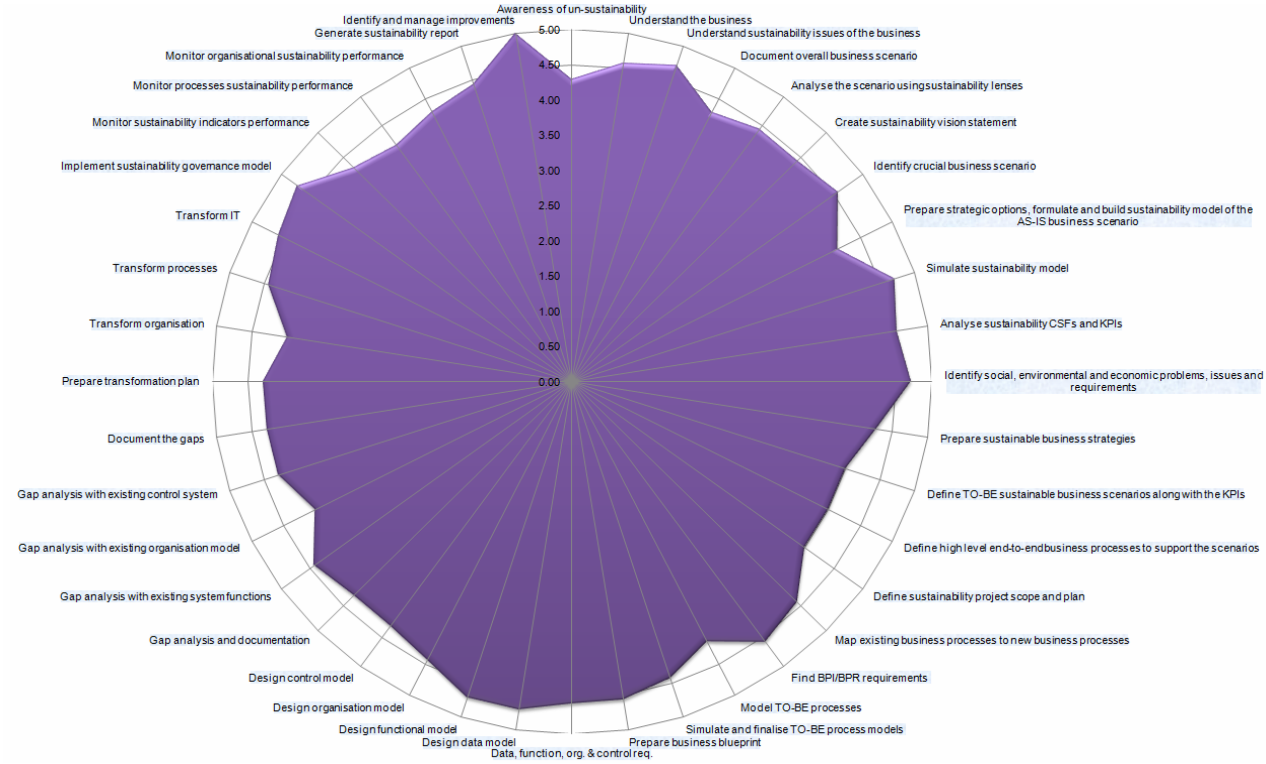

Figure 3: Evaluation of the SBT Roadmap

then computed using

Likert's 5-point rating: Very Poor = 1, Poor = 2, Average = 3, Good = 4, Very Good = 5 and the findings are presented using both table and spider graphs. The graphs are similar to the Figure 3, which visually presents both the level of support, and gaps between expected and practical decision making supports for each of the 41 roadmap steps.

Evaluation of Usability, Performance and Reliability Features

Usability is a qualitative attribute of the user interface that assesses among others consistency, simplicity, usability level, learning curve, and exception handling and reporting attributes. *Performance* is concerned with characteristics such as response time and speed, and *Reliability* with the ability of the system to produce consistent output, and meantime between failures. During this evaluation, usability, performance and reliability features of the SMART System are presented to each of the selected experts from a pool of system architects, system analysts, and academics) separately, as mentioned in the 4th row of

Table *1*. These experts then separately evaluate the usability, performance and reliability features of the SMART system using a five-point scale. The feedback is then computed using Likert's 5-point rating: Very Poor = 1, Poor = 2, Average = 3, Good = 4 and Very Good = 5 and presented using table and bar graphs (Figure 4). The figure displays extent of SMART System's support for various aspects of usability, performance and reliability features.

Evaluation of Supportability Feature

Supportability is a highly important non-functional, architecturally significant feature concerned with characteristics such as configurability, connectivity, workflow, compatibility, extensibility, maintainability, integrability, persistence and adaptability. Solutions to some of the research problems and issues such as configurability, connectivity, flexibility, versatility, extensibility and adaptability are entirely dependent on the supportability features of the SMART Framework, Architecture and System.

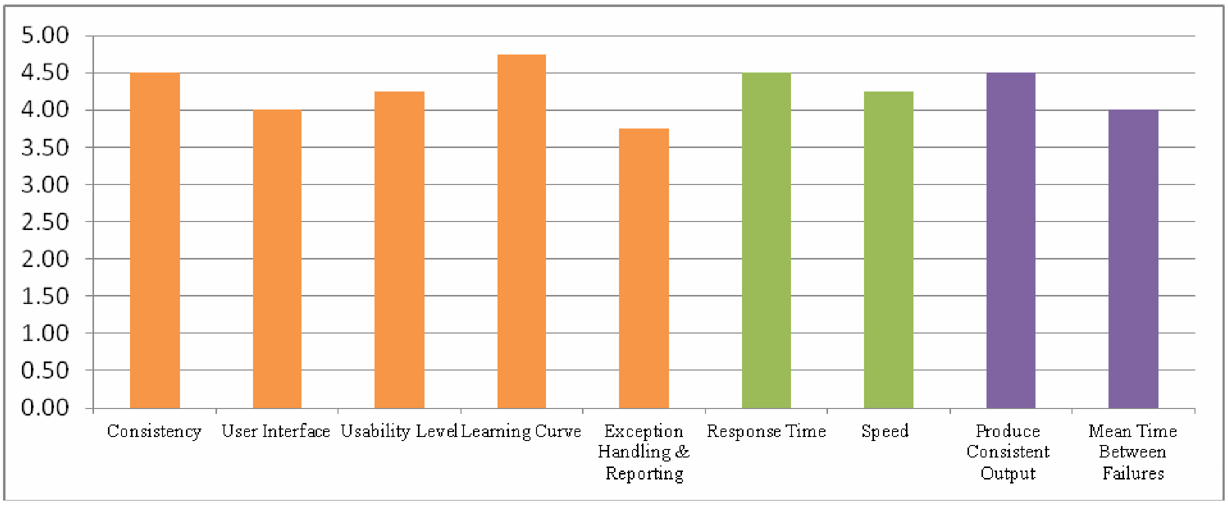

Figure 4: Evaluation of Usability, Performance and Reliability Features of the SMART System

Demonstrations are given to each expert separately (3rd row of Table 1) and sought their feedback using a peer review feedback form. The experts rated the SMART framework, architecture and system separately using a five-point Likert scale from Very Poor to Very Good. The reviews are compiled using Very Poor = 1, Poor = 2, Average = 3, Good = 4, Very Good = 5 and computed using table and graphs (Figure 5). Figure 5 visually presents expert's judgement regarding configurability, connectivity, data versatility, models and modelling versatility management services of the SMART framework, architecture and system.

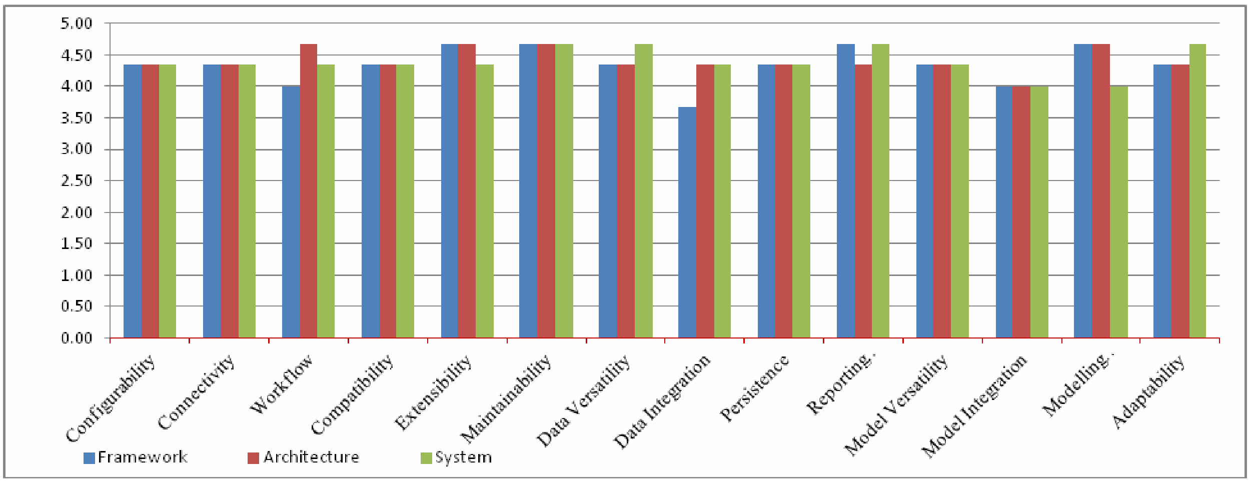

Figure 5: Evaluation of the Supportability Features of the SMART Framework, Architecture and System

CONCLUSIONS

This research adopts and applies the design science research methodology proposed by a number of design science research experts, especially Nunamaker et al.'s (1990) multi-methodology based proof of concept. These research methodologies propose a number of evaluation approaches. Most of them attempt to critically analyse the research process and design artefacts by the researchers. Research artefacts in information systems are logical rather than physical like that of the engineering disciplines. Currently applied evaluation process in design science research in information systems is not robust on many occasions and struggle to enhance the degree of reliability to ensuring trust and confidence among researchers.

This paper proposes an inter-woven artefact creation and evaluation methodology that builds upon the proposals of other design science researcher such as Nunamaker et al. (1991) and Hevner et al. (2004). The proposed methodology begins with observation which is followed by theory building which in turn is followed by an interwoven artefact creation and artefact evaluation processes. The artefact creation process focuses on the creation of key artefacts that include conceptual models, processes, conceptual frameworks, system frameworks, system architectures, and system implementations. The evaluation process incorporated in this methodology is comprised of a number of peer review processes effectively related to various steps and stages of the research process. Peer review technique is the main focus of this evaluation process that includes presentation of the research process and artefacts at various targeted expert forums for evaluation. These experts comprise individuals or groups from various disciplines and domains such as, academics, business analysts, systems analysts, system architects, developers, testers and relevant decision makers. This evaluation process provides a robust method by which we can ascertain whether or not the research objectives are met through the creation of research artefacts.

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