Designing and Architecting a Shared Platform for Adaptive Data Collection in Surveys and Censuses

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Abstract
This paper discusses the challenges in building shared information technology systems for survey data collection. We discuss the pitfalls of supporting multiple and redundant data collection systems. We recount our interviews with a cross-section of colleagues in the statistical field and argue that to achieve the best outcomes, technology innovations in system and enterprise architecture must be intertwined with methodological innovations such as adaptive survey design.

Key Words: Adaptive Survey Design, Statistical Methodology, IT architecture, balance, Pasteur's Quadrant

1. Introduction[1]

The current state of national statistical organizations as well as statistical firms and academic statistical organizations often involves a search for balance between opposing ideas and motivations. This balance frequently rests on a fulcrum of innovation, with statistical methodology on one side and information technology on the other. Efficiency is the driving force. The perennial promise of IT modernization is increased efficiency, but we have observed that too great a focus on the process-driven aspects of the IT approach can miss the mark. Likewise, an organizational focus on specific survey requirements in service of statistical methodology frequently results in multiple, duplicative systems that complicate interoperability and increase costs (see for example Seyb, McKenzie, Skerret 2013, Savage 2008, Thieme 2010).

Finding the appropriate balance is difficult work, requiring in part, an uncommon combination of cross-organizational vision from the top with a willingness to cooperate across business and cultural siloes at every other level. However, we propose that there is another piece of the puzzle that we have come to think is significant in our work at the U.S. Census Bureau. This is the role that a transformative methodological idea can play in bringing the two sides into balance. Though in our case, that transformative idea has been adaptive survey design, we believe that technology innovations must be linked to methodological innovations of *some* kind to achieve the best outcomes, and that initiatives weighted too heavily in ether direction will not be as successful. We will explain how adaptive survey design helped to broaden our thinking and compelled us to intertwine methodology and technology to the benefit of the organization.

2. Background & Motivation

With four separate and distinct systems for frame and sample development, six systems for sample control, and over 18 systems for data collection operational control, the U.S. Census Bureau provides an appropriate case study for what the United Nations Economic Commission for Europe calls 'Accidental Architecture' (UNECE, 2013).

[1] Disclaimer: Any views expressed are those of the authors and not necessarily those of the U.S. Census Bureau

Accidental Architecture starts quietly and moves slowly. It takes hold over a period of many years as separate areas in the organization, minding their own business, so to speak, design and build highly customized systems to administer and control what are, at a basic level, highly similar if not identical functions in the survey lifecycle. All statistical organizations collect, process, analyze and disseminate data, but accidental architecture occurs because different surveys within our organizations frequently create unique and incompatible systems to execute those functions (see Figure 1).

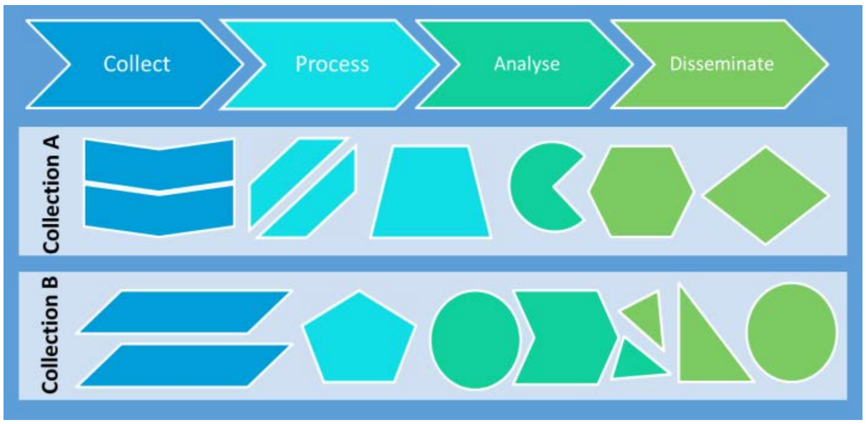

Figure 1 - Accidental Architecture

Source: Fostering Interoperability in Official Statistics: Common Statistical Production Architecture (UNECE, 2013)

As the name implies, we do not conceive accidental architectures on purpose. Statistical organizations did not set out to build redundant capabilities, duplicative cost centers, and limited interoperability between systems. We simply had no overarching plan (a comprehensive Enterprise Architecture, for example) that would have helped us avoid building them. The result of this phenomenon is that when we began the effort to implement adaptive survey design at the Census Bureau, we had a dizzying array of systems and interfaces to negotiate, as shown in Figure 2.

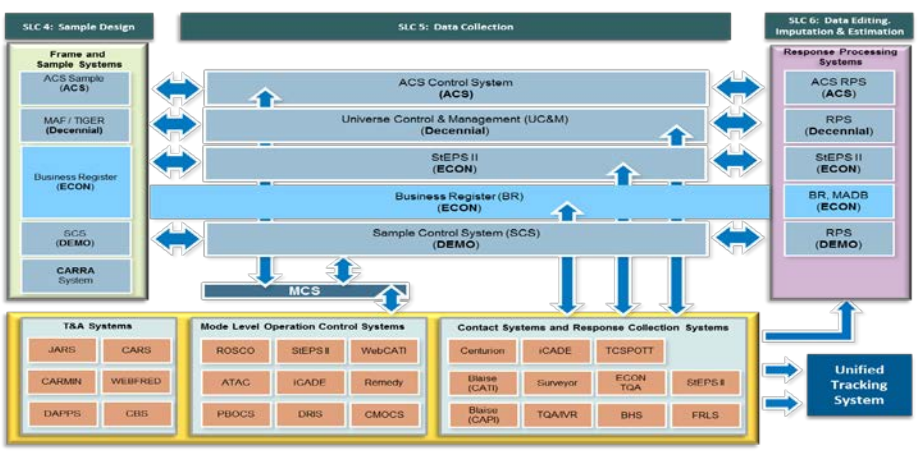

Figure 2 - Census Bureau Current State

A defining goal of the Census Bureau's Center for Adaptive Design (or CAD) is to increase survey and census efficiency by enabling the use of empirical data in near real-time to facilitate intelligent business decisions during data collection – the most costly segment of our survey lifecycle. Adaptive design needs sophisticated and robust computer systems in order to deliver the efficiency it promises, but figure 2 suggested a starting point that would require a cumbersome and complicated solution. A complicated IT solution would also lack sufficient standardization and integration – a phenomenon closely associated with unintended and undetected survey error (Thalji, et al 2013).

The interesting thing about Figure 2 is that we developed it with the idea of understanding and documenting our as-is state, not as a justification for change. This picture both surprised us and made us ask some important questions – like why do we need this many different systems to do what we do? How much are all these systems costing us? Are our operations so different from one area to the next that this number of unique systems is necessary? This clarified our motivation to the following:

- Is it even possible to be adaptive using our current IT systems?
- Is the best solution to create common/shared systems, and if so, what is the best way to design and build them?
- Within this context, how do we effectively introduce and gain acceptance of new methodological innovations, such as adaptive survey design?

3. Emerging Architectural Standards

A treatment offered for the ills of accidental architecture is the Enterprise Architecture approach. For the statistical community, this treatment manifests in standards like the Common Statistical Production Architecture (CSPA), the Generic Statistical Business Process Model (GSBPM), the Generic Statistical Information Model (GSIM), the Standard Data and Metadata Exchange (SDMX), and the Data Documentation Initiative (DDI). (UNECE 2013).

In determining our approach to launching adaptive survey design at the Census Bureau, we looked closely at these standards. Concurrent with our efforts, our own Office of Risk Management and Program Evaluation was shaping the new Census Bureau Survey Lifecycle/Mission Enabling Services (SLC/MES) framework – work they based largely on the GSBPM.

These standards provide a common conceptual framework within which we can build shared systems to handle not only the varying requirements presented by the surveys within our organizations, but also to satisfy the data discovery and data sharing requirements between and among statistical organizations, and even governments. However, just as accidental architecture takes hold over a period of many years, loosening that hold with the introduction of architectural standards will likewise be a lengthy and involved process requiring great effort and great patience.

While we are implementing the SLC/MES as the framework around which we organize work at the Census Bureau, we have some distance to go before our approach to system development can claim alignment with the Common Statistical Production Architecture. As we will discuss below, communication and collaboration with our colleagues in other national, academic, and private statistical organizations will increase our knowledge and inform our strategies in this area.

4. A Different Model for Research and Implementation

The Census Bureau leadership established the Center for Adaptive Design within its Research and Methodology Directorate – a place in the organization devoted to basic research on statistical methodology. However, they did not staff the center with the traditional research approach in mind. Rather, they brought together a unique combination (for Census) of experts in research, IT architecture, survey implementation, and program management. The intent was that the Center would take on both the pure research aspects of adaptive survey design as well as its real-world implementation in surveys. This is in line with a *Pasteur's Quadrant* approach to the research/technology relationship (Stokes 1997). Stokes argued that a linear model, with basic research leading to the advances that technology subsequently exploits, is less effective than a model in which there is intentional interaction between research and technology from the beginning (Figure 3).

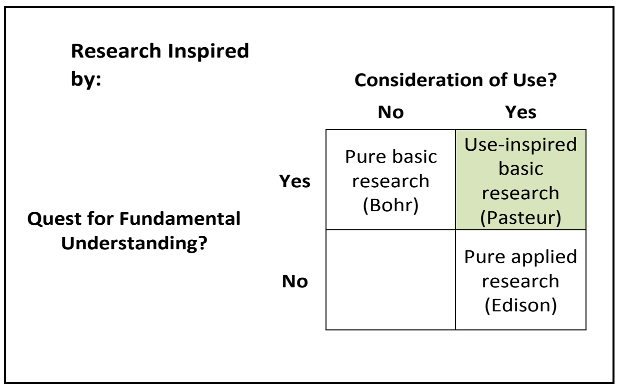

Figure 3 - Pasteur's Quadrant (Stokes 1997)

Indeed, Stokes believed that technology could provide a powerful influence on science, even at times reversing the flow of the traditional linear model – i.e., technology can and does enable basic discovery, rather than the other way around. This idea fit with our concept of the search for balance between statistical methodology and Information Technology. Just as pure research and pure utility intersect to beneficial effect in Pasteur's Quadrant, IT modernization and statistical research can, we believe, intersect to the greater benefit of both.

We were given the opportunity to attempt this intertwined approach in our research and implementation of adaptive survey design. There are aspects of the scientific endeavor, i.e., the search for a basic understanding of adaptive principles, which are not feasible without a new technological foundation in place (see Axinn, Link, Groves 2011). We propose that the progress back and forth between IT capabilities and methodological experiments will lead to greater collaboration across the agency, greater cohesion of projects and goals, faster solutions to system problems, and greater longevity of the systems that result. Because this approach offered the potential to be a significant for the implementation of IT systems in general, we set out to find examples.

5. Interviews with Colleagues

Many other statistical organizations in the U.S. and abroad are in the midst of modernization and system consolidation efforts – some with adaptive survey design as a key motivation (see JOS, Vol. 29 No.1 March 2013). With this in mind, we set up a number of interviews with colleagues from other national statistical organizations, private statistical firms, and academic statistical organizations. In all we conducted over 15 interviews with international and domestic colleagues split roughly evenly across the areas of statistical methodology, survey management, IT architecture, and IT management. During our interviews, we asked a standard set of questions while maintaining an open enough format to allow the interviewees to expand on certain areas or bring up related topics as they saw fit. Though we discuss many of the insights gained from our interviews in quantitative terms, the results are not necessarily generalizable.

5.1 Discussion on Architectural Standards

We opened the interviews with discussion about whether or not the emerging architectural standards mentioned above are having any impact in their organizations. We found that a majority of interviewees were, like the Census Bureau, implementing survey lifecycle frameworks based on the Generic Statistical Business Process Model (GSBPM). The GSBPM functions largely like a work breakdown structure that is helpful in classifying activities into logical containers. It is not particularly onerous to implement, as it can be overlaid on existing functions without requiring major application or process redesign. However, the use of this or similar models can help reveal duplicative or inefficient processes and systems and provide key information to address accidental architecture challenges.

Interestingly, the architectural standard with the lowest incidence of implementation, at 6 percent, was the Common Statistical Production Architecture (CSPA). This is not surprising, as it can be seen as the overarching standard within which all the other standards fit. It is the proposal most closely associated with the costly and disruptive move from accidental architecture to a shared systems approach not only across an enterprise, but also across governments. Nonetheless, nearly half of the colleagues we spoke with described their organizations as highly interested in working to implement these standards eventually.

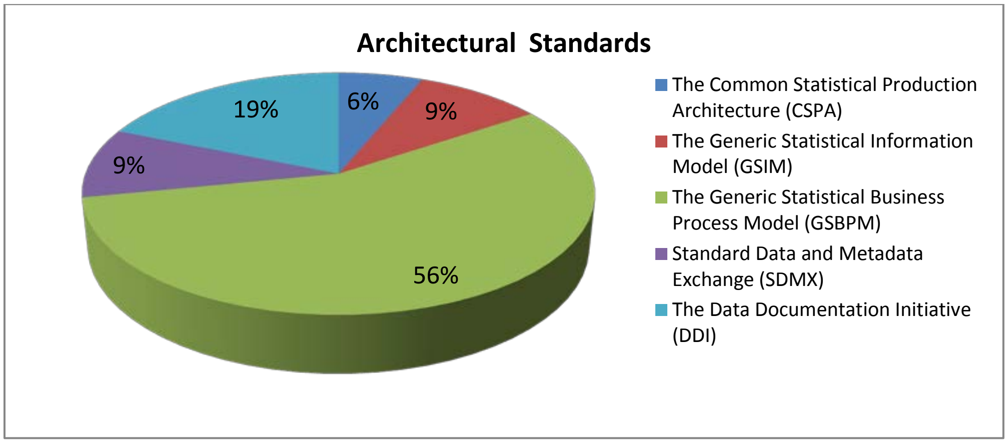

Figure 4 – What portion of interviewees are implementing the new standards?

When we discussed some of the reasons statistical organizations might *not* be interested in implementing the new standards, the most frequent response (44 percent) was that the effort would be disruptive to survey production work. Interestingly, there were an equal number of interviewees (about 10 percent each) who thought that there was either no need to implement new architectural standards (i.e., *why fix what isn't broken?*), or that the financial costs would be too high to justify the effort. Possibly two sides of the same coin.

5.2 Discussion on Shared Systems

Our interviews also touched on how statistical organizations are implementing a shared systems approach. In this part of the interview, we wanted to get a sense of the speed at which the statistical community is moving away from unique systems for each survey, toward shared systems for many (or all) surveys in an organization. We were surprised to find that a majority of our interviewees work in organizations where all surveys use the same core set of systems.

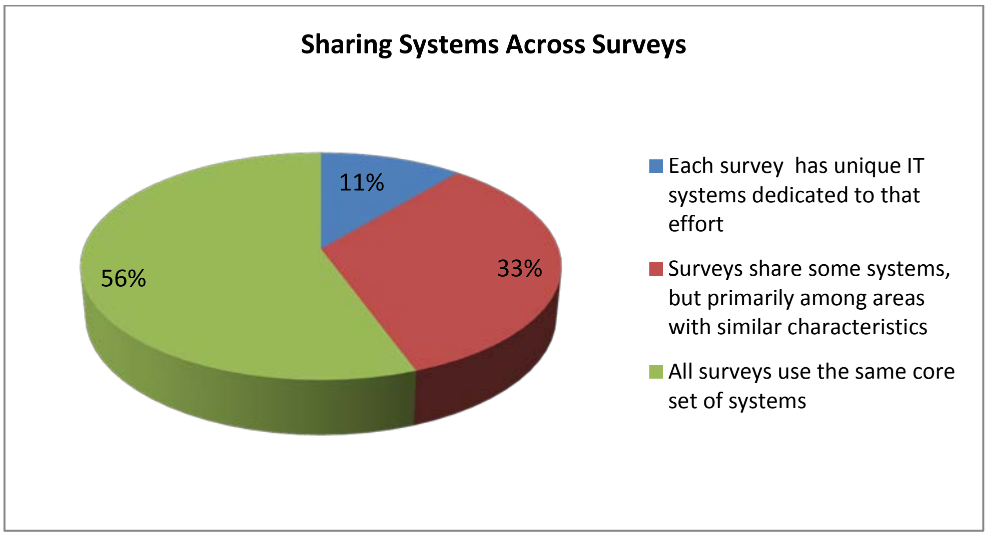

Figure 5 – A shared systems approach is not uncommon

This was significant for us because, as we suggest in Section 2, the challenges involved with implementing adaptive survey design are more manageable in a shared systems environment.

This idea of shared services and common platforms is not new – it is actually very common in other industries, but has been slower to take hold with statistical organizations. Mergers and acquisitions forced companies in the private sector to consolidate IT systems serving similar functions to lower operational costs (Lasko, Webb 2013). The U.S. Government published a *Shared Services Strategy* in May 2013 as a complement to the Federal Enterprise Architecture. This strategy provides architectural guidance for the use of shared services to replace multiple systems that perform similar mission enabling functions in a government agency.

Within the U.S Government the Shared Services Strategy promotes inter-agency sharing of Line of Business (LOB) services where a managing partner such as the U.S.

Department of Agriculture, for example, provides a payroll business function to a large number of government agencies. The CSPA and other Enterprise Architecture standards from the UNECE promote a model for statistical organizations to develop shared services that may be usable across organizations. National Statistical Organizations have shared services programs at different stages of implementation. An example is the Information Management Transformation Program (IMTP) implemented at the Australian Bureau of Statistics (Studman 2010). At the U.S. Census Bureau we are building a suite of shared services in the data collection segment of our Survey LifeCycle. We discuss this effort in section 6.

5.3 Discussion on Collaboration between Research and IT

We continued by asking interviewees about their organizational culture – specifically the relationship between researchers and IT. This was interesting to us because we believed it could shed light on a key proposal of this article – that methodology and IT should be intertwined. We framed the discussion as follows:

> Please discuss the way your organization assigns survey methodology and IT Architecture work to employees:
>
> 1. Is the boundary clear and definite, with survey methodologists assigned to the Research and Methodology area or directly to a survey implementation, and IT Architects assigned to the IT area?
> 2. Is there a nominal boundary between Survey Methodology and IT Architecture, where both Survey Methodologists and IT Architects are assigned by their respective organizations to projects, on a project-by-project basis?
> 3. Is there no clear boundary between Survey Methodology and IT Architecture – i.e., are staff with both Survey Methodology and IT skills permanently assigned to a specific survey and spend years on that survey sharing methodology and IT responsibilities?

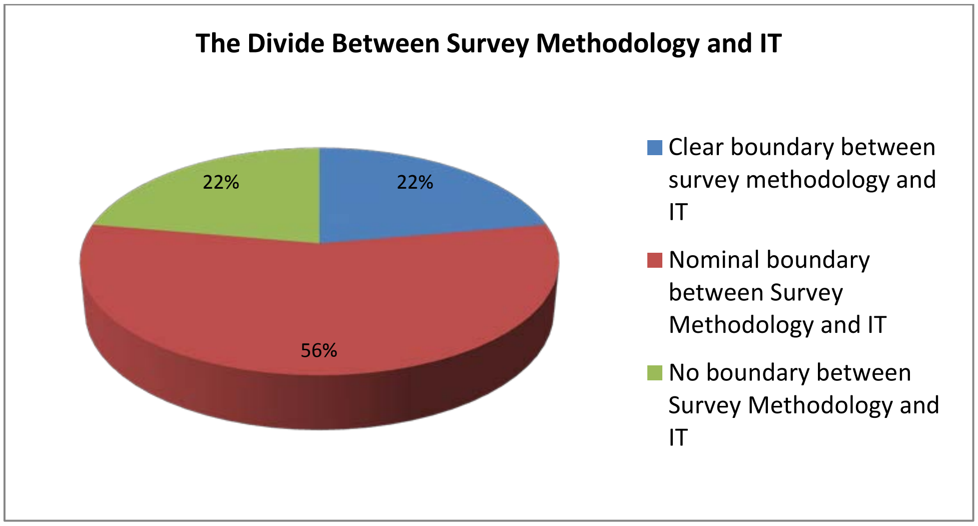

Figure 6 – We seem to be moving toward greater collaboration

The organizations in the first category, where a clear boundary exists between IT and methodology (blue portion of the pie chart in Figure 6), were generally large National Statistical Organizations that have undergone major IT centralization initiatives. This approach has been effective, particularly in reducing IT spending, and interviewees stressed that it still allows for interaction between methodologists and IT. However, they also often referred to the difficult, even painful transition associated with the centralization process. Considering our proposal that balance is critical, these challenging transitions make sense, as the very nature of IT centralization initiatives assumes the situation is heavily weighted in the direction of IT issues.

The U.S. Census Bureau has had many examples that fall into the third category (no boundary between survey methodology and IT). The interviews we conducted with our own staff put us firmly in the green slice of the pie chart in Figure 6. Though there are a number of recent initiatives at Census that are moving us away from this operational model, we arrived here as a result of building permanent, self-contained staffs around well established surveys. It is often the case with this approach that the people responsible for implementing the IT work are actually statisticians who have developed computer programming skills in order to design and maintain their survey-specific systems. There are benefits to this, including the deep, survey-specific expertise that comes from spending years employed on a single program. However, we do not suggest that this is the most effective way to intertwine IT with methodology.

Rather we believe, and our interviews suggest, that a nominal boundary, where methodologists and IT experts rotate on a project-by-project basis may be more effective. Having IT resources available for assignment where they are most needed increases integration across a statistical enterprise. It enables coordinated approaches to IT tools and standards, security, training and staff development.

Likewise, with methodologists, cross-fertilization among projects helps to promote awareness of new and emerging methodological ideas and the various settings in which they can be applied.

We found that a majority of our interviewees work in organizations where this nominal boundary between methodology and IT exists. Interestingly, we also found that organizations taking this approach are the ones that most often have shared systems across surveys. Our assertion that shared systems will reduce the complexity of operations is not new or original. However, our suggestion that there should be robust IT capabilities combined with expertise in research methodology, available in a fluid manner where they are most needed, is an organizational pattern worthy of further research.

5.4 Discussion on the origins of system innovation

As we state in the introduction, the search for balance in statistical organizations frequently rests on a fulcrum of innovation, with statistical methodology on one side and information technology on the other. We asked whether our interviewees feel that one side or the other originates more innovative system projects in their organizations.

An important point here is that in our interviews we referred to *system* innovation, not simply innovation. There were two reasons for this. First, we wanted to keep the conversation focused on the balance issue, and second we believe, as we discuss in section 4, that the frontier of statistical methodology (administrative records use, paradata, adaptive survey design, big data, etc.) is now inextricably linked to the computer systems that are required to bring it to fruition. We framed the discussion as follows:

> Please discuss the way in which new, innovative system projects begin in your organization.
>
> 1. Statistical methodologists generate new ideas, test concepts, build small system prototypes within the Research and Methodology area, and then pitch new ideas to the organization and to leadership
> 2. IT architects generate new ideas, test concepts, build small system prototypes within the IT area, and then pitch new ideas to the organization and to leadership
> 3. Statistical methodologists and IT architects are assigned by their respective organizations to work together to generate new ideas, test concepts, build small system prototypes, and then pitch new ideas to the organizational leadership
> 4. Don't know/Not sure

We note that none of our interviewees felt that statistical methodologists were the sole source of new system-related innovation in their organizations. This did not mean, however, that methodologists do not play a critical role in innovation. Rather, our interviews indicated simply that statistical methodologists rarely undertake innovation that involves new system development on their own.

Nearly two-thirds of the people we interviewed believe that innovation originates in cooperative teams that include methodologists and IT architects working together (Figure 7). This aligns with our proposal that there are positive effects of comingling methodology and IT. Still, 25 percent of our interviewees said that system innovations come primarily from the IT side. This set of responses correlated primarily with academic statistical organizations where, interviews indicated, the education and research environment may be a contributing factor in encouraging IT staffs to work differently from other organizations.

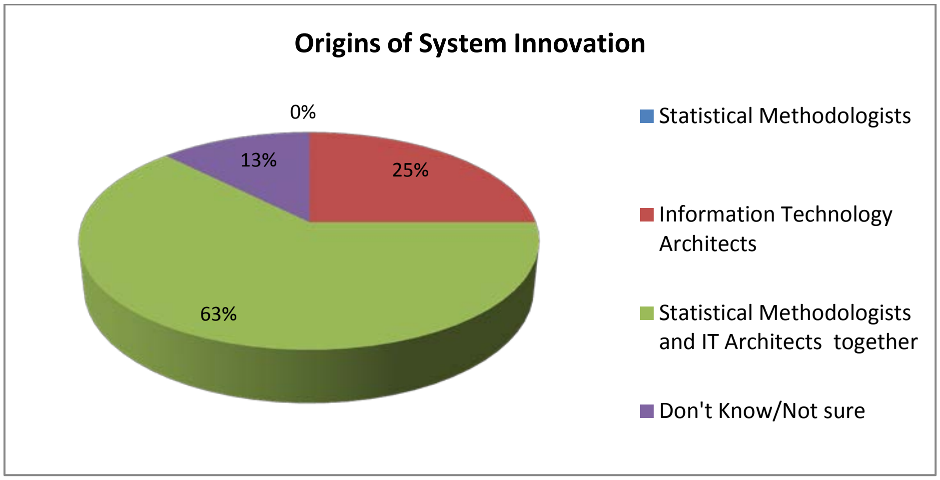

Figure 7 - Where system innovation is likely to originate – more collaboration

5.5 Discussion on the success of new IT systems

We finished our interviews with a general discussion of how successful organizations are at implementing new IT systems. We framed the discussion as follows:

> Please choose the description that most closely matches your organization's experience with IT systems that have been implemented in the past seven years.
>
> 1. They generally work well when implemented
> 2. They eventually work well, but have a rocky start
> 3. They often do not deliver what was promised and rarely work well.
> 4. We have scrapped one or more new IT system implementations in the last seven years.

Our initial motivation for this part of the discussion was to see if there is any correlation between the organizational characteristics that we believe indicate a balance between methodology and IT, and successful IT system implementation. In this, we were not successful. The results of our interviews did not indicate that there is any correlation. However, myriad cause and effect relationships exist in the realm of innovation – system or otherwise. Budgets can be cut, requirements can change, and critical team members can come or go. Balancing the influence between methodologists and IT architects is one more factor that we propose is important to consider, and more observation and research is needed to help determine the extent to which causal relationships can be measured.

A notable finding from this part of our discussion is that a full three quarters of our interviewees characterize their new IT systems as either working well or eventually working well. A quarter of our interviewees have scrapped an IT system within the last seven years.

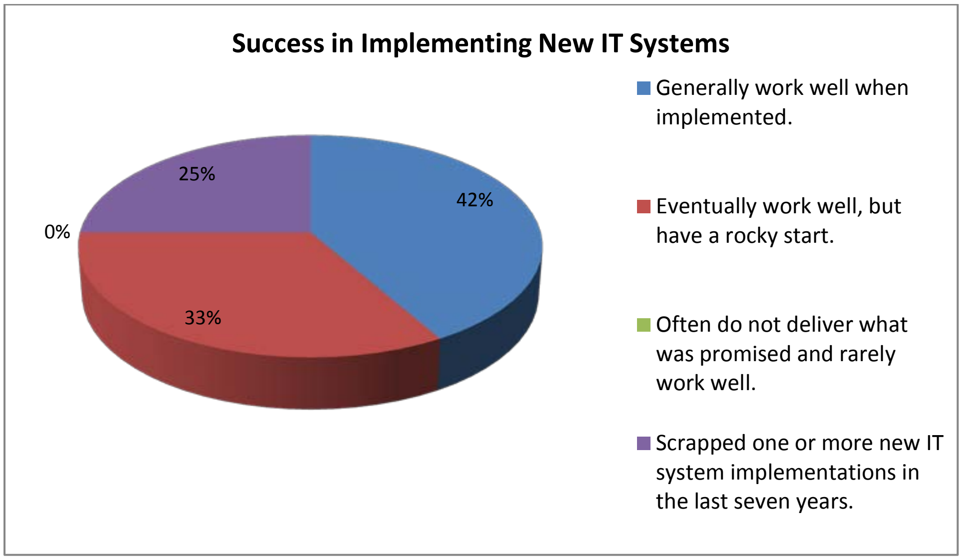

Figure 8 - 75% of interviews said that new IT systems work well

6. The Adaptive Design Solution at Census

As is the case in many large undertakings with external deadlines and dependencies, we had to move forward with a plan and direction within the same timeframe that we were doing research to help inform that plan and direction. However, our discussions with colleagues from all over the world have helped to reinforce the decisions we have made thus far.

6.1 The solution at a high level

In line with our proposal that a methodological idea should drive IT solutions, our pursuit of a solution for adaptive survey design led to a broader planning effort that spans the data collection and processing segment of the Census Bureau Survey Lifecycle. The goal of this planning effort is to create a shared service corresponding to each unique function in that segment.

To accomplish this goal we are building several new shared systems and modifying existing systems so that multiple surveys and censuses can be on-boarded in a way that has the least impact on ongoing operations. The data collection and processing segment of the Census Bureau survey lifecycle contains numerous business processes with a high degree of complexity. Therefore, we plan to transition to the future state of operations through a multi-phased effort that we expect to take a number of years to be fully realized.

In addition, to achieve end-to-end interoperability we are standardizing both the structure as well as semantics of the data that flow through shared services. An example of this is a new canonical schema we have developed for both survey workload and survey response that aligns with the Data Documentation Initiative (DDI) architectural data standard.

Figure 9 shows a high-level view of the shared services we have planned. It shows a shared service platform for creating the sample/universe, another for multimode operational control, and another for post collection processing. This represents a major move forward in reducing redundant systems and increasing interoperability when compared to our previous (accidental) architecture.

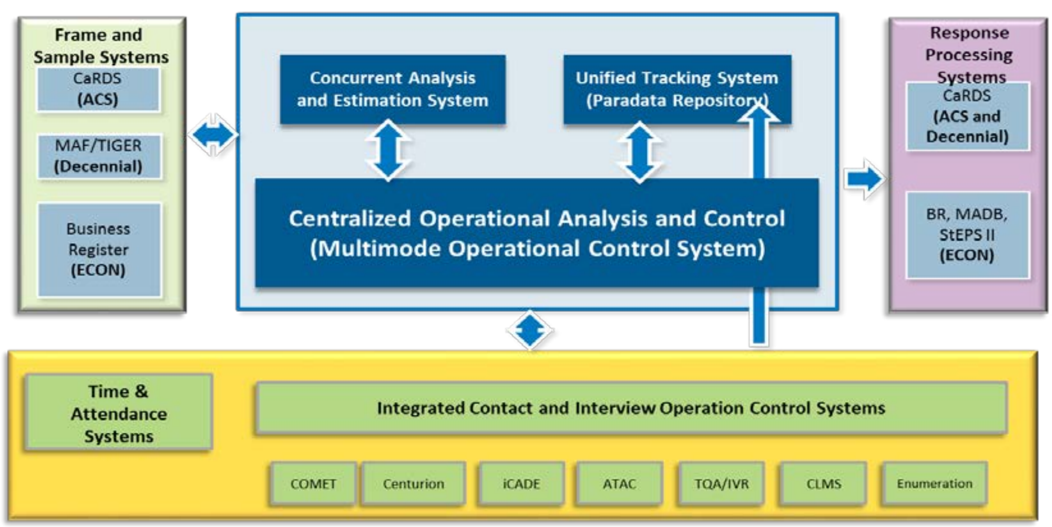

Figure 9 - Shared Services for Survey Data Collection and Processing

6.2 The Multimode Operational Control System in context

In this section, we describe the *Multimode Operational Control System* (MOCS), one of the key shared services under development. MOCS is the primary orchestrator of data collection operations for a survey. It controls cases across multiple modes of data collection. To illustrate how we are building a common system for multiple surveys and censuses we will briefly look at the salient features as well as key architecture and technology decisions.

Features of the MOCS include:

- Variation in the sequencing of data collection operations to accommodate different surveys
- Creation of workloads for modes based on changes in case status, inspection of response data, and sub-sampling
- Workload creation based on business rules that are specific to different surveys
- Adaptive orchestration of data collection operations as well as workload selection based on statistical models. Examples of such orchestrations may include the switch of a data collection mode or the stopping of survey data collection.
- Creating and providing normalized response data for post data collection processing

Figure 10 shows the MOCS in context with other data collection and processing shared services.

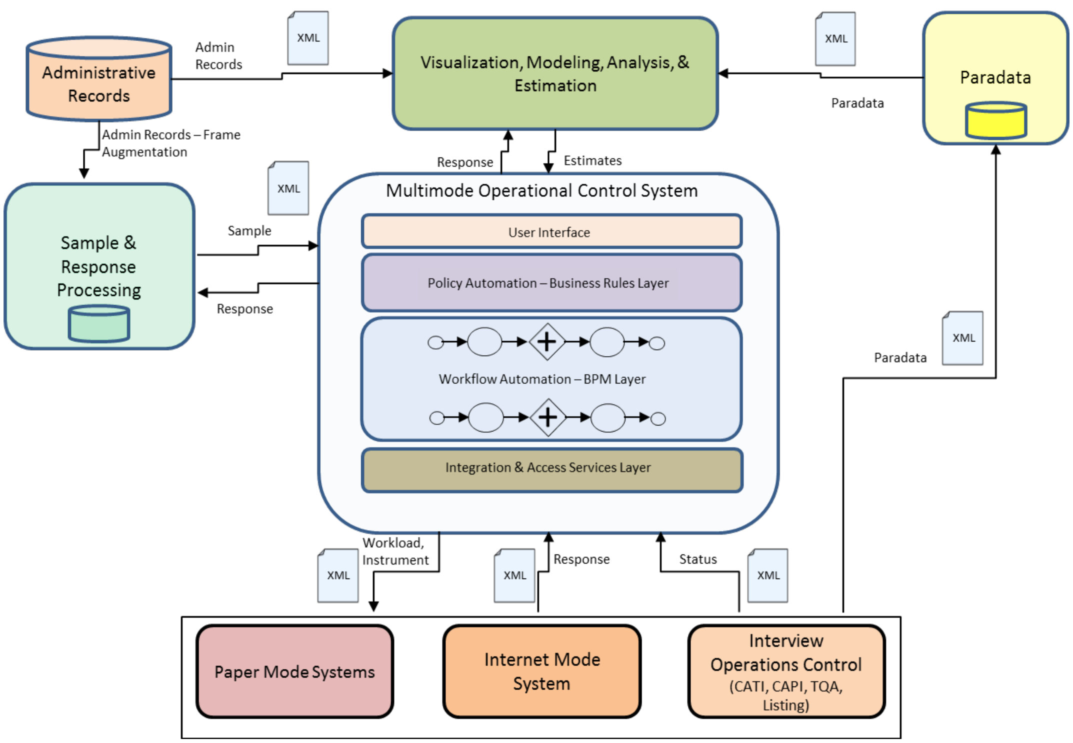

Figure 10 - Our Multimode Operational Control System (MOCS) is at the center of adaptive design

A shared service (called the Control and Response Data System, or CaRDS) will provide MOCS with the incoming sample as well as any updates to the sample. The MOCS will manage all cases in a survey across all modes. Initial workload allocation for all modes will be determined in the MOCS, and MOCS will perform subsequent allocation of cases from one mode to another. During data collection, we will make use of near real-time response data and paradata in a modeling environment to orchestrate interventions for the purposes of optimization. The goals of optimization will be manifested in a flexible business rules approach allowing for cost/quality trade-offs. Finally, MOCS will receive survey response data from all data collection modes and provide the normalized response data back to CaRDS for processing.

We are using four fundamental building blocks to implement the MOCS.

1. A Business Process Management (BPM) and Business Process Execution Language (BPEL) layer to implement a flexible and customizable workflow automation platform. This allows us to accommodate the variations in the survey workflows for multiple surveys.
2. A flexible business rules layer, invoked with response data and paradata as inputs. For example, a business rule that inspects case status immediately removes a case from the telephone interview or personal interview mode if that case has been completed in a self-response mode. Business rules are also invoked based on the results output from statistical models that influence adaptive survey design decisions. A modeling, analysis, and estimation layer is also in planning to work in concert with the MOCS. The modeling layer will marshal administrative records data, paradata, and response data and run statistical models to produce estimates such as response propensity scores that can enable optimization.
3. An integration and access services layer manages all in-bound and out-bound data exchanges from the MOCS. As mentioned above, MOCS uses a new standard schema for sample delivery, workload delivery, paradata, and response data to interoperate with the data collection modes, and CaRDS.
4. A user interface layer allows survey owners to execute interventions such as manually selecting cases and manually invoking workflows.

Though there are additional components that will complete the picture of data collection modernization at the U.S. Census Bureau, including, for example, geo-enabled mobile computing for personal interview data collection optimization, the MOCS is the heart of our systems approach to adaptive survey design.

7. Conclusion

The introduction of the methodological idea of adaptive survey design began this conversation. Over the last two years, considerations of adaptive design have provided the direction and the yardstick to measure our plans and efforts. The new assessments that grew out of the requirements for adaptive design broadened our thinking and revealed important limitations in our architecture that led to a major new initiative called the Census Enterprise Data Collection and Processing (CEDCaP) program that will launch in 2015.

Organizational transformations like system consolidation are difficult and risky. Our interviews with colleagues confirmed that we are not at all unique in our efforts to consolidate systems and achieve greater efficiency. We learned that there are a number of common yet critical ingredients to making such efforts work, including a strong architectural approach, disciplined project management, senior executive buy-in, and incremental delivery, among others. The interviews we did for this paper helped to reinforce our belief that intertwining the work of methodologists and IT practitioners should be added to that list of ingredients.

We believe that this approach can provide a potent mitigation to the challenges and risks statistical organizations are facing in the struggle to modernize. In the case of the U.S. Census Bureau, we will continue at times to feel the gravitational pull in either direction that threatens to disrupt the appropriate balance. However, we have committed to building adaptive design systems as shared services, and to maximizing the benefits of close collaboration between methodology and IT.

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