Inadequate Interoperability: A Closer Look at the Costs

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***Abstract*—The 2004 NIST interoperability cost study estimated an annual cost burden of $15.8 billion due to inadequate interoperability in the capital facilities segment of the U.S. construction industry. The $15.8 billion estimate is the sum of individual annual cost burdens for four key stakeholder groups: architects and engineers ($1.2 billion); general contractors ($1.8 billion); specialty fabricators and suppliers ($2.2 billion); and owners and operators ($10.6 billion). From a business perspective, these costs represent approximately one percent of annual receipts for each of the first three stakeholders and nearly three percent of the annual value of construction put in place for owners and operators. Building on the NIST interoperability cost study, this paper addresses the cost burden and business-related issues by explaining the methodology behind the estimates, analyzing key "cost impacts," and discussing challenges and implications for change within the industry.**

***Index Terms*—buildings, economic impact evaluation, industrial facilities, integration and automation technologies, interoperability**

I. Introduction

THE capital facilities industry[1] is facing several significant competitive challenges that will affect its future growth potential. Owners of capital facilities and contractors engaged in the construction of those facilities are pressing for reductions in delivery time as a means of improving their competitive positions. Owner concerns over both the first costs and the life-cycle costs of capital facilities and tightening profit margins for contractors are also affecting the competitive positions of each stakeholder. One means of improving the competitive position of each stakeholder in the capital facilities industry is through improvements in interoperability.

One-time data entry and the seamless flow of information to all project participants throughout the project life cycle is a goal of the interoperable construction environment. Interoperability among computer-aided design, engineering, and construction software systems offers the potential for revolutionary change in the effectiveness with which construction-related activities are executed and in the value they add to construction industry stakeholders. Unfortunately, the construction industry has been slow to embrace interoperability as a means for integrating its design, construction, and operational processes. It is well known that inadequate interoperability increases the cost burden of construction industry stakeholders. The lack of quantitative measures of the annual cost burden, however, has hampered efforts to promote change within the industry.

Two reports published by NIST in 2000 and 2001 focused on measuring cost savings stemming from its construction systems integration and automation technologies (CONSIAT) research program [1, 2]. Estimates of potential CONSIAT-related cost savings for the capital facilities industry were based on a small set of commercially available technologies. The two NIST reports generated interest within the construction industry for a comprehensive look at the costs of inadequate interoperability. Renewed interest in the costs of inadequate interoperability sparked by the creation of FIATECH, and the need for an unbiased effort at measuring the magnitude of those costs, led to NIST's decision to embark on a formal study that went considerably beyond its internal CONSIAT program. The study, published as NIST GCR 04-867, produced a $15.8 billion estimate of the annual cost burden due to inadequate interoperability in the capital facilities segment of the U.S. construction industry [3]. These cost impacts are of interest to multiple stakeholders—owners and operators of capital facilities; design, construction, operation and maintenance, and other providers of professional services in the capital facilities industry; and public- and private-sector research organizations engaged in developing interoperability solutions.

This paper addresses the cost burden and business-related issues of interoperability by explaining the methodology behind the estimates, analyzing key "cost impacts," and

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[1] The capital facilities industry covers construction-related activities and the associated supply chains throughout the life cycle of industrial facilities and commercial buildings. Industrial facilities include utilities, government facilities, and facilities where the manufacturing of products or commodities takes place. Commercial buildings include private- and public-sector office buildings, institutional buildings, and service businesses.

discussing challenges and implications for change within the industry. The paper highlights the cost impacts of inefficient business process management as a potential target of opportunity. Because multiple stakeholders share the same inefficiency for a well-defined subset of their internal business functions, there is a potential for mutual gains if they address the root causes of the problem.

II. METHODOLOGY

Estimating the cost of inadequate interoperability in the U.S. capital facilities industry involved a two-step procedure in NIST GCR 04-867. Average costs per unit of floor area were first estimated through the use of survey data supplemented by information from government and industry publications. The per unit average costs were then weighted by construction activity in 2002 or the capital facility stock in place in 2002 to develop national impact estimates.

To generate estimates of the average cost per unit of floor area, it was first necessary to develop a means for comparing current costs of business activities with those in a scenario where information is entered electronically only once. Focus group meetings and telephone interviews were used to develop the "counterfactual" scenario against which efficiency losses were measured.

Examples of efficiency losses associated with current business activities include manual reentry of data, duplication of business functions, and the continued reliance of paper-based information management systems. These efficiency losses are indicative of three generic cost categories: avoidance costs, mitigation costs, and delay costs. Avoidance costs are related to activities undertaken to prevent or minimize the impact of interoperability problems before they occur. Mitigation costs stem from activities responding to interoperability problems. Most mitigation costs result from electronic or paper files that have to be reentered manually into multiple systems and from searching paper archives. Delay costs arise from interoperability problems that delay the completion of a project or the length of time a facility is not in normal operation.

The economic methodology used to estimate annualized costs in 2002 is summarized in Figure 1. The three dimensional framework shown in Figure 1 is needed because costs are categorized with respect to where they are incurred in the capital facility supply chain. Thus, interoperability problems affect an array of stakeholders and encompass a large number of activities. Finally, the capital facility life cycle spans a number of phases, each of which poses its own set of interoperability challenges. Figure 1 provides a simple yet concise statement of how life-cycle phases, stakeholders, and cost categories are combined to produce estimates of the average cost per unit of floor area:

- Life-Cycle Phases: planning, engineering and design, construction, operations and maintenance (O&M), and decommissioning;
- Stakeholders: architects and engineers, general contractors, specialty fabricators and suppliers, and owners and operators; and
- Cost Categories: efficiency losses from activities incurring avoidance, mitigation, and delay costs.

A series of survey instruments were used to implement the economic methodology. Each stakeholder group had a survey instrument customized to their needs. The questions within each survey instrument were designed so they could be mapped to each of the "cells" at the base of Figure 1. For example, there were specific questions in the general contractors' survey instrument that mapped into mitigation costs during the construction phase.

With the exception of the decommissioning phase, average cost estimates per square meter ($/m^2) were calculated by life-cycle phase, stakeholder group, and cost category. These per-unit impacts were then weighted by construction activity or, in the case of the O&M phase, by capital facility stock to develop national impact estimates for the capital facilities industry. Total new construction activity in 2002 was estimated to be 106 million square meters put in place. The capital facility stock in 2002 was estimated to be 3.6 billion square meters. These estimates were developed using source data from the U.S. Energy Information Administration [4, 5].

III. KEY COST IMPACTS

Based on interviews, survey responses, and government and industry publications, the annual cost burden due to inadequate interoperability in the U.S. capital facilities supply chain was estimated to be $15.8 billion in 2002. Table 1 summarizes the results for each stakeholder group according to facility life-cycle phase; Table 2 summarizes the results for each stakeholder group according to cost category.

Table 1 shows clearly that the majority of estimated costs are borne by owners and operators and that the O&M phase has higher costs associated with it than other life-cycle phases as information management and accessibility hurdles hamper efficient facilities operation. Owners and operators bore approximately $10.6 billion, or about two-thirds of the total estimated costs in 2002. Architects and engineers had the lowest interoperability costs at nearly $1.2 billion. General contractors and specialty fabricators and suppliers bore the balance of costs at $1.8 billion and $2.2 billion, respectively. Reference to Table 1 shows that costs increase sharply as we move from the planning, engineering and design phase, through the construction phase, to the O&M phase. The cost burdens borne by the various stakeholder groups also shift. In the planning, engineering and design phase, architects and engineers bear the majority of the cost burden at $1.0 billion. In the construction phase, general contractors and specialty

fabricators and suppliers shoulder most of the cost burden at nearly $1.3 billion and $1.8 billion, respectively. As noted earlier, O&M phase costs are borne almost exclusively by owners and operators.

As shown in Table 2, most costs fall under the mitigation and avoidance cost categories. Owners and operators and architects and engineers primarily incur mitigation costs, and general contractors and specialty fabricators and suppliers primarily incur avoidance costs. Estimated delay costs are primarily associated with owners and operators. However, all stakeholder groups indicated that seamless exchange of electronic data would shorten design and construction time, even though many could not judge the impact.

Information presented in chapter 6 of the NIST study [3] sheds light on the cost drivers behind the individual entries in Tables 1 and 2. Consider the case of mitigation costs. For architects and engineers, mitigation costs in the planning, engineering and design phase were driven by two cost items: manual reentry costs ($463 million) and design and construction information verification costs ($114 million). For contractors, mitigation costs were also driven by two cost items: manual reentry ($184 million in the planning, engineering and design phase and $126 million in the construction phase) and RFI management costs ($131 million in the planning, engineering and design phase and $184 million in the construction phase). Manual reentry costs were also a significant factor for specialty fabricators and suppliers ($128 million in the planning, engineering and design phase and $116 million in the construction phase). Owners and operators, like the other three stakeholder groups, bore significant manual reentry costs ($177 million in the planning, engineering and design phase and $168 million in the construction phase). However, these costs are dwarfed by the $4.8 billion O&M information verification costs during the O&M phase.

IV. CHALLENGES AND IMPLICATIONS

The $15.8 billion annual cost burden demonstrates that significant opportunities exist both for increasing the efficiency of the project delivery process and for better resource allocation in the O&M phase. However, these opportunities face major challenges that must be addressed to bring about change. Of central importance is the fragmented nature of the construction industry, which complicates the diffusion of new ideas and technologies. In addition, the prevalence of design-bid-build contracts limits opportunities for collaboration.

The four stakeholder groups—architects and engineers (A&Es), general contractors (GCs), specialty fabricators and suppliers (SF&Ss), and owners and operators (O&Os)—have differing measures of economic performance against which to compare their cost burden. For A&Es, GCs, and SF&Ss, the key measure is the annual receipts for the work they perform. For O&Os, the key measure is the value of construction put in place. Annual receipts for each stakeholder group in 2002 were: $105.2 billion for A&Es; $209.3 billion for GCs; and $177.2 billion for SF&Ss [6]. For O&Os, the value of construction put in place in 2002 was $374.1 billion [7]. When these measures of economic performance are compared to the annual cost burdens, the impact of inadequate interoperability on the corporate balance sheet begins to emerge. These inefficiency losses, expressed as a percent of the economic measure of performance, for each stakeholder group are: 1.1 % for A&Es; 0.9 % for GCs; 1.2 % for SF&Ss; and 2.8 % for O&Os. In an industry where profit margins are often razor thin, these inefficiency losses represent a genuine opportunity for improvement. The key for initiating change, however, is to identify specific inefficiencies and to find opportunities for collaboration—both within individual firms and across firms and stakeholder groups in the capital facilities industry—that will result in mutual gains.

A previous study by the author found that more than 80 % of all construction firms have less than 10 employees and approximately 98 % have less than 50 employees [8]. These figures are for the construction industry as a whole. However, when the focus is placed on the capital facilities industry, average firm size is still quite small. Based on information published by the U.S. Census, average firm size in the capital facilities industry was 12.0 employees for A&Es, 15.0 for GCs, and 10.1 for SF&Ss [6]. In all, approximately 180,000 firms provide professional services to the capital facilities industry. Because fragmentation of the industry creates challenges for the diffusion of new ideas and technologies, early efforts at change will likely involve larger firms.

One mechanism that both addresses the above statement as well as opportunities for collaboration is the use of design-build contracts for large, complex capital facility projects. A collaborative effort between NIST and the Construction Industry Institute (CII) examined data from more than 600 projects to compare how the project delivery system affected project outcomes and the use of industry best practices [9]. The NIST/CII study focused on design-build and design-bid-build projects. Project outcomes examined included cost, schedule, safety, and change management. The key finding, which provides insights into the interoperability issue, is that as project size increased the proportion of design-build projects increased dramatically. Furthermore, the NIST/CII study demonstrated a significantly higher use of industry best practices on design-build projects. Key among those industry best practices were team building and design/information technologies. From the results of the NIST/CII study, we are able to conclude that design-build projects offer a greater opportunity for collaboration and the larger size of design-build projects implies the presence of larger firms which have embraced best practice use as a means of achieving better project outcomes. Thus, large design-build projects may provide a test bed for addressing a variety of interoperability issues.

Earlier it was noted that all four stakeholder groups experienced substantial manual reentry costs. Because these costs are incurred in order to fix interoperability problems after they have occurred, it is natural to consider possible root causes of the problem to see if it could be avoided altogether or at least reduced. One area which is worth exploring concerns business process management functions. All firms have administrative and internal service functions that support their revenue centers. Interoperability affects these functions because information management and exchange issues increase the workload for these functional areas. Inefficient business process management costs occur when inadequate interoperability ripples through the firm, from revenue centers to administrative and technical support functions.

The NIST interoperability study considered the effect of inadequate interoperability on internal business functions. Specific questions in each stakeholder group's survey instrument were used to estimate the magnitude of inefficient business process management costs. These survey questions were also useful in identifying the top five business processes which were the prime areas of concern. Table 3 records the key business processes impacted by inadequate interoperability and prioritizes them by stakeholder group. The top five business processes are listed in rank order for O&Os, GCs, and SF&Ss. For A&Es the top three are listed. The rank-ordered list presented in Table 3 contains seven business processes. What is noteworthy is that two business processes—information request processing and project management—rank in the top five for all four stakeholder groups. Two processes—document management and facility planning and scheduling—rank in the top five for three of the four stakeholder groups.

Because business process management functions affect both internal efficiency between different units within the firm and information exchange between project participants external to the firm, reducing their cost burden offers potential for mutual gains. The potential for mutual gains is highlighted in the bottom three rows of Table 3, which record for each stakeholder group annual inefficient business process management costs, the total cost burden, and the percentage of the total cost burden due to inefficient business process management costs. Values for the total cost burden are drawn from the last column of Table 1. Reference to Table 3 shows that inefficient business process management costs range from almost $400 million for A&Es to $2.6 billion for O&Os. Overall, inefficient business process management costs are $6.0 billion or nearly 40 % of the $15.8 billion annual cost burden. O&Os have the lowest percentage share at slightly less than 25 % of their $10.6 billion total. In the case of SF&Ss, almost 85 % of their $2.2 billion total is due to inefficient business process management costs.

V. CONCLUSION

Inadequate interoperability imposes a significant cost burden on all stakeholders in the capital facilities industry. Having a measure of that cost burden creates opportunities for change. However, major challenges remain and addressing them will require a concerted effort by a number of key players. O&Os have come to the realization that costs compound as one moves forward in the facility life cycle and that their heavy costs in the O&M phase are a result of disconnects in the design and construction phases. A&Es, GCs, and SF&Ss, also view interoperability costs as stemming from disconnects as well as a lack of incentive to improve interoperability—both within and among firms. Thus, areas which offer the potential for mutual gains are candidates for bringing about change within the industry. Business process management functions offer such an opportunity. Focusing on business process management functions will likely result in significant reductions in the annual cost burden both within and among firms, but technical solutions to support these activities are still needed. Efforts underway at FIATECH and the International Alliance for Interoperability on standards for data exchange could become the catalyst for change within the capital facilities industry.

REFERENCES

[1] Chapman, Robert E. 2000. *Benefits and Costs of Research: A Case Study of Construction Systems Integration and Automation Technologies in Industrial Facilities*. NISTIR 6501. Gaithersburg, MD: National Institute of Standards and Technology.

[2] Chapman, Robert E. 2001. *Benefits and Costs of Research: A Case Study of Construction Systems Integration and Automation Technologies in Commercial Buildings.* NISTIR 6763. Gaithersburg, MD: National Institute of Standards and Technology.

[3] Gallaher, Michael P., Alan C. O'Connor, John L. Dettbarn, Jr., Linda T. Gilday. 2004. *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry*. NIST GCR 04-867. Gaithersburg, MD: National Institute of Standards and Technology.

[4] Energy Information Administration. *The 1998 Manufacturing Energy Consumption Survey*. Washington, DC: Energy Information Administration.

[5] Energy Information Administration. *The 1999 Commercial Building Energy Consumption Survey*. Washington, DC: Energy Information Administration.

[6] U.S. Census Bureau. 2002. *1997 Economic Census: 1997 Economic Census: Construction Subject Series.* EC97C23S-IS. Washington, DC: U.S. Census Bureau.

[7] U.S. Census Bureau. 2004. *Annual Value of Construction Set in Place*. C30. Washington, DC: U.S. Census Bureau.

[8] Chapman, Robert E. 2000. *An Approach for Measuring Reductions in Construction Worker Illnesses and Injuries: Baseline Measures of Construction Industry Practices for the National Construction Goals*. NISTIR 6473. Gaithersburg, MD: National Institute of Standards and Technology.

[9] Thomas, Stephen R., Candace L. Macken, Tae Hwan Chung, and Inho Kim. 2002. *Measuring the Impacts of the Delivery System on Project Performance—Design-Build and Design-Bid-Build*. NIST GCR 02-840. Gaithersburg, MD: National Institute of Standards and Technology.

Figure 1. 3-D Representation of Estimation Approach of Inadequate Interoperability Costs

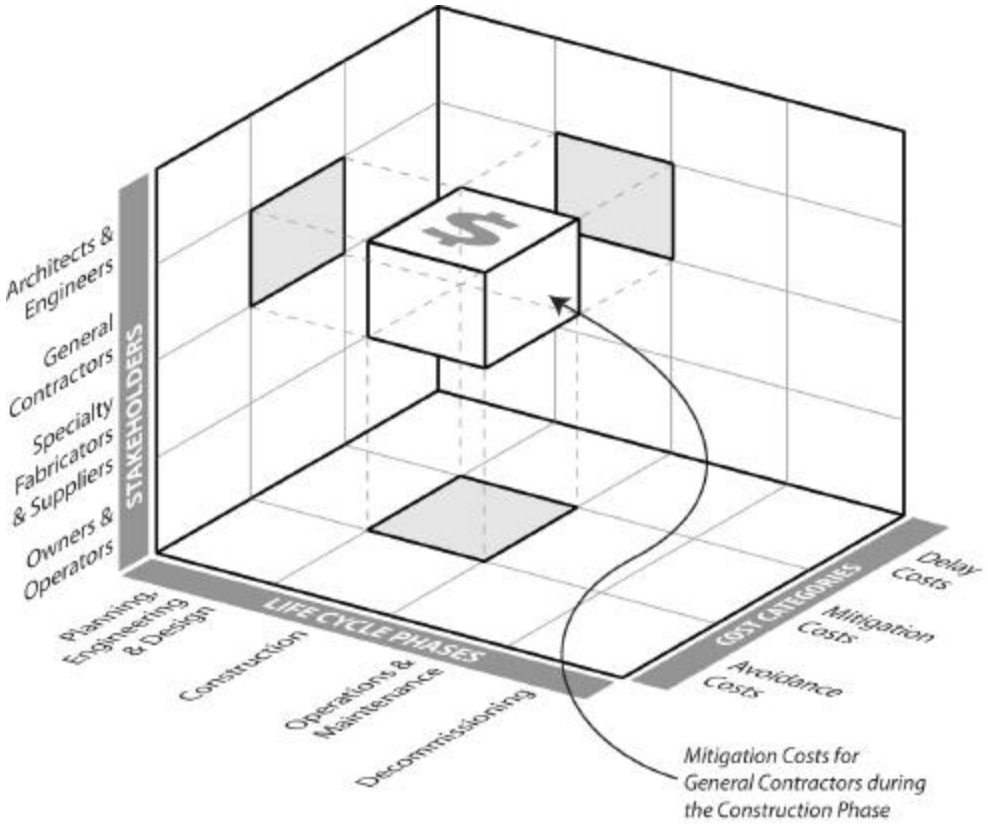

Table 1. Costs of Inadequate Interoperability by Stakeholder Group and Life-Cycle Phase (in $Millions)

Stakeholder Group	Life-Cycle Phase			
	Planning, Design and Engineering Phase	Construction Phase	Operations and Maintenance Phase	Total
Architects and Engineers	1,007.2	147.0	15.7	1,169.8
General Contractors	485.9	1,265.3	50.4	1,801.6
Specialty Fabricators and Suppliers	442.4	1,762.2	—	2,204.6
Owners and Operators	722.8	898.0	9,027.2	10,648.0
Total	**2,658.3**	**4,072.4**	**9,093.3**	**15,824.0**

Source: NIST GCR 04-867. Sums may not add to totals due to independent rounding.

Table 2. Costs of Inadequate Interoperability by Stakeholder Group and Cost Category (in $Millions)

Stakeholder Group	Cost Category			
	Avoidance Costs	Mitigation Costs	Delay Costs	Total
Architects and Engineers	485.3	684.5	—	1,069.8
General Contractors	1,095.4	693.3	13.0	1,801.7
Specialty Fabricators and Suppliers	1,908.4	296.1	—	2,204.5
Owners and Operators	3,120.0	6,028.2	1,499.8	10,648.0
Total	**6,609.1**	**7,702.0**	**1,512.8**	**15,824.0**

Source: NIST GCR 04-867. Sums may not add to totals due to independent rounding.

Table 3. Key Business Processes Impacted by Inadequate Interoperability, Prioritized by Stakeholder Group

Business Process	Stakeholder Group				
	A&Es	GCs	SF&Ss	O&Os	Total
Document Management	2	2		1	
Facility Planning and Scheduling		5	2	4	
Information Request Processing	3	1	3	3	
Maintenance Planning and Management				2	
Procurement		4	4		
Product Data Management			5		
Project Management	1	3	1	5	
Inefficient Business Process Management Costs (in $Millions)*	399.4	1,091.2	1,864.4	2,630.9	5,985.9
Total Costs (in $Millions)	1,169.8	1,801.6	2,204.6	10,648.0	15,824.0
Inefficient Business Process Management Costs (in $Millions)	34.1	60.6	84.6	24.7	37.8

* Other Business Processes included in the cost estimate but not listed separately are: Accounting; Cost Estimation; Enterprise Resource Planning; Facility Simulation; Inspection and Certification; Materials Management; and Start-up and Commissioning.