THE EFFECTS OF DESIGN COORDINATION ON PROJECT UNCERTAINTY

David Riley[1], Michael Horman[2]

ABSTRACT

Improved design coordination can minimize project uncertainty by decreasing disruption, and reducing waste in the construction processes. While the relationship between coordination and uncertainty is understood, there is little empirical evidence that quantifies the linkage. This paper explores the effects of design coordination on project uncertainty, and demonstrates that investments in design coordination can typically return savings to building projects by reducing field-generated change orders and disruptions. Evidence is provided to demonstrate the cost-benefit relationship between investment in coordination planning and the cost of field conflicts. The effects of project delivery systems on the coordination process are examined through a comparison of the coordination process on fourteen laboratory construction projects. Suggestions for characterizing coordination effort based on project type and delivery system are provided and recommendations are made for future research on the time and cost metrics of the coordination process.

KEY WORDS

Design coordination, Variability, Work Flow

[1] Associate Professor, Department of Architectural Engineering, Penn State University, 104 Eng. Unit A, University Park, PA, 16802. Ph: 814/863-2079 driley@engr.psu.edu

[2] Assistant Professor, Department of Architectural Engineering, Penn State University, 104 Eng. Unit A, University Park, PA, 16802. Ph: 814/863-2080 mjhorman@engr.psu.edu

INTRODUCTION

Design coordination is a key to reducing uncertainty in production processes on building projects. Field conflicts that result from interfering systems are an avoidable source of production disruptions. The risk of interference problems is highest on building projects that have intense mechanical, electrical, and plumbing (MEP) requirements. Production risks are compounded, as schedules become more intense. Eliminating coordination problems can be characterized as a prerequisite to the start of construction work on intense projects with dense MEP system requirements.

Fast pace and mechanically intensive facilities such as data-centers, hospitals, and laboratories typically require the most intense coordination efforts. Architectural and structural systems are often designed first with allowances for MEP systems. Tensions between the size of these MEP spaces, usable floor space, and ceiling height exist. As a result, piping, ductwork, and electrical systems must often be fit into very tight spaces and routed in inefficient configurations that are difficult to detail, construct, and maintain.

Architect / Engineers typically produce schematic designs of MEP system layouts and routing. It is often up to specialty contractors to finish the design by specifying sizes of ducts and piping, fixtures, and equipment. The design coordination process is performed to allow each trade to compare the materials that are intended for given spaces in a building to ensure they will not conflict physically, or impair the installation and maintenance of subsequent systems. In current practice, building contractors perform design coordination with variable levels of effort and results. The timing and necessity of design coordination is highly variable, and the investments and in coordination are dependent on project delivery methods.

In building construction, the design coordination process is most often performed by comparing or combining shop drawings in a coordination meeting. Systems that cross or overlap are detected by visual inspection, and evaluated for conflicts. If a conflict exists, one or more of the systems must be relocated. New technologies such as 3D and 4D modeling promise to improve design coordination efforts by making design conflicts more visible to designers and construction planners. In isolated cases these technologies have yielded great benefit to users, but are currently perceived to be too costly for widespread use by building contractors. It can be envisioned however, that in the near future, the development of scale digital models of buildings will increase, and that building contractors will find themselves utilizing this technology to complete building design and plan construction operations.

There are legitimate questions about how, when, and to what level of detail coordination efforts should be carried out on different types of building projects. As a result, the coordination process is often not given performed at an appropriate level of effort during construction planning. The processes and technology used to perform coordination are currently being re-invented by companies that recognize the need for intensive coordination efforts. This transition presents an opportunity to incorporate new concepts such as Lean Thinking into traditional construction processes, and hopefully elevate the importance of removing avoidable risks to production systems in building construction. This paper presents a pre-study of the cost metrics of design coordination, and the relationships between coordination efforts, types of project delivery systems, and field interference problems. This research his part of a larger effort in progress at Penn State University to develop predictive models of the timing, cost, and process variables associated with design coordination in building projects.

COORDINATION AND PRODUCTION

To streamline flow in construction, trades must complete work in a logical sequence with minimal interruptions to flow. When conflicts are discovered in the field, it is usually too late to avoid some form of interruption and delay while the conflict is resolved. When a crew is forced to stop work and relocate, wait for information or for materials, productivity will be adversely affected. Subsequent crews of following activities are often affected in the same way, compounding the problem. The costs of these conflicts and the extent to which other crews are affected will vary depending on project complexity Riley (2000).

Effective production management strives to maximize conversion processes, or actual construction work, align flow processes between subsequent activities in a sequence, and minimize non-value added activities such as the movement between work areas and material handling (Womak, 1996). Extensive research has been conducted on the coordination of specialty contractors and issues surrounding contract management. Tommelein (1998) provides a comprehensive review of this literature. Discussion of the design coordination of however, is limited to computer modeling, either through frameworks for design collaboration (Ahmed (1992), Jin and Levitt (1996), and Mokhtar et al (1998)) or through 3D modeling of components and automatic interference detection (Chang and Cook (1996) and Neggers and Mulert (1993)). Tommelein (1998) creates perhaps the most thorough map of the issues surrounding the coordination of specialty contractors. She specifically highlights the role of the general contractor in clarifying contract documents and acquiring as-built drawings for work done by others on which specialty contractors must build. She notes that unless exact field dimensions are obtained, it may be impossible for the specialty contractor to complete design details, thereby delaying procurement, fabrication, and field installation. Current research on MEP coordination is in progress at Stanford University (Korman and Tatum 1998). This research characterizes the knowledge needed in the design coordination process in an effort to develop a support tool for the MEP coordination process.

In current practice, great disparity exists in the level of effort placed on the design coordination process, and the timing in which coordination is performed. Pressures to reduce field staff and general conditions costs conflict with needs to invest in extensive coordination efforts. While it is understood that coordination efforts can reduce overall project costs by minimizing field conflicts, little data is available to demonstrate the value of coordination in real dollars. The research presented here is an initial effort to demonstrate this value in the terms that are most likely to convince owners and contractors to invest in the design coordination process - time and cost.

CASE STUDIES

The goal of this research is to seek cost-benefit relationships between investments in coordination and field production. The metrics of time and cost are examined for design coordination on four case study projects. Conflict costs were also recorded for laboratory projects that were built using different delivery methods. The data collected to date is insufficient to allow a predictive model of coordination costs to be generated, however patterns are evident, and will be pursued through further investigation. Four sets of data were collected:

Coordination effort: How much effort went into ensuring systems could be fit into buildings without physical interference?

Field Conflicts: How many field conflicts were found on projects that should have been identified through coordination efforts?

Coordination Costs: What were the quantitative costs of the coordination process?

Conflict Costs: What were the average costs of field conflicts that were not caught by the design coordination process, and how did these vary by delivery systems.

This data will be presented first to show the causal link between design coordination and the reduction of field conflicts occurrence, and second to explore the relationships between coordination, conflict costs, and coordination costs based on types of project delivery system.

COORDINATION EFFORT VS. FIELD CONFLICTS

Figure 1 illustrates the relationship found on case study projects between the effort spent on coordination and the resulting reduction in field conflicts. Coordination effort was measured by the diligence observed in identifying all potential interference problems prior to allowing construction to proceed in given area. A rating of 100% indicated that no work was permitted to proceed prior to a coordinated design agreement between all contractors. This rating was reduced on projects when some contractors did not participate, or if some systems or areas of the building were not included. Field conflicts were measured based on the number of field generated change orders pertaining to MEP systems interference.

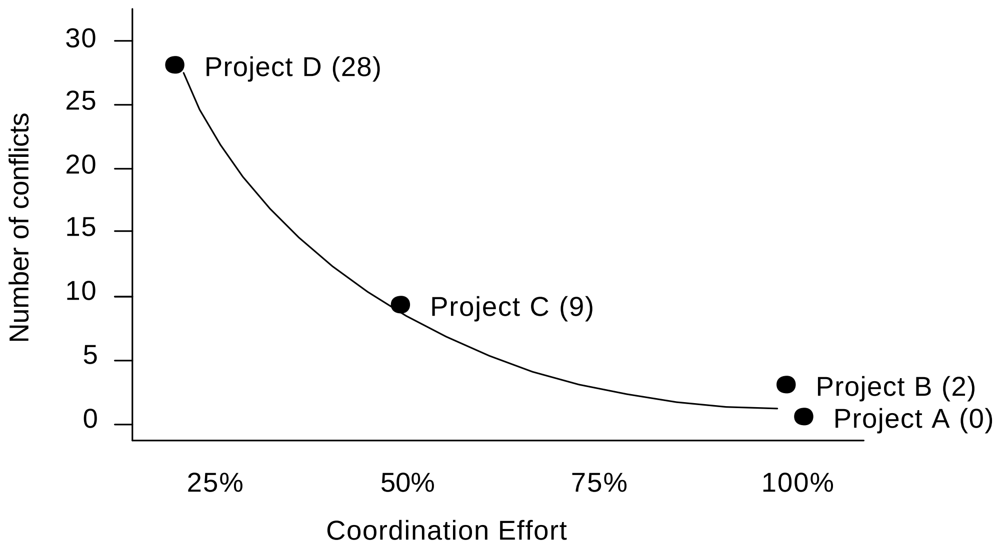

Figure A: Coordination effort and field conflicts

On projects A and B the coordination process was carried out with diligence and treated as a prerequisite for construction. Project A had zero field generated change orders, and project B had only two, both of which occurred due to extreme congestion and re-engineering of systems. On project C a less systematic process was used, and several contractors were did not take part in the process. On project D, the general contractor absolved himself from the coordination process, and instructed specialty contractors to perform the coordination process for MEP spaces on their own. The results are less than surprising. It should also be noted that on all four projects, minor conflicts occurred that were settled by negotiation and did not require documented change orders. The use of field generated change orders was thus found to be a crude but effective method to measure occurrences of conflicts and disruptions.

COST OF FIELD CONFLICTS

Historical cost data from fourteen (14) laboratory construction projects of similar size, scope, and cost were examined in an effort to identify a range of costs associated with field conflicts. These costs were measured by the total cost of field generated change orders found on projects. As the cost of individual change orders varied greatly between $1500 and $60,000. For this reason only the total cost of all field-generated change orders is presented. Variable types of delivery systems and coordination methods were used on these projects, and were categorized as follows:

Plan and Spec – Lump sum bid – The General contractor has no involvement in architecture / MEP design and engineering, and specifications absolve the A/E from the coordination process.

Negotiated / Limited Preconstruction – General contractor gets involved in design and engineering during production of construction documents, and directions for the MEP coordination process are included in specifications.

Negotiated / Full Preconstruction – General contractor gets involved in design and engineering during schematic design, and directions for the MEP coordination process are included in specifications.

Negotiated / Design-Build MEP – General contractor has design-build MEP engineering/construction subs, and MEP coordination process is included negotiated contracts.

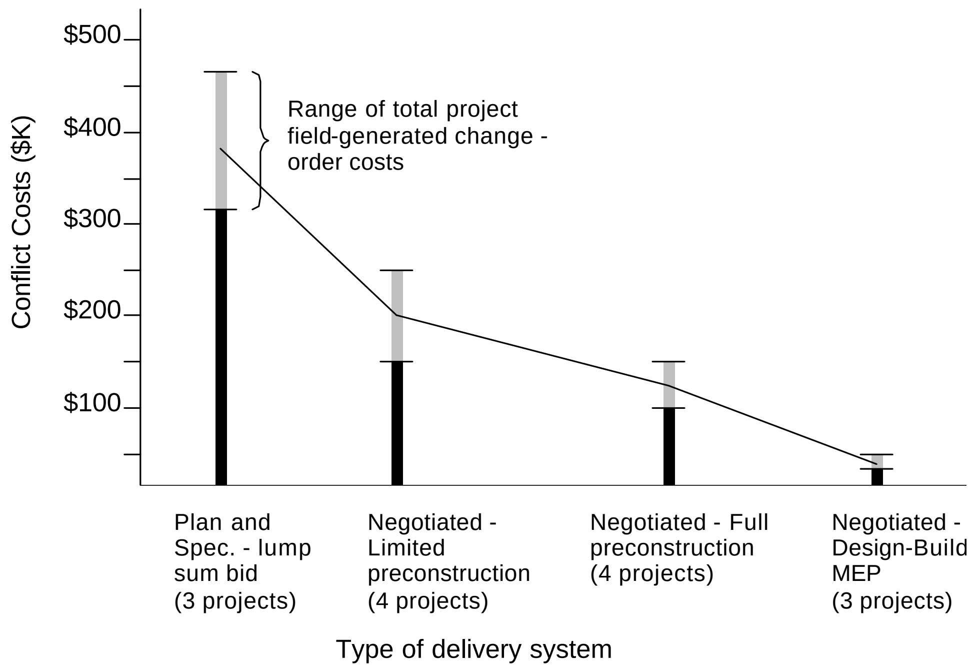

Figure 2: Delivery system and total project conflict costs

Figure 2 illustrates the ranges of conflict costs found on projects with similar delivery systems. A pronounced decrease in the costs of field conflicts for projects with earlier involvement of general contractors and subcontractors in the design process and the associated increase in coordination efforts. An implied analogy can be made between the delivery methods described here and levels of coordination effort described in Figure 1, however, there is insufficient data to make such a characterization. It is important to note that these coordination efforts came at a cost, and are thus included in the analysis of these projects.

COST OF DESIGN COORDINATION

Historical cost data from the same 14 projects was examined in an effort to identify the range of costs associated with performing design coordination. Costs were measured in terms of hours required for the MEP project manager (general contractor) and for CAD operators, foremen, and project managers (specialty subcontractors). Variable types of delivery systems and coordination methods were used on these projects. Figure 3 illustrated the ranges of coordination costs found on projects with similar delivery systems. The cost increase of the earlier involvement in negotiated delivery methods was found to significant but less dramatic than the costs of field conflicts show in Figure 2.

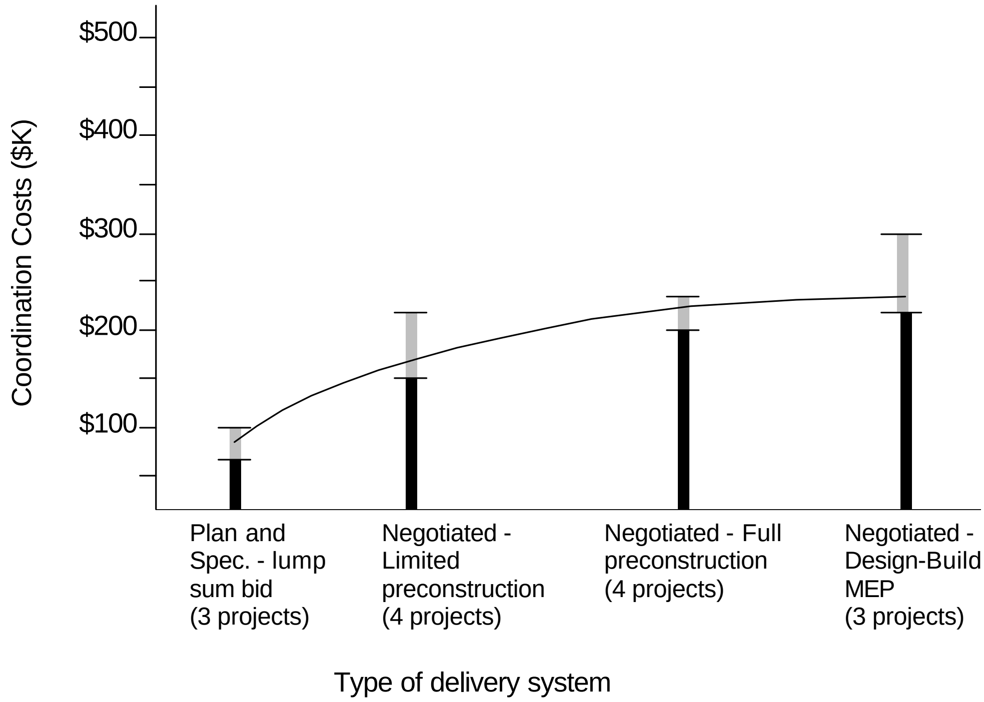

Figure 3: Delivery system and coordination costs

A conservative comparison of coordination costs (Figure 2) and typical conflicts costs (Figure 3) for different types of delivery systems demonstrates that coordination efforts on MEP intensive projects typically pay for themselves in real costs. This is encouraging, as contractors struggle to justify preconstruction expenses and planning costs in negotiated contracts. The limited data used in this research is not sufficient to develop predictive models of coordination costs and resulting savings in field conflicts costs. A more robust study needed to characterize the time and cost metrics of coordination investments by based on project type, system design, project intensity, and density of MEP systems.

INTANGIBLE BENEFITS OF COORDINATION

The data presented above indicates that investments in coordination typically pay for themselves by reducing conflicts and field generated change order costs. MEP intensive projects. There are many other benefits observed on projects that are free of coordination problems. Materials and systems are installed in their correct positions the first time, and in a sequence that results in a productive flow of work for different trades. Fewer conflicts are encountered, resulting in fewer interruptions to crews. Crews have more reliable work environments, and the project experiences fewer downstream effects of unreliable flow. When conflicts are encountered they are often the result of work installed incorrectly, or a mistake in the coordination process. In either case, trades are likely to quickly resolve conflicts in the field, as they have taken responsibility for coordination. In addition, mistakes can be detected earlier and possibly avoided in other areas.

Another compelling reason to execute detailed coordination is the sequencing and production information that can be extracted during the process. Trade foreman and superintendents testify that by building the intricate details of a project on paper or in a computer model, they can better visualize the construction process. This visualization allows complex areas of a building to be broken down into a logical order that accommodates crew access and material handling constraints in additional to the physical coordination of building components. As a result, more quality work plans can be developed, and work flow can be planned more accurately.

CONCLUSIONS

The link between design coordination and production needs to be clearly understood and elevated in importance to help contractors take advantage of the reductions in field conflicts and production planning information that can be achieved through the coordination process. This research demonstrates the causal link between design coordination effort and the reduction of field conflicts. A limited sampling of projects also suggests that investments in coordination can typically pay for themselves by direct savings in field conflict costs on projects that have intense MEP requirements. At a minimum, the argument for coordination investments is strengthened, and justified to those who question the benefits of costly coordination efforts. Additional research is needed to determine a more precise measure of the relationship between the occurrences of disruptive field conflicts and number of field generated change orders. Further research is also needed to characterize both the coordination process and variable costs of field conflicts for different delivery systems and project types.

REFERENCES

Ahmed, S. (1992) “Transaction Issues in Collaborative Engineering,” *ASCE Journal of Computing in Civil Engineering*, Vol. 6, No. 1, January 1992, pp.85-105.

Ballard, G., and Howell, G. (1998) “Shielding Production: An Essential step to production control,” *Journal of Construction Engineering and Management*., ASCE, New York, NY, 124 (1) 18-24, January.

Chang, D.Y and Cook, E.L. (1996) “Construction Coordination: A Knowledge-Based Approach,” *Proceedings, ASCE Computing in Civil Engineering* Washington, D.C. pp. 559-568.

Korman, T. Tatum, R. (1998) “Improving the MEP Coordination in Building and Industrial Projects,” CIFE Research Report, Stanford University, Stanford, CA http://www.stanford.edu/~tkorman/MEP/descirption.html.

Jin, Y. and Levitt, R.E. (1996) “The Virtual Design Team: A Computational Model of Project Organizations,” *Comp. & Math. Organ. Theory*, 2 (3) 171-196.

Mokhtar, A., Bedard, C., and Fazio, P. (1998) “Information Model for Managing Design Changes in a Collaborative Environment,” *ASCE Journal of Computing in Civil Engineering*, Vol. 12, No. 2, April 1998, pp. 82-92.

Neggers and Mulert (1993). "Interference Detection with 3D Computer Models," *Proceedings, ASCE Computing in Civil Engineering* Anaheim, CA, pp. 1279-1282

Riley, D.R. (2000). "Coordination and Production Planning for Mechanical, Electrical and Plumbing Construction," *Proceedings: ASCE Construction Congress VI*, Orlando, FL.

Tommelein, I.D. and Ballard, G. (1998). "Coordinating Specialists," *Journal of Construction Engineering and Management*., ASCE, New York, NY, 126 (2) 56-64, January.

Womak, J.P. and Jones, D.T. (1996*). "Lean Thinking: Banish Waste and Create Wealth in your Corporation*. Simon and Schuster, New York, NY, 350pp.