Richmond Highway
Heavy Design-Bid-Build

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1. Case Study Method

The Project Case Study Method involves an in-depth examination of a single project, the case. It provides a systematic way of looking at events, collecting data, analyzing information, and reporting the results. Case Studies are one of the most effective tools you can use to promote best practices and cost-effective, experiential training. A recent search on Google.com for the term “case study” showed over 15 million hits. Of those hits, almost 750,000 hits included references to Java, which demonstrates a phenomenal uptake in the IT industry. Like its close cousin the White Paper, case studies appear to be growing in popularity every year.

1.1. NORA Goal 10

This Case Study was developed under a Cooperative Agreement with NIOSH in support of the National Occupational Research Agenda (NORA), Goal 10. Goal 10 is concerned with improving understanding of how construction industry factors relate to injury and illness outcomes; and increasing the sharing and use of industry-wide practices, policies, and partnerships that improve safety and health performance (NIOSH, 2013).

More specifically, the aim of NORA Goal 10.1 is to: Analyze how construction industry complexity and fragmentation can affect safety and health performance. Evaluate safety roles, responsibilities, interactions, and oversight among the multiple parties involved with complex construction projects. Address regular and accelerated construction project lifecycles. Identify obstacles and opportunities for improving system performance.

National Institute for Occupational Safety & Health. (2013, April 24). ”NORA Construction Sector Strategic Goals.” Retrieved from http://www.cdc.gov/niosh/programs/const/noragoals/Goal10.0/

1.2. Case Study Design

The research adopted a comparative case study approach (Yin, 1994). Data were collected from a total of 23 construction projects, 10 in Australia/New Zealand and 13 in the United States of America. For each project, features of work were purposefully identified by project participants in consultation with the research team. Features of work were selected as the unit of analysis because they presented a particular health and safety problem or challenge.

“Features of work were selected as the unit of analysis because they presented a particular health and safety problem or challenge.”

For each feature of work, comprehensive data was collected to capture decisions that were made in relation to the design of the feature of work, the process by which it was to be constructed and the way that health and safety hazards were to be addressed. Data were collected by conducting in-depth interviews with stakeholders involved in the planning, design and construction of the selected features of work. These interviews explored the timing and sequence of key decisions about each feature of work, and the influences that were at play as these decisions 'unfolded' in the project context. During the course of the research 288 interviews were conducted (185 in Australia and 103 in the USA). The average number of interviews per feature of work was 6.7.

Projects chosen for data collection represent four different construction sectors (residential, commercial, industrial, and heavy) as well as four different delivery methods (Design-Bid-Build, Design-Build, accelerated, and collaborative). This was done to help determine the role OSH plays in each type of construction project. The projects were then placed on a matrix. Figure 1 represents the 14 projects studied within the United States with the project featured in this case study highlighted in yellow. Figure 2 shows where American and Australian projects overlap on the matrix.

Figure 1: Matrix of American projects

	Residential	Commercial	Industrial	**Heavy**
Design-Bid-Build	Roanoke House	Dining Hall	Wastewater Tank	**Highway Expansion**
Design-Build	Blacksburg House	Psychiatric Hospital	Server Farm	New Highway
Accelerated	Blitz Build	Football Stadium	Chemical Plant	Bridge Project
Collaborative	Mountain House	New Hospital	Coal Plant*	Coal Plant*

**Note: The coal plant project is considered to be both an industrial and a heavy construction project.*

Figure 2: Overlap of American and Australian Projects

	Residential	Commercial	Industrial	Heavy
Design-Bid-Build	US	AUS+US	US	US
Design-Build	AUS+US	US	AUS+US	AUS+US
Accelerated	US	AUS+US	AUS+US	AUS+US
Collaborative	US	US	US	AUS+US

From: Wakefield, R., Lingard, H., Blismas, N., Pirzadeh, P., Kleiner, B., Mills, T., McCoy, A. & Saunders, L. (2014). 'Construction Hazard Prevention: The Need to Integrate Process Knowledge into Product Design'. Paper presented at the CIB W099 International Conference: Achieving Sustainable Construction Health and Safety, 2-3 June 2014 Lund, Sweden.

1.3. Case Study Analysis

Dependent variable

Data was collected about OSH hazards and the risk control solutions implemented within the case examples. This data was elicited during the interviews and supplemented with site-based observations and examination of project documentation (e.g. plans and drawings). For each feature of work, a score was generated reflecting the quality of implemented risk control solutions. This score was based on the hierarchy of control (HOC).

> *The Hierarchy of Control classifies ways of dealing with OSH hazards/risks according to the level of effectiveness of the control*

The hierarchy of control (HOC) is a well-established framework in OSH (see, for example, Manuele, 2006). The HOC classifies ways of dealing with OSH hazards/risks according to the level of effectiveness of the control. At the top of the HOC is the elimination of a hazard/risk altogether. This is the most effective form of control because the physical removal of the hazard/risk from the work environment means that workers are not exposed to it. The second level of control is substitution. This involves replacing something that produces a hazard with something less hazardous. At the third level in the HOC are engineering controls, which isolate people from hazards. The top three levels of control (i.e, elimination, substitution and engineering) are technological because they act on changing the physical work environment. Beneath the technological controls, level four controls are administrative in nature, such as developing safe work procedures or implementing a job rotation scheme to limit exposure. At the bottom of the hierarchy at level five is personal protective equipment (PPE) – the lowest form of control. Although, much emphasized and visible on a worksite, at best, PPE should be seen as a "last resort," see, for example Lombardi et al.'s analysis of barriers to the use of eye protection (Lombardi et al. 2009). The bottom two levels in the HOC represent behavioral controls that they seek to change the way people work (for a summary of the limitations of these controls see Hopkins, 2006).

Each level of the HOC was given a rating ranging from one (personal protective equipment) to five (elimination). The risk controls implemented for hazards/risks presented by each feature of work were assigned a score on this five point scale. In the event that no risk controls were implemented, a value of zero was assigned.

Independent variable

Social network analysis (SNA) was used to map the social relations between participants involved in making design decisions about each feature of work. SNA is an analytical tool to study the exchange of resources between participants in a social network. Using social network analysis, patterns of social relations can be represented in the form of visual models (known as sociograms) and described in terms of quantifiable indicators of network attributes. In a sociogram, participants are represented as nodes. To varying extents, these nodes are connected by links which represent the relationships between participants in the network.

SNA has been recommended as a useful method for understanding and quantifying the roles and relationships between construction project participants (Pryke, 2004; Chinowsky et al. 2008). The technique has been used to analyse knowledge flows between professional contributors to project decision-making (see, for example, Ruan et al. 2012; Zhang et al. 2013). Network characteristics have also been used to explain failures in team-based design tasks (Chinowsky et al. 2008) and identify barriers to collaboration that arise as a result of functional or geographic segregation in construction organizations (Chinowsky et al. 2010). More recently, Alsamadani et al. (2013) used SNA to investigate the relationship between safety communication patterns and OSH performance in construction work crews.

In order to gauge the construction contractor's prominence in a project social network, the contractor's degree centrality was calculated. Degree centrality refers to the extent to which one participant is connected to other participants in a network. Thus, degree centrality is the ratio of the number of relationships the actor has relative to the maximum possible number of relationships that the network participant could have. If a network participant possesses high degree centrality then they are highly involved in communication within the network relative to others. Pryke (2005) argues that degree centrality is a useful indicator of power and influence within a network.

Degree centrality can be measured by combining the number of lines of communication into and out of a node in the network (see, for example, Alsamadani et al., 2013). This presents an aggregate value representing the participant's communication activity. However, the independent variable used in this research was calculated using only the construction contractors' outgoing communication. This was a deliberate choice because the research aim was to investigate whether OSH risk control is of a higher quality when project decisions are made with due consideration of construction process knowledge. Thus, the flow of communication from the construction contractor to other network members was deemed to be of greater relevance that the volume of information they received.

From: Wakefield, R., Lingard, H., Blismas, N., Pirzadeh, P., Kleiner, B., Mills, T., McCoy, A. & Saunders, L. (2014). 'Construction Hazard Prevention: The Need to Integrate Process Knowledge into Product Design'. Paper presented at the CIB W099 International Conference: Achieving Sustainable Construction Health and Safety, 2-3 June 2014 Lund, Sweden.

1.4. Benchmarking and Best Practices

Benchmarking is a powerful management technique that can be used to improve an organization's performance by searching for a partner organization that is the best at a given process and constantly adapting or adopting the partner's practices to increase performance (Kleiner, 1994). The process to be benchmarked is usually determined by analyzing performance figures and other data. A process that has relatively low performance figures and could be improved is often chosen to be benchmarked. Demand for benchmarking comes from several sources, such as increasing enforcement activity, regulations, investor and liability concerns, customer perceptions, and competition with other organizations. The results of effective benchmarking include increased productivity, efficiency, employee morale, and a competitive advantage.

The benchmarking process can be divided into five stages: Planning, analysis, integration, action, and maturity. During the planning stage, the organization identifies the process that needs to be benchmarked. This selection is usually done to fulfill a predetermined need, such as boosting performance figures in an area that needs improvement. Measurable performance variables are also identified. Benchmarking partners are selected based on their best-in-class performance in the targeted process. The partner does not necessarily have to be in the same industry. The organization concludes the planning stage by determining the data collection method and collecting the data. It is important for the organization to be able to distinguish between ethical and unethical means of data collections, especially if it involves handling sensitive information from the partner company.

During analysis, the organization determines the current performance gap for the process that will be benchmarked. The team then predicts future performance levels.

The integration stage involves the organization communicating their benchmark findings. Communication is crucial during this phase of benchmarking, especially when seeking approval from those with more organizational authority. Operational goals and plans are established from the benchmarking findings.

The action stage is characterized by implementing practices, monitoring progress and results, comparing results to stakeholder needs, and adjusting the benchmark goals as necessary. Since benchmarking is a continuous process, the last step will certainly be repeated as industry standards and the needs of stakeholders change over time.

A benchmarking process reaches the maturity stage after the best practices are fully implemented into the targeted process. While benchmarking begins with management, the employees involved in the process are the ones who ultimately integrate the new process.

“Kleiner, B. M. (1994). Environmental benchmarking for performance excellence, Federal Facilities Environmental Journal, 5(1), 53-63.”

1.5. Learning Objectives

- *Understand sociotechnical systems complexities of a construction work system*
- *Understand different sectors, delivery systems, and cultures*
- *Understand project and industry supply chain and work system complexities*

2. Road and Utility Reconstruction

2.1. Overview

The project involved in this case study was a state highway maintenance and reconstruction project in a major city. Originally, the project was divided into two sub-projects. Sub-project #1, designed by the Virginia Department of Transportation (VDOT), was the reconstruction of a six-lane highway and replacement of utilities along a 1.5 mile stretch with many commercial storefronts on both sides. Sub-project #2, designed by a variety of private engineering firms, was road reconstruction and replacement of 2.5 miles of gas, water, and sewer system along the smaller roads near the highway.

2.2. Project Profile

2.2.1 Case Background

The project was located in a section of the city that was annexed from the county 25 years ago. The project team had access to the as-builts the county created when the utilities were originally installed; however the as-builts were not very accurate.

2.2.2 Case Narrative

Maintenance of Traffic (MOT)
A Maintenance of Traffic (MOT) plan was created to control and manage traffic during the construction. Sub-project #1 was designed and documented for bid in the late 1990s, but not bid on at the time due to budget constraints. The design documentation was not revised for this bidding due to the perceived lack of value in time and cost of performing a new design.

The MOT plans are guided by traffic counts. If there are over 1,500 cars per hour, then the State standards required two lanes to be open for traffic at all times if possible. A second guideline is where lanes transition from one side of the highway to the other. The state suggested a construction sequence that could be used to determine the transitions based on the vertical and horizontal distances and contour measurements. The contractor had to formally request any changes to the MOT plan in the design if they felt it was not adequate.

The high amount of businesses and traffic in the area led to a high traffic flow. Thus, lane transitions with closures, rather than detouring and diverting traffic to other roadways, were considered because of these potential influences to the commercial area. Meanwhile, the real time traffic count shown that over 1,500 cars per hour passed through the area during the daytime while the volume was much lower during the night. At least two lanes were required to keep the traffic flow according to state standards. However, the lane transitions in the bid documents would not work because the contours onsite differed from what was in the plans. This meant that the transitions could not be done according to standards at the locations in the original designs since the elevation changes were too great. The work to get the MOT plan within standard meant that traffic could not be transitioned as planned, and thus traffic was adjacent to workers when the plan originally called for traffic to be transitioned away from them. The proposed phases of the job also did not work with the depth profiles of the utilities, and thus the CM had to rework this plan as well. The CM said that this also affected the MOT plan, as utilities had to go in at times that were not ideal for where traffic was at that time.

Once the decision was made, the owner wanted work to occur in certain areas while crews were mobilized in the vicinity. This consideration led to a decision that sub-project #2 should be combined in order to make management and coordination easier for the state's PM. This decision resulted in multiple design firms being involved.

Based on standard bid requirements, the winner contractor has two months to start the construction after bid date. The contractor's construction manager (CM) agreed this was typical, even though they would have liked more time for pre-construction planning and scheduling. The CM decided on a work plan of two 10 hour shifts per day, 5 days per week, with sub-project #2 work being performed during the day and sub-project #1 work at night. Safety issues were considered for this decision, as the contractor did not feel safe enough to work on the main highway during daytime with just one lane of traffic closed. Instead, working during the night allowed close an extra lane which would result in a 10 foot buffer between workers and adjacent traffic. As a result, 90% of the highway work had been done with two lanes closed, and the remaining 10% was on parts of the job that allowed the 10 foot buffer to be placed. The CM confirmed the success of this measure since most work on the adjacent streets could be done safely during daytime with the help of flagmen in locations where they were working.

The CM identified the safety criticality as a combination of engineering and administrative controls. The administrative control of enforcing the daily MOT plan and ensuring the proper engineering controls, cones and barricades, were placed correctly. During night-time, the CM dedicated a full-time employee to enforce the MOT plan on the main highway. The CM also put additional administrative and personal protective equipment (PPE) controls in place such as morning huddles, media alerts to communicate changes in the traffic patterns to the public, amber lights on all equipment, job hazard analysis documents, daily MOT checklists, nightwalker headlamps and leggings for employees, and 18 light towers to provide sufficient lighting. Further, the CM had set up a rule that workers could not cross two lanes of traffic or more without getting in a vehicle.

Trench Excavation and Utility Installation (Sub-project #2)
A total of four utilities (120,000 linear feet total) needed to be replaced in this project. The city controlled all of these utilities, but a decision was made to include the replacement of them in the bid packet so that the same entity would be doing the road work and coordinating the replacement of the utilities.

Within the design unit cost line items were included for bidding for trenching or boring. Typically is cheaper to trench, and thus that is what was included in the original bid. However, as the CM's project manager said, the sequence/phasing of installation had to be changed because for storm/grading the design engineers did not coordinate the installation of gas/water installation with the other utility designers. This affected the project phasing because out of sequence work was required throughout the project to install new water/gas/storm utilities to avoid conflict with the existing water/gas/storm lines. The result was the new water/gas/storm had to be installed prior to removing the old lines etc.

On the other side, according to the owner's PM, most of the line items in the design for the utility installation were priced according to opening trenching and not directionally boring. Directional boring has become more common for natural gas and when the sequencing was changed the gas line was put in first. The subcontractor decided to directionally bore the gas line because they felt it was more efficient and safer due to the fact it was going in adjacent to traffic. This also made it easier to avoid conflict with the existing utilities because they were boring in a straight line once it was at depth and not having to dig down through multiple utilities.

The location of utilities was a major obstacle on this job. The as-builts were not accurate, and they were replacing 120,000 feet of pipe among 4 different utilities. The local global information system (GIS) locators had a difficult time locating and marking the new lines (even though the constructor knew where the new lines were installed). Utility markings were updated every 15 days in accordance with state law.

As a result of the inaccurate as-built drawings and the decision to place new lines before removing existing lines, the constructor had to exercise additional care when excavating. In order to remain efficient and minimize hand-digging, the CM dug test holes in front of the excavation so that they could stay efficient during excavation. This was done even though the existing lines had been located and marked. Trench boxes were used to eliminate cave-in hazards of open trench excavations.

Similarly, several administrative and PPE controls were put in place by the CM for the excavation process. All personnel had to be tied-off if within a 6 foot marked area around a trench, and other controls such as job hazard analysis and safety training for all workers was also required.

2.2.3 Stakeholders

Internal supply for this project was produced by several sources. The architect was the client's designer for sub-project #?. The principal contractor that was awarded the bid for construction management of the job was responsible for tracking progress and managing the different trade contractors. The engineer was hired by the client to design the utility replacement for sub-project #2. The utility locators located the placement of the existing utilities. Excavation and installation of new utility lines was performed by the utility installation sub, who also pot-holed before construction to determine the actual locations and depths of the existing utilities. The paving sub set up daily traffic control and performed construction for the highway reconstruction portion of the project.

Internal demand came from the client and the client's employees. As the client, VDOT Finance/Programs approved the need and budget for the project. The client's employees included VDOT's Traffic Engineering, Design/Engineering, Utilities, and Right of Way (ROW) groups. Traffic Engineering collected traffic counts and determined traffic control plans in the bid document. They also approved any changes to the MOT plan. Design/Engineering was the client's main project manager. Utilities managed the design for new utilities and approved changes made to existing utilities. ROW obtained right of way for the new utilities from local residents.

There were several external stakeholders in this project. External private stakeholders included motorists who drove through the site on a daily basis and local businesses that were impacted by construction. Traffic control was designed in a way to minimize the project's impact on these businesses. The state government, local government, and local utilities district were all external public stakeholders. The state government approved the overall budget for the client and provided input into work priorities for projects. The local government proposed the need for the project, worked with the CM on communication, and managed the roads once completed. Utilities provided the as-builts for the existing utility lines, gave input for the design and capacity of the new lines, and was the owner of the lines once completed.

2.2.4 Project Objective

The objective of this project was to 1) reconstruct a portion of a six-lane highway and utilities along a 1.5 mile stretch and 2) road reconstruction and utility maintenance along smaller side roads near the highway.

2.2.5 Sector x Delivery System

This project is an example of heavy design-bid-build (DBB) construction.

2.2.6 Features of Work

Three features of work are featured in this case study. Those features are Maintenance of Traffic (MOT), trench excavation, and utility installation.

3. Problem

3.1. Context

One issue that the project team ran into was the inaccuracy of the as-built drawings. The location of the project is in an area originally owned by the county, so the documents were not completed to the city’s standards in terms of accuracy. In addition, the contour lines were also off, which meant that the elevation changes were significant enough to warrant changes to the lane transitions in the original MOT plan.

The project also included the replacement of 120,000 feet of four utilities near the roads. As opposed to having the individual utility owners remove and replace their respective utilities, the utility replacement was merged with the highway repair so that the same entity would be working on both projects. The as-builts did not accurately document the locations of the existing utility lines. Lack of coordination among design engineers also meant that some of the new utility lines would need to be installed before all of the old lines were removed, thus disrupting the construction sequence.

3.2. Objectives

The MOT plan was largely based off of traffic counts. If over 1,500 cars passed through a given area within an hour, two lanes needed to be open if possible. Traffic counts during the day recorded over 1,500 cars per hour during the day, but at night the traffic count was significantly less and permitted closing an extra lane. Having an extra lane closed gave workers an additional 10 foot safety barrier.

The altered construction sequence meant that the new gas lines had to be installed before removing the existing utilities. This was accomplished by using directional boring. This method eliminated the need for trenches, reduced the chance of conflicts with existing lines, and was safer. One-calls and test holes in front of each planned excavation were used to help crews accurately locate the existing underground lines.

4. Results

4.1. Safety-Critical Decision Making

A construction project consists of multiple components that all have different decision-making processes. For each project, different decisions from the earliest planning stages through construction all have an impact on occupational safety and health (OSH) based on how the hazards are controlled.

Decisions, Decisions: Quick View

Thom's table here

The project in this case study was originally two separate sub-projects that were bid together to make coordination easier from the state. The plans for the drawing were originally drafted in the late 1990's as a Design-Bid-Build project. While Design-Build is more common for this kind of project, DBB was chosen as the delivery method for this project because the inaccurate as-built drawings presented a number of unknown variables. The design documents were then used to develop a Maintenance of Traffic (MOT) plan. The project team had the option of either closing individual lanes or detour the entire highway. The number of businesses located along the highway influenced the decision to close individual lanes and still allow traffic through. The contour lines on the original drawings were inaccurate and the elevation changes were much greater than anticipated. This meant that the original lane transition plan could not be used in compliance with state standards. Traffic counts were collected to determine the average amount of cars passed through the site per hour. During the day, the traffic counts only allowed one lane to be closed. However, from 7pm until 7am the count was much lower and the workers could close a second lane to provide an extra safety buffer. A full-time MOT supervisor was brought on to help with administrative workload related to required safety features (such as cones, lighting, signage, etc.)

In the original bid documents, the utility replacement was bid as one project to encourage coordination among the subs during the removal and replacement of four different utilities. However, lack of coordination between design engineers working on the utilities meant that the new lines would have to be installed before removing the old lines. Trenching was included in the original bid document as the method for removing and replacing the old utility lines. For installation of the new gas line, directional boring was used because it is quicker, less likely to conflict with existing underground utilities, and safer to traffic on the adjacent road. Trench boxes wherever trenching was taking place. One-calls and test holes were used to determine the exact location of existing utilities and eliminate the need for excessive hand-digging.

4.2. Hierarchy of Controls

Elimination is seen as the most effective method of hazard control. An example of elimination in this project was using directional boring to install the gas pipeline instead of trenching. While the original bid documents and pricing estimates called for trenching, the CM felt that directional boring would be more efficient when installing among the old utilities and safer since the installation site was near traffic. Directional boring does not require a trench to be dug, so there was no longer a risk for workers in a trench to be struck, caught in, or crushed by a collapsing structure.

If elimination is not a possibility to solve a safety problem, the next desirable alternative is substitution, which could mean substituting in a safer material or a safer process. Having the work on the six-lane highway done at night was safer for workers since traffic was lighter and an extra lane could be closed as a safety barrier between the traffic and the workers. Another example of substitution in this project was pot-holing to locate utilities instead of hand-digging. This reduced worker risk of being exposed to underground electrical wires.

Engineering control is the third most effective form of hazard control. If the hazard cannot feasibly be eliminated or substituted, and engineering control reduces worker exposure to the hazard. A traffic barrier between workers and traffic and a trench box used in utility excavation are two examples of engineering controls implemented by the project management team and CM respectively

Administrative controls were used extensively during all stages of the project. Administrative controls for the six-lane highway were the substance of the MOT plan and included barricades, high-visibility clothing for workers, signage, lights, and flagmen. Safety training was the primary administrative control used for utility work. Workers were trained in how to properly excavate using a backhoe, directionally bore the gas lines, lift and place pipes with the backhoe, and weld or connect the pipes together in the trench.

The least effective form of hazard protection is Personal Protective Equipment (PPE), which was a common response for many tasks throughout the project where the above mentioned controls would not have been possible or economically feasible. PPE such as gloves, sturdy shoes, and safety glasses were absolutely required for all workers on the site, along with high-visibility vests and leggings for nighttime workers on the highway.

4.3. Social Network Analysis

4.4. Project Performance

The project was originally developed and ready for bid in the late 1990's. However, the project did not go up for bid until 2010. The total value of the job was $35 million at the start of the bidding and rose to $41 million with over 60 workers on-site by the end of the project. The project did not receive any awards or ratings. Aside from road closure alerts, there was no media coverage for this project. It is not known if any injuries or deaths occurred during the project.

5. Case Evaluation

5.1. Results

Widening the stretch of highway allowed for traffic to flow more efficiently with fewer delays. This had benefits for businesses located along the highway. Replacing the old utilities with new lines laid out in a logical manner reduced the chances of pipe failure from old age or fatigue.

5.2. Lessons Learned

Describe the positive aspects of project implementation, the problems encountered and how (if) were they addressed. Describe how other parties could use the solution. Describe best practices that can be adopted or adapted.

(15 to 25 lines)

6. References

Kleiner, B. M. (1994). Environmental benchmarking for performance excellence, Federal Facilities Environmental Journal, 5(1), 53-63.

National Institute for Occupational Safety & Health. (2013, April 24). "NORA Construction Sector Strategic Goals." Retrieved from http://www.cdc.gov/niosh/programs/const/noragoals/Goal10.0/

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