The Application of Root Cause Analysis and Target Value Design to Evidence-Based Design in the Capital Planning of Healthcare Facilities

by

Zofia Kristina Rybkowski

B.S. (Stanford University) 1985
M.S. (Brown University) 1987
M.Arch. (Harvard University Graduate School of Design) 1991
M.Phil. (Hong Kong University of Science and Technology) 2004

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Committee in charge:

Dr. Iris D. Tommelein, Chair
Dr. Glenn Ballard
Dr. Sara Beckman

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By Zofia Kristina Rybkowski

This dissertation is dedicated to my mother

Mrs. Charlotte Bunting Rybkowski

for the example of intellectual curiosity she sets for me

every day of her life

and to my late father

Mr. Władek Thaddeus Rybkowski

for his belief in me

and in the importance of higher education.

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TITLE: THE APPLICATION OF ROOT CAUSE ANALYSIS AND TARGET VALUE DESIGN TO EVIDENCE-BASED DESIGN IN THE CAPITAL PLANNING OF HEALTHCARE FACILITIES

Preface

Like a cue ball that collides with an unexpected target, two sharply contrasting incidents spun into my life nearly a decade ago, and tapped thoughts about this dissertation research into motion.

The first incident happened in 1999. Newly married, I had just returned to Hong Kong following a friend’s recovery from a stroke. My friend’s healthcare story was especially interesting to me because, although he was grateful to have survived his medical crisis, he had a difficult time overcoming memories of his time at the hospital. He complained about overstuffed patient rooms and, even worse, hospital corridors filled with patients in cots. Sharp noises and buzzing fluorescent lights left continuously on overnight kept him from sleeping. Amazingly—at least according to him—one nearby patient pulled off his oxygen mask to draw from a cigarette; staff members seemed to be no where in sight. His story was especially intriguing to me because I had been trained in and practiced architecture and felt strongly about the potential of the built environment to shape our psyche, for better or for worse.

Ironically, only a few months after my friend’s experience, I too found myself in a Hong Kong hospital one Saturday afternoon. That morning, I had joined a university field trip to explore one of Hong Kong’s more remote reservoirs. Focusing intensely through a camera lens, I had absent-mindedly stepped backward and fell off a reservoir wall. I later learned the vertical distance of the fall was only six feet and thankfully interrupted by an intermediate ledge, but the impact combined with an awkward landing position gave me six broken ribs and a collapsed lung. An ambulance rushed me to Tseung Kwan O Hospital—about 40 minutes from the site and the closest healthcare facility at the time. I still recall mentally preparing myself for a difficult recovery period, even as I was falling. But my hospital story turned out to be nothing like that of my friend’s. To be sure, I was in enormous pain and barely able to breathe with my one remaining lung. Gasping for oxygen and wincing from having a tube inserted into my side to drain blood from my collapsed and hemorrhaging lung, I felt frightened and lonely. However, one nurse sensing I could not sleep came to my bedside twice during the night and calmed me with her reassurances. During the three weeks I spent recovering in the hospital, I was treated to a steady supply of visitors who lent me riveting books and tuneful music; these helped distract me from my pain. Thanks to a television mounted high in the room, I became engrossed in world events portrayed by morning news broadcasts from the US and evening BBC documentaries. Most of all, I remember waking every morning, grateful for a window that framed a verdant, sun-streaked Hong Kong hillside; this view offered a great source of refreshment and comfort for me.

After a three-week inpatient stay, I was discharged and thanked the doctors and staff for the graciousness of their care. One remarked, “You recovered more quickly than expected. Thank your husband and friends. We’ve observed that patients with regular visitors recover faster.” This comment was especially striking because it alluded to something medical personnel have noticed for years—that psychological well-being and health are intimately connected. Even while recovering, I had in fact, been cognizant of the emotional support that came during my husband and friends' visits. I was also aware that books, music and television documentaries were diverting my attention away from considerable pain, that the nurse who stood beside my bed at night allaying my fears was reducing my stress, and that the view of the sunlit hills brought me a sense of inner serenity and spiritual well-being.

To be sure, some of these effects could have been generated in the older, chaotic hospital that the friend I had mentioned earlier in this story had described. But these events would have had to happen *in spite* of the built surroundings, and not because of them. For example, although friends could still have visited me in a crowded patient room, an overly compressed environment can be discouraging to visitors who fear their voices may disturb other patients or who find they have difficulty finding a place to comfortably sit while there. By the same token, nurses stationed far from their charges may be less likely to notice and calm a patient in distress. Similarly, rooms devoid of positive distractions—such as a television set, audio system or reading material—miss an opportunity to divert a patient's attention away from her boredom and pain. And, a cramped, enclosed space devoid of natural sunlight or view can be profoundly depressing and stress-inducing for a patient. Ironically, at a time when healing of body and mind is so critical to a patient's successful recovery, such types of healthcare facilities are anything but restorative.

The hospital in which my unfortunate friend had recovered had been founded in 1937 and substantially expanded in 1955 and 1983. By contrast, the healthcare facility I had occupied had opened just 30-days prior to my arrival that autumn day. During the intervening years that separated the construction of these two facilities, architects had become enlightened about the environmental needs of healthcare patients.

Educated as a biologist at Stanford and later at Brown, I had at first been skeptical that a topic as seemingly taste-driven and subjective as aesthetics could be founded on objective biological principles. It was not until a post-college graduation trip to two very different cities in Poland—Krakow and then Warsaw—that I observed changes in my own state of mind. Heavily destroyed during World War II and later subjected to Soviet occupation, Poland's capital city of Warsaw had been rebuilt in the heavy, drab, functionalistic style ubiquitous to Communist and Socialist countries of that era. By contrast, Krakow's medieval town center had been spared similar bombardment during the war and despite years of acid rain from Poland's coal-driven economy, the city's cloth hall, cobblestone square, surrounding town homes and double-spire church still stood resplendent. An express train running between Warsaw and Krakow juxtaposed the two urban environments sharply in my mind that summer, dramatically altering my sense of well-being. What types of physiological changes were taking place within me to make me respond so strongly? Surely I was not the only one who experienced the difference? Was this what drove individuals to erect great works of architecture? I began to wonder how we, as a species, had been evolutionally selected to respond differently to varied environmental contexts.

Role of Evidence-Based Design in Engineering Project Management

If this were to be a doctorate in biology or in psychology I might focus on testing for stress in subjects by measuring and comparing amounts of cortisol—a well-known stress hormone—released in the saliva of experimental subjects while they occupy different types of spaces. I might also conduct an Implicit Association Test to detect inherent biases subjects hold about contrasting environmental contexts, but that they might not openly admit. Or I might peer into the brain's neurological inner-workings using Magnetic Resonance Imaging while research subjects are exposed to images of disparate spaces.

However, this doctorate is not in biology, but in the applied field of Engineering and Project Management in the Department of Civil and Environmental Engineering. Establishing the physiological impact of the environment may belong to the realm of science, but establishing the financial impact of recommended applications falls squarely within the domain of project management research.

This dissertation looks to the rapidly growing field of Evidence-Based Design (EBD)—an analysis methodology that seeks to rely on the most credible evidence available when making design decisions (2003). This research aggregates experimental results obtained by clinicians and psychologists and uses these results to establish a framework that will enhance accuracy when forecasting the life cycle costing impact of design interventions on healthcare facilities. The dissertation also examines opportunities to make EBD interventions more affordable, by investigating ways to reduce first cost through Target Costing and lean construction processes.

Built environments influence those of all stages and stations in life, including those who work in commercial office environments. Although EBD could be applied to office buildings, for example, I have chosen to specifically focus on the financial implication and application of EBD on healthcare facilities because these institutions offer ideal research opportunities. For example, hospital patients (especially those who are immuno-compromised) are physiologically more vulnerable and less adaptable than healthy individuals and therefore more easily influenced by environmental stimuli. Furthermore, healthcare associations continually collect data on patient wellbeing—as measured by indicators such as error-rates or length-of-stay (LOS). Finally, my advisors at UC Berkeley, Dr. Glenn Ballard and Dr. Iris Tommelein, enjoy established and ongoing relationships with healthcare providers who are eager to understand the financial impact of the design decisions they make, and thus could provide access to research sites.

Research process

To begin research for this dissertation, I searched for literature that explored the influence of the built environment on human physiology. It became apparent that some of the most active work is being generated under the ever-expanding EBD umbrella.

The Center for Health Design (CHD) sits at the epicenter of the development of the EBD analysis methodology in the US. My advisors and I paid a visit to this non-profit organization in Concord, CA for the first time in 2006. The CHD started by organizing annual events called Healthcare Design conferences—an event that now attracts over 3,000 national and international participants. I attended my first international Healthcare Design Conference that same year in Chicago, and subsequently presented workshops at the 2007 and 2008 conferences in Dallas and Washington DC, respectively. In 2007, the American Institute of Architects Academy of Architecture for Health (AAH) and Coalition for Health Environments Research (CHER) joined forces with the Center for Health Design, holding their previously separate annual conferences concurrently. Through the conferences, I met EBD pioneers, many of whom now also serve on the Center for Health Design board, including Roger Ulrich, Craig Zimring, D. Kirk Hamilton, Blair Sadler, and Derek Parker, and came to know the energetic staff who generate the publications of the Center for Health Design, such as President and CEO, Debra Levin, as well as researchers Anjali Joseph and Carolyn Quist.

The EBD analysis methodology is clearly growing in influence as specific design interventions are promoted by the Center and its non-profit services are requested by owners. However, although I am convinced of the importance of EBD interventions through my own personal observations, I am nevertheless cognizant that academic research must assume an unbiased stance. Academic research is expected to culminate in peer-reviewed articles scrutinized in light of the truth it professes to reveal.

EBD is a branch of applied research that involves both academic researchers and industry stakeholders who may be tempted to varnish results of post-occupancy reviews, for example. The challenge is that it may be asking a lot of an architect or owner to publicly admit that an expensive new hospital atrium may actually spring more from ego than legitimate evidence and may therefore represent an unnecessary expense. For this reason, academics sometimes view with suspicion results obtained from research partnership with industry, however beneficial and useful that research may be.

Also, industry representatives can either be reluctant to share certain types of information (especially financial) or do so in such a way that the information is too vague to be informative. I therefore especially appreciate the lessons in facilitation I learned from my advisors Professors Glenn Ballard and Iris Tommelein during Project Production Systems Laboratory (P2SL) workshops. They demonstrate that it is possible to work hand in hand with industry representatives to develop solutions to many of the major challenges facing the building industry today.

The non-confrontational, collaborative problem-solving strategies implemented by P2SL appear to be ideal for dealing with financial challenges. The financial issues surrounding EBD are critical, because we are now living at a time when demands to expand and rehabilitate healthcare facilities are colliding with dwindling resources and cost escalation. It is therefore worthwhile to equip engineers and architects with the financial tools necessary to help clients make informed decisions.

Structure of the dissertation

This dissertation research addresses the financial implications and application of evidence-based design to healthcare facility capital planning. This is done by developing a research-based framework to (a) help increase the accuracy of long-term cost saving predictions resulting from EBD interventions, and (b) help clients overcome the burden of increased first cost sometimes associated with EBD.

These two concepts, as related to EBD, bind together the entire dissertation. In my experience, payback period is used frequently in the construction industry. There are at least two ways to represent payback period: (1) simple payback, and (2) discounted payback. Both of these concepts are relatively easy to understand with the assistance of a cumulative cash flow diagram.

Engineering economy specialists express cash flows along a time line, such that upward pointing arrows represent revenue; downward-pointing arrows represent expense. Unlike a traditional cash flow diagram, however, where all arrows originate from the x-axis (at y=0), the cumulative cash flow diagram uses the y-axis to maintain a running balance. In a typical diagram, the investment expense, or first cost, takes place at time 0. Revenue flows after that point usually represent incremental financial savings generated as a result of that investment. When simple payback is represented, all revenue flows appear identical because there is no discounting. In the diagram in **Figure 1**, the payback period is approximately 3.5 years.

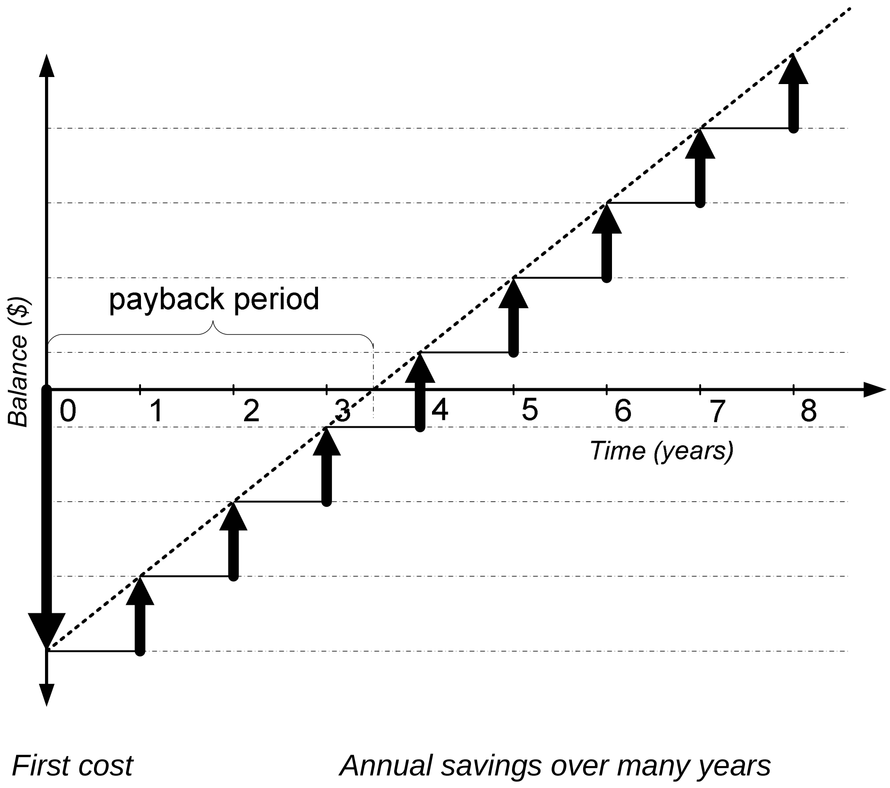

Figure 1. Cumulative Cash Flow Diagram representing simple payback

Simple payback periods are easy to understand and calculate. However most scholars of engineering economy are reluctant to use simple payback period calculations because such calculations ignore time value of money (discounting) and do not consider cash flows beyond the point of payback.

To address both of these concerns, I have opted to use a cumulative discounted cash flow diagram as my graphic representation of choice. In this format, every cash flow is discounted to its present value as follows:

$$\mathbf{PV=F(1+}\boldsymbol{i}\mathbf{)^n}$$

where PV=present value
F = future value
i = opportunity cost of capital
n = number of discount periods from time 0

In the case of a traditional investment where an initial expense is offset by a stable long-term revenue stream, the slope of the line (derivative) remains positive. However, because of discounting, the rate-of-the-rate-of-change (second order derivative) usually diminishes over time. The payback period is the point at which the cumulative cash flows cross the x-axis; note that this cross-over is later than with a simple payback diagram because discounting (at a rate > 0) reduces the present worth of long-term flows, as shown in **Figure 2**.

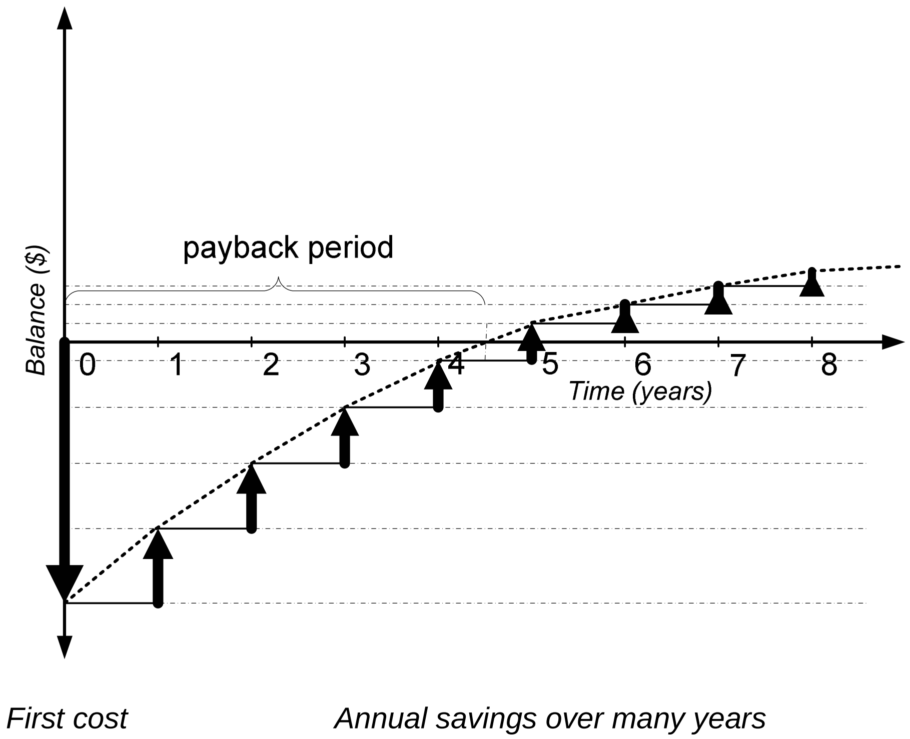

Figure 2. Cumulative Discounted Cash Flow Diagram representing Payback Period

One advantage of using a cumulative payback period, instead of other measures such as Net Present Value (NPV) or Internal Rate of Return (IRR) is that, unlike NPV or IRR, payback period calculations can be sketched on the back of a cocktail napkin during the natural flow of a casual conversation and are easy to understand and explain.

The two research questions associated with this dissertation are bound by the cumulative cash flow diagram. For clarity, and because I will not be addressing the concept of discounting, per se, I will illustrate the concepts with a simplified conceptual diagram. The two elements of this EBD research are: (a) amount of annual savings due to EBD interventions and (b) amount of first cost, as depicted in **Figure 3**. From the perspective of the investor, the former should be maximized and the latter should be minimized, since either and both of these actions reduce the payback period. It is important to remember that flows after the payback period are equally important and need to be considered, because they can lead to long-term financial savings or loss.

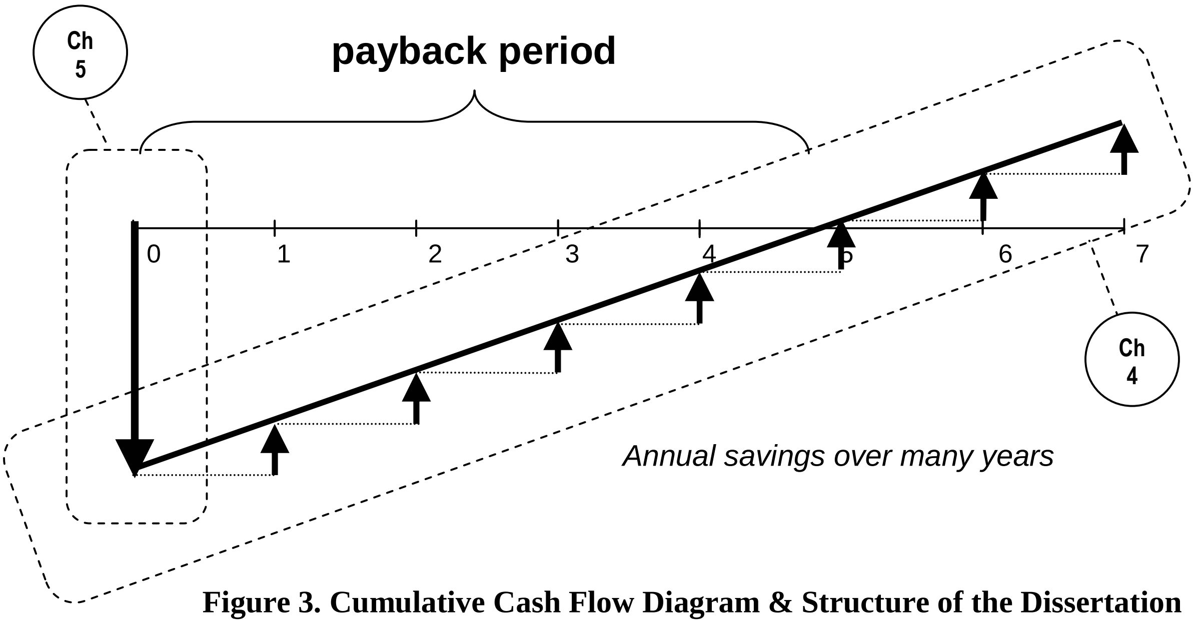

Figure 3. Cumulative Cash Flow Diagram & Structure of the Dissertation

These two concepts with respect to EBD implementation—that of the amount of long-term cash flow savings and reduction of first cost—are explored more fully as follows:

In **Chapter 1**, the current state of healthcare construction in the US is discussed. This chapter introduces the EBD movement and sets the stage and motivation for the research that is presented in the chapters that follow.

Parameters and Methodology used during this research are presented in **Chapter 2**. In this chapter, I introduce the two primary research projects in which I was engaged at UC Berkeley, define the scope and boundaries for this research and make explicit the research methodology used. The chapter also puts this work into the context of methodologies for scientific inquiry.

In **Chapter 3**, key players driving EBD research and historical landmarks are presented. This chapter offers both a broad-brush and detailed overview of EBD through a literature review.

The aim of **Chapter 4** is to develop a framework that can be used by future EBD researchers to enhance the accuracy of—and therefore confidence in—EBD financial forecasts.

This chapter provides the requisite background for Life Cycle Cost Analysis (LCCA), because one of the attractions of EBD is its ability to offer long-term (life cycle) financial benefits.

This chapter also discusses available evidence and assesses the adequacy of the financial claims being made about EBD. It then proposes a statistical methodology used in clinical research—the cumulative meta-analysis—as a potential strategy to enhance decision-making confidence and more accurately predict future cash flows. This work links the

Root Cause Analysis tool used in lean construction to EBD decision-making to ensure that a range of appropriate solutions are considered before making a decision.

By synthesizing and analyzing the techniques used in one Target Costing and one Target Value Design case study, **Chapter 5** tackles the topic of overcoming the hurdle of increased first cost sometimes associated with EBD. It documents some of the procedures used during action research projects conducted as part of P2SL, and presents initial results. This chapter examines some of the logic behind lean thinking and captures methodologies used by the case study project teams.

The final research component of this dissertation, **Chapter 6**, summarizes results of the dissertation research, identifies original contributions made, discusses possible limitations of the research, and suggests future research opportunities in this growing and exciting field.

Please note: There is currently disagreement about the spelling of "healthcare." Although I have elected to use the single-word version in this dissertation, I have also preserved the original two-word spelling in cases where it appears in the titles of articles and agencies.

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Acronyms

AHRQ	Agency for Healthcare Research and Quality
AIA	American Institute of Architects
ASHE	American Society of Healthcare Engineering
ASTM	American Society for Testing Materials
BCA	Benefit Cost Analysis
BIM	Building Information Modeling
CHD	Center for Health Design
CHH	Cathedral Hill Hospital
EBD	Evidence-Based Design
EBM	Evidence-Based Medicine
H&HN	Hospitals and Health Networks
HEPA	High Efficiency Particulate Air
HFM	Healthcare Financial Management
HGRC	Health Guidelines Revision Committee
ICU	Intensive Care Unit
IFOA	Integrated Form of Agreement
IRR	Internal Rate of Return
JIT	Just-In-Time
LCCA	Life Cycle Cost Analysis
LCI	Lean Construction Institute
LOS	Length of Stay

MEP	Mechanical, Electrical and Plumbing
MRSA	Methicillin-resistant *Staphylococcus aureus*
P2SL	Project Product Systems Laboratory
PPC	Percent Planned Complete
RCT	Randomized Controlled Trial
TFV	Transformation, Flow and Value
TVD	Target Value Design

Abstract

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Zofia Kristina Rybkowski

Doctor of Philosophy in Engineering—Civil and Environmental Engineering

University of California, Berkeley

Professor Iris D. Tommelein, Chair

The US is currently engaged in a large-scale building boom to upgrade and expand healthcare facilities. Facility decision-makers need an unbiased information source in order to improve quality and maximize value for money.

Concurrent with this surge in hospital construction is the growing application of Evidence-Based Design (EBD) to healthcare facility design.

The objective of this dissertation research is to assist capital-budgeting decision-makers in two ways: (1) to increase accuracy—and therefore confidence—in financial savings predicted after implementation of EBD interventions by developing a framework for an Evidence-Based decision-making tool based on Root Cause Analysis, and (2) to investigate how an owner can overcome the hurdle of increased first cost sometimes associated with the application of EBD, by describing and analyzing processes used during case study projects that implemented Target Costing and Target Value Design.

Results from this study suggest that (1) while a Root Cause Analysis decision-making framework for EBD is possible, accuracy will be enhanced with more rigorously controlled experimentation, and (2) the challenges of increased capital cost sometimes associated with EBD can be addressed using Target Value Design—a methodology which appears to reduce capital cost predictions by up to 20%.

Chapter 1

This chapter discusses the current state of healthcare construction in the US, as well as challenges the country is facing with respect to providing quality care. The chapter also introduces Evidence-Based Design as a partial response to these challenges and argues there is a need for unbiased research on the topic.

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind. It may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science."

—Lord Kelvin, 1883

1.0 Introduction

The purpose of this research is to develop a conceptual framework to assist those wishing to apply EBD considerations to Life Cycle Cost Analysis (LCCA) or Benefit Cost Analysis (BCA) during the capital budgeting phase of healthcare facility planning.

This chapter sets the stage for examining the financial implications and application of Evidence-Based Design (EBD) in the capital planning of healthcare facility design. It begins by critically examining the state of the healthcare facility design industry, existing literature reviews on EBD, as well as sources of primary research. It examines how these sources may be used to enhance the predictability of financial benefits.

At the time of this writing, a need to construct new healthcare facilities in the US on a large scale is converging with a striving by architects and designers to improve the quality of healthcare facility design using EBD (Ulrich et al. 2004). Although improving quality is generally a positive thing, EBD may also be hijacked and misused by those who see it as a marketing opportunity, potentially misleading those who must pay for the additional cost its implementation may require. Therefore the science behind EBD claims needs to be better developed and clarified.

1.1 Current state of healthcare construction in the US

1.1.1 Healthcare facility building boom

Healthcare facility construction is projected to increase. Carpenter and Hoppszallern (2006) enthusiastically proclaimed the start of the new millennium to be “the most significant expansion and replacement of US hospitals since the post-World War II building spree” and project the trend to last at least through the end of the decade **(Figure 4).** Although, at the time of this writing, the US is embroiled in an economic recession, the need remains for new and renovated facilities.

According to a survey by HFM/H&HN/ASHE, the need is being driven by a number of factors, including the need to: repair and replace aging facilities (68%), increase operational efficiency and patient flow, especially given new forms of technologies (62%), respond to increased competition in the marketplace (51%), meet the needs of a specific population (48%), and increase market share (47%) (Carpenter and Hoppszallern 2006). The aging and retirement of baby boomers in the US is also fueling an urgency to construct new facilities (Babwin 2002; Carpenter 2004a).

Additionally, hospitals must be updated to be consistent with new guidelines and regulations; the Health Guidelines Revision Committee (HGRC) updates guidelines every 5 years (Nelson et al. 2005). For example, a large proportion of construction is taking place in California, where seismic retrofitting of facilities is required, especially thanks to code revisions following major earthquakes (Babwin 2002; Moon 2005).

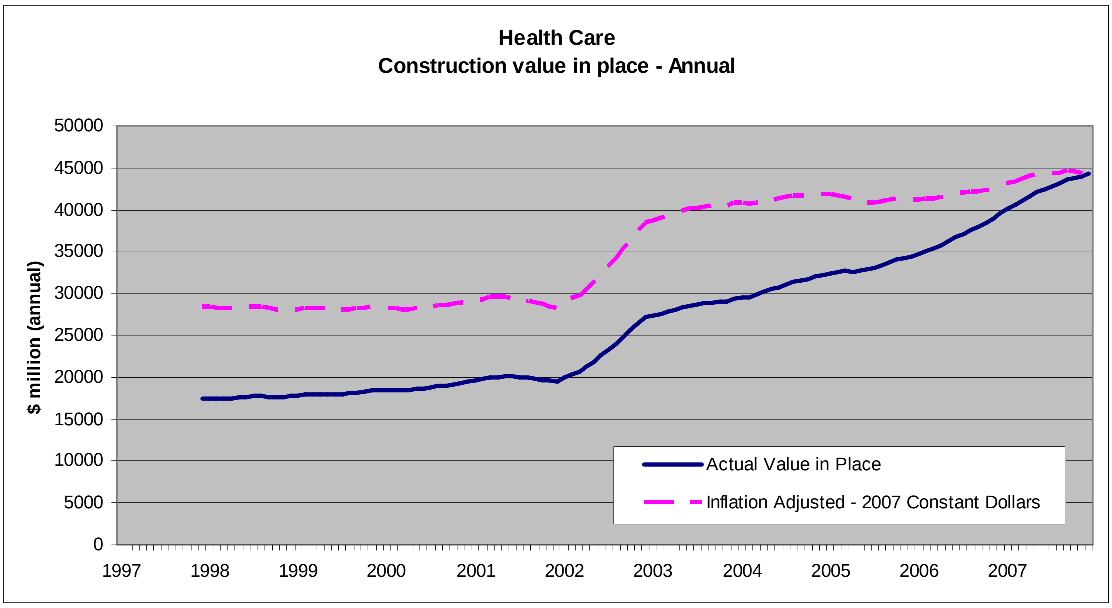

Figure 4. Volume of recent hospital construction in the US.
Data from U.S. Census Bureau (2007). Adapted from Morris (2007).

1.1.2 Challenges to quality care

Coincident with this boom is an urgent drive to improve the quality of care provided in the US. According to two Institute of Medicine reports released within this decade, *To Err is Human* (2000) and *Crossing the Quality Chasm* (2001), the US healthcare system faces serious challenges. The reports reveal that between 44,000-98,000 Americans die each year due to preventable medical errors. These reports raise concerns about patient safety.

Proponents of the EBD analysis methodology suggest that improving the design of the healthcare environment is one way to reduce the occurrence of such errors and to enhance the overall quality of care (Ulrich et al. 2004). Interest in EBD will likely increase even further because Medicare transitioned toward a widespread “pay-for-performance” reimbursement system, as of October 2008 (CMS Hospital Pay-for-Performance Workgroup et al. 2007; Leavitt 2006).

1.2 Evidence-Based Design as partial response to healthcare challenges

1.2.1 Current state of the evidence in Evidence-Based Design

According to D. Kirk Hamilton (2006), Evidence-Based Design (EBD) is “the conscientious and judicious use of current best evidence, and its critical interpretation, to make significant design decisions for each unique project. These design decisions should be based on sound hypotheses related to measurable outcomes.” Examples of health benefits associated with EBD decisions include faster recovery rates thanks to views of foliage and sunlight, reduced patient falls thanks to rubberized flooring, reduced hospital-acquired infections thanks to single patient rooms, reduced drug costs thanks to patient stress reduction from quieter rooms, reduced nursing turnover thanks to a less stressful work environment, increased market share, and increased philanthropy thanks to a more patient-oriented design space.

The promise of potential financial benefits appears to be making inroads with owners, as suggested by a survey administered by the *Hospitals & Health Network.* The organization randomly sampled 5000 hospital and healthcare system executives. Returns from 173 completed surveys suggest that 37% of hospitals and 63% of healthcare systems were already using EBD to make design decisions in some way at the time the survey was administered (Carpenter 2004b) **(Figure 5).** The appeal is that restorative spaces can potentially enhance patient recovery rates and therefore offer strategic business advantages.

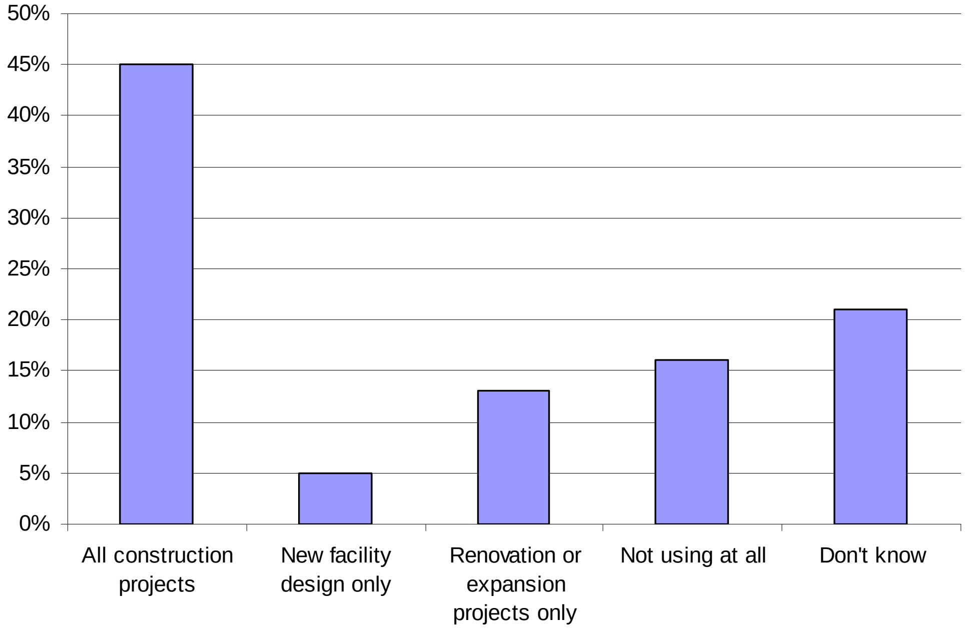

Figure 5. Percentage of healthcare systems using EBD for construction projects. Data from H&HN Research, 2004, as reported in Carpenter (2004b).

EBD is a developing field. Although an increasing number of hospital decision-makers are implementing its recommendations, the literature that supports EBD is of mixed reliability and ranges from observational data to that obtained from more rigorous randomized controlled trials. In the preparation of one report prepared for the Agency for Healthcare Research and Quality, researchers searched 328 articles on EBD and classified them into categories of rigor as shown in **Figure 6** (Nelson et al. 2005).

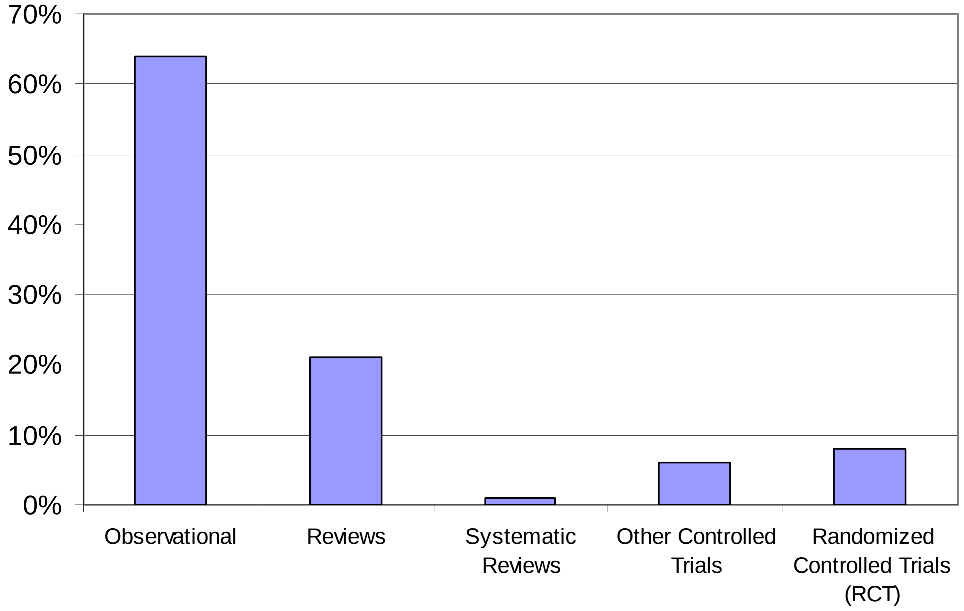

Figure 6. Distribution of article types in EBD literature review report.
Adapted from Nelson et al. (2005).

The large percentage of observational data-based articles (64%) Nelson et al. (2005) discovered versus those representing randomized controlled trials (8%) (RCT are the research "gold standard") helps to explain the controversial nature of EBD proponent claims. Although sources of peer-reviewed data are still growing and improving, their quantity and quality do vary.

Figure 7 illustrates three types of literature reviews common to medical literature, ranging from a perception of more risky to less risky, according to the medical research community. Traditional reviews tend to be more qualitative in nature; they are based on the judgment of the reviewer. A meta-analysis is highly quantitative; individual judgment is suppressed in favor of blind reviews and analysis. Much literature on EBD still falls toward the left of the review arrow; it is just beginning to become subjected to systematic review processes. A report by Ballard and Rybkowski (2007) for the Health Research and Education Trust suggests that, in order to validate the claims being made, EBD analysis methodology needs to shift its focus to the more widespread preparation of systematic reviews and ultimately, the most rigorous forms of review, the meta-analysis. More will be said about levels of evidence in **Section 4.2.1.2**.

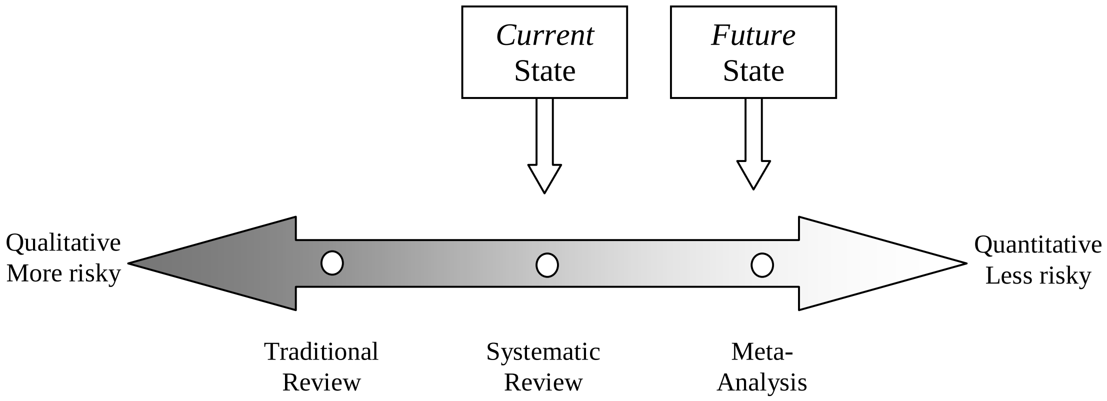

Figure 7. Range of potential literature review categories

While EBD reviews should aim for meta-analyses, the most rigorous form currently prepared is the systematic review.

Adapted from Ballard and Rybkowski (2007)

Articles published in industry trade magazines, as well as the intuitive appeal of EBD claims, help attract thousands of facility owners and design professionals to annual EBD healthcare design conferences (e.g., the Healthcare Design series, administered by the Center for Health Design and the Vendome Group). Nevertheless, because the field offers enticing marketing opportunities for architects and interior designers (Bilchik 2002; Sandrick 2003), some facility decision-makers are concerned that claims by EBD advocates may be exaggerated or distorted to benefit the proponents (Chambers 2006; Dijkstra et al. 2006; Mazurek 2007; Stankos and Schwarz 2007).

To address these concerns, academic researchers are attempting to offer an unbiased assessment of the claims. As with other bodies of medical knowledge, most academic reviews of EBD-related literature represent little more than *ad hoc* collected citations of experimentation in fields related to EBD (Devlin and Arneill 2003). This method of approaching reviews of literature has been challenged (Dickersin and Min 1993; Oxman and Guyatt 1993) because of poor consistency between expert ratings resulting from a number of factors, including lack of blinding of authorship and publication bias (Oxman and Guyatt 1993). The need to consolidate an unwieldy expansion of data, as well as to better assess the reliability of health impact claims, requires a more systematic and rigorous approach. This has led to the adoption of a systematic review methodology (Antman et al. 1992; Buendia-Rodriguez and Sanchez-Villamil 2006; Chalmers 1993; Counsell 1997; Meade and Richardson 1997; Mullen and Ramírez 2006; Mulrow et al. 1997).

In fact, systematic reviews are increasingly being compiled by those who advocate Evidence-Based Medicine (EBM), an analysis methodology which regards randomized controlled trials (RCT)[1] as its gold standard (Sandercock 1993). In some sense, EBD runs both parallel to and intersects with EBM (**Figure 8**). Both EBM and EBD regard evidence as supreme when making decisions. Since some EBD decisions, such as stress-reducing music or sunlight, can arguably lessen or displace the administration of some forms of medication, EBD has much in common with EBM. However, EBD logic can be applied to business as well as medical decisions, and therefore needs to be considered a subject in its own right. Some of EBD recommendations can easily intersect with physiological research common to medicine (i.e., rate of healing vis-à-vis exposure to sunlight), whereas some are less tangible and more difficult to measure (i.e., amount of philanthropic gift-giving vis-à-vis presence of family seating areas).

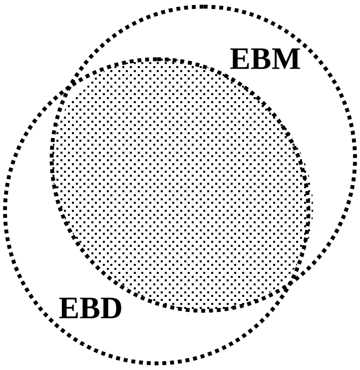

Figure 8. Intersection of EBD and EBM

Adapted from Ballard and Rybkowski (2007)

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[1] A *randomized controlled trial (RCT)* is a clinical study with two major characteristics: randomization and the presence of a control group (Leandro, G. (2005). "Meta-analysis in Medical Research: The Handbook for the Understanding and Practice of Meta-Analysis." Blackwell Publishing.)

Collaborative not-for-profit organizations have emerged to produce systematic reviews within EBM. For example, the Cochrane Collaboration statistically combines homogeneous RCT results from researchers around the world (Institute of Medicine 2001). However, randomized controlled trials in EBD-related topics are generally more difficult to develop than in EBM areas, perhaps because so many confounding variables in an environment need to be controlled. Preparation of randomized controlled trials is predicated on the ability to hold constant all variables between experimental and control groups but one—a trick that is not as simply done with environmental cues as with testing the effects of a pill versus a placebo.

Although preparation of meta-analyses may still be far off, a form of systematic review *has* started to emerge within Evidence-Based Design (Rubin et al. 1998; Ulrich et al. 2004). These reviews represent an early step toward the coveted gold standard of reviews, the meta-analysis. Migration toward meta-analyses is clearly desirable in order to quantify the outcomes resulting from EBD; however the number of randomized-controlled trials related to EBD concerns does not suffice yet to be able to conduct meta-analyses. I have advocated, with Dr. Glenn Ballard, the need to progress toward this goal in a separate report for the Health Research and Education Trust (HRET): *The Evidence-Based Design Literature Review and its Potential Implications for Capital Budgeting of Healthcare Facilities* (Ballard and Rybkowski 2007).

1.2.2 Additional need for unbiased research

The desire to improve design in a way that benefits patients has advocates. In the case of EBD, supporters are primarily organized around two organizations: the Center for Health Design and Planetree. The latter, Planetree, focuses on similar issues as the former, but describes its mission as advocating “patient-centered care” through healing environments (Nelson et al. 2005).

A volunteer advocacy group of the Center for Health Design—the Environmental Standards Council—lobbies the Health Guidelines Revisions Committee of the American Institute of Architects to include EBD recommendations in AIA standards, many of which will eventually be adopted by states and carry the force of law (Ballard and Rybkowski 2007). Intuitively, both groups’ missions appear well-intentioned. However, because their voices are increasing in strength and influence, EBD recommendations should also be founded on a strong tradition of peer-reviewed evidence.

Chapter 2

This chapter presents the goals and significance of this research, its scope and boundaries, questions addressed, methodology used, situation of this research within the circle of scientific inquiry, and compliance Institutional Review Board requirements.

2.0 Parameters and Methodology

2.1 Goals and significance of this research

In summary, the US is engaged in a large-scale healthcare facility construction boom. Error rates are high and quality of care has been declared low in two condemnatory Institute of Medicine (2000, 2001) reports leading hospital decision-makers to seek solutions to improve the quality of their services. Decision-makers are grasping for the types of outcomes that EBD advocates appear to promise.

Although evidence to support EBD claims is mounting, it is not yet organized in a way that is helpful to capital budgeting decision-makers. A number of research centers, both academic and non-profit organizations funded by industry—as well as researchers in evidence-based design case study projects—are investigating the reliability of EBD claims, by ranking articles within systematic literature reviews. As yet, to my knowledge, no one has published research on the intersection between EBD and the capital budgeting process.

Therefore one goal of this research is to lay a foundation upon which capital budgeting decision makers can evaluate EBD design claims with a reasonable level of confidence. A second goal of this research is to make EBD interventions affordable by reducing the additional first cost sometimes associated with EBD. This latter goal is relevant, because even if life cycle cost analysis reveals favorable long term savings associated with an

EBD intervention, those who wish to realize the intervention must still be able to overcome the hurdle of first cost.

The means I used to achieve these goals were as follows:

1) *Develop an overall framework for an EBD tool* that can be used to enhance confidence in future EBD-LCCA decision-making.
2) *Describe and analyze primary procedures used during Target Costing (TC) and Target Value Design (TVD) exercises of two case study projects*, Sutter Fairfield and Cathedral Hill Hospital, as defined in Chapter 5. Synthesize and analyze initial results obtained from these exercises, thus offering an initial roadmap for those who wish to introduce EBD interventions into their facilities but who may have difficulty overcoming the hurdle of increased incremental capital cost sometimes associated with the interventions.

2.2 Scope and boundaries of this research

Although EBD interventions can be applied to many types of businesses and institutions, this research focuses on healthcare facilities. The decision to limit this study to healthcare facilities institutions is primarily practical; these facilities continually collect performance data whether or not they are experimenting with EBD, making it easier to identify potential patterns of influence.

The research has focused on the innermost core of a healthcare facility’s financial concerns. For example, an administrator’s decision to offer certain types of care, to the exclusion of others, likely impacts society at large. Constructing the medical facility may also displace certain individuals in a neighborhood or impact their livelihood. Such wider concerns can be addressed using full cost accounting or Social Impact Assessment (SIA) methodologies (**Figure 9**) (Becker 2001). However valid larger societal concerns may be, they are challenging to quantify and extend beyond the scope this dissertation research.

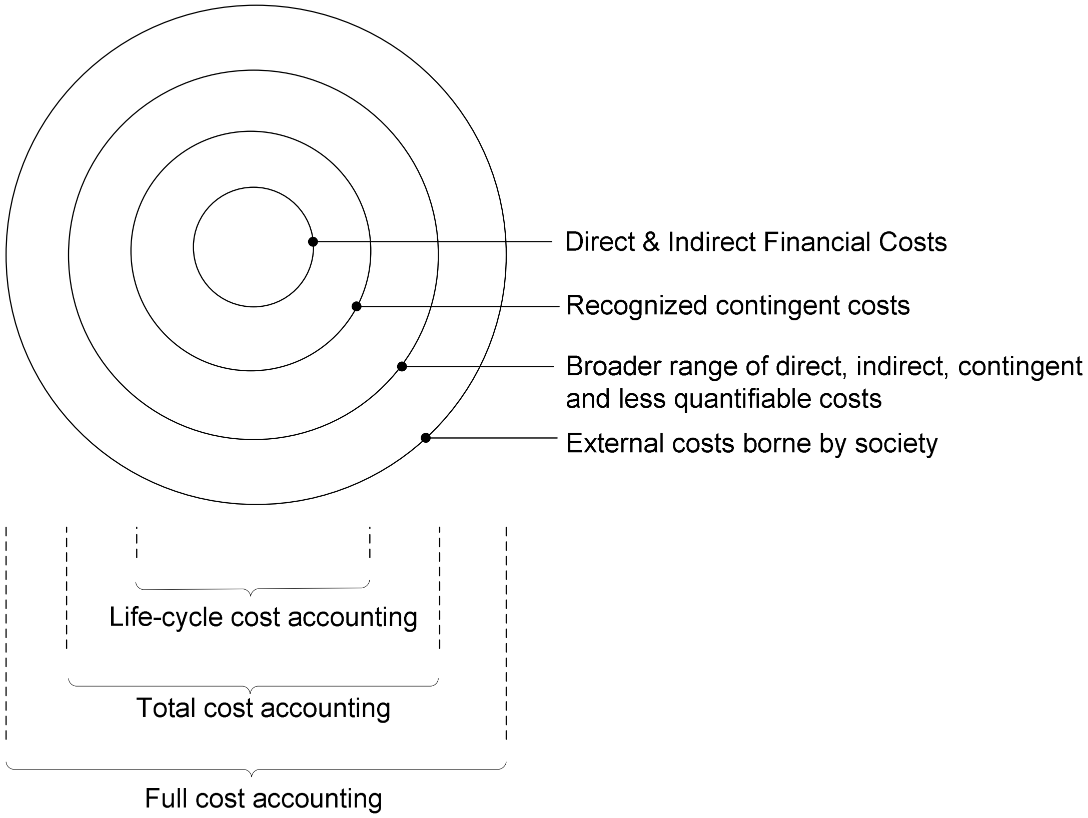


Figure 9. Scope and boundaries of dissertation research

Adapted from Boussabaine and Kirkham (2004) and Cole and Sterner (2000).

2.3 Questions addressed

The question central to this thesis research is:

> *How might healthcare facility decision-makers incorporate Evidence-Based Design decisions in their capital budgeting process—with a reasonable level of confidence—so that (1) the projected cash flow savings are relatively accurate, and (2) those who choose to implement EBD interventions can overcome the hurdle of sometimes increase first cost?*

Adequately responding to this question has required exploring a number of corollary questions, such as:

About Evidence-Based Design:

- How might it be possible to quantify savings afforded by EBD interventions?
- How can EBD be placed within the larger context of potential healthcare solutions?
- When medical challenges are subjected to Root Cause Analysis, how might the literature support—or undermine—proposed solutions?
- How advanced is current EBD research when screened for rigor?
- Which of the potential alternatives would most impact a facility's design and therefore be considered an EBD intervention?

About TVD:

- How does TVD intersect with lean principles?
- How reproducible are the results obtained from TVD case studies?
- What types of incentives will make TVD attractive to team members?
- How satisfied are team members with the TVD process compared to other delivery processes currently being used?

2.4 Methodology for this research

Part I: Building an EBD Framework

The steps taken to develop an EBD decision-making framework were as follows:

1) After conducting an initial literature review on Evidence-Based Design, I engaged in exploratory interviews with a number of practitioners to understand the needs and controversies within the EBD field.

Privacy restrictions imposed by UC Berkeley’s Institutional Review Board prohibit revealing the specific identities of the individuals involved. However, the interviewed individuals can be classified into specific categories, as follows:

	O	**A&E**	**Ac**	**CB**	**A**
# of organizations	6	8	6	3	6
# of individuals	12	17	8	4	13

O	Owners
A&E	Architects & Engineers
Ac	Academics specializing in EBD and infection control
CB	Capital budgeting consultants for healthcare
A	Advocacy group members

More individuals than organizations were interviewed because, in some instances, several individuals within the same organization volunteered to share their expertise. I recorded these interviews on tape to enhance accuracy of my understanding.

2) I investigated what would be required to embed EBD decision-making into Root Cause Analysis—a methodology recommended by the Joint Commission, as will be explained in **Section 4.4.1.1**.

3) I proposed a framework for such a tool.

4) I tested part of the tool's framework, using prevention of the spread of hospital-acquired Methicillin-resistant *Staphylococcus aureus* (MRSA) as an example of how such a tool might be used. Testing the tool for MRSA prevention required undertaking an in-depth literature review on the topic and then screening the resulting articles for level of rigor, according to methodologies described in **Section 4.2.1.1**. Databases searched included:

- SpringerLink
- Web of Science
- PubMed
- Google Scholar

Table 1 identifies the keywords I used in my database search.

Table 1. Keywords used to search databases

Keyword(s)	*and*	*and*
evidence-based design		
hospital acquired infection		
isolation	cost	
Methicillin-resistant *Staphylococcus aureus*		
MRSA		
	clean$	
	clean$	cost
	cohort	
	contaminat$	
	hand hygiene	prevent$
	hand wash$	
	hand wash$	compliance
	hospital	cost
	isolate$	
	isolate$	systematic review
	staff	
	staff	compliance
	surveillance	
	visitor$	compliance
nosocomial		
	cause$	
	hand wash$	
	infection$	
	infection$	prevent$
	isolation	cost
patient room		
	design	
systematic review		
	surveillance	

5) I assessed what might be necessary to populate such a tool on a larger scale with the results of literature review searches. I did this by estimating what might be required to populate the tool in terms of:

- Approximate number of labor hours needed
- Expertise of workforce required

- Reliability of results obtained

Part II: Documenting TVD

The steps I took to describe and analyze TVD methodologies used on two case study projects were as follows:

1) I developed an initial understanding of Lean Construction and TVD principles by undertaking in-depth literature reviews

2) I observed first hand, synthesized and analyzed Target Costing, TVD and Last Planner exercises as applied to two case studies:

   a) Sutter Fairfield: a small (69,000 SF) Medical Office Building project, and
   b) Cathedral Hill Hospital: a large (912,000 SF) healthcare facility project

3) In collaboration with research partner John-Michael Wong, I confirmed that benefits obtained from lean methodologies can be quantified by using a computer-based simulation and then validated the results with a live playing of the game.

4) From observations of the processes, I analyzed and diagramed procedures and key results obtained from both TVD case study projects, Sutter Fairfield and Cathedral Hill Hospital, in order to assess the possibility of reducing the increased incremental capital cost sometimes associated with implementation of EBD interventions.

The observation process at Sutter Fairfield involved attending biweekly and then weekly Target Costing meetings for nearly six (not all consecutive) months at the project office in Fairfield, CA, starting in January 2006. The meetings involved discussions between team members about project design and cost-reduction strategies and included exercises in reverse phase scheduling, Target Costing and the Last Planner System (defined in Sections 9.1.5.2, 5.1.2 and 9.1.5.2, respectively). My role was primarily observational and analytical, although I also hosted a workshop to elicit feedback about the Target Costing process. I developed a fuller understanding of the Target Costing methodology, and its pros and cons, through interviews with team members participating in the process.

The research process at Cathedral Hill Hospital was likewise observational. It involved attending TVD and cluster group meetings, interviewing and recording responses from key members of the design team, especially cost estimator Paul Klemish, and photo recording parts of the TVD environment and process relevant to this study. The financial values and processes described at the end of Chapter 5 in this dissertation have been validated by cost estimator, Paul Klemish.

2.5 Position of dissertation research within the circle of science

This study implements several types of research methodologies. It is therefore worth presenting a brief overview of how this work sits within the larger methodological spectrum of scientific research.

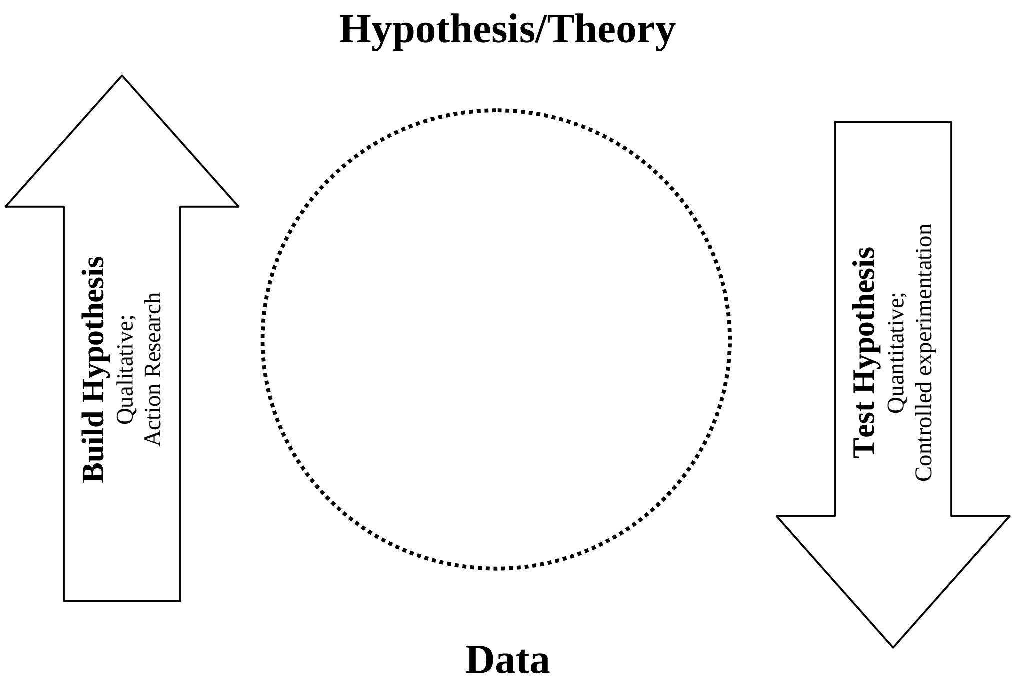


Figure 10. Circle of Science
Adapted from Gil (2009).

Scientists tend to recognize the hallmarks of traditional scientific experimentation: the presence of a control group and blinding of researcher and subjects. However, this type of experimentation needs to be viewed within the context of the entire circle of science (**Figure 10**). On one hand, hypotheses and theories are often generated from intuitive hunches; the process is generally observational, creative and *qualitative* in nature. On the other hand, hypothesis testing demands a series of rigorous systematic steps which may engage statistical analysis. Hypothesis testing is generally *quantitative* in nature—at least in the realm of medical research.

In medical research, *randomized controlled trials* have come to represent the gold standard of scientific research. This experimental methodology uses a *test* group and a *control* group from which the experimental procedure has been withheld but to which a “look-alike” placebo is administered, members of both groups have been randomly assigned, and subjects and researchers are blinded as to the affiliation of the group to ensure freedom from conscious or subconscious bias. Hypothesis testing within a statistical framework has evolved to imply a series of specific actions taken to test an Alternative Hypothesis (H_A) against a Null Hypothesis (H_o)—determining whether or not the Null Hypothesis can be rejected to an acceptable level of statistical significance. If H_o is true, there is *no* difference between the experimental group and the control. If H_A is true, the experimental and the control groups do differ. A statistically significant result states that there is greater than a 90 or 95 ($p<=0.01$ or $p<=0.05$) percent probability that the observed difference between the experimental and control group is *not* due to chance and therefore H_o can be rejected. To yield accurate results, hypothesis testing within a statistical framework should ideally be done using randomized controlled trials with a sample size, N, of greater than 30.

The reality of most construction project experiments is that they represent a sample size of N=1, seldom have a control group and are plagued by confounding variables—meaning that if there is a control, more than one variable often differs between the experimental and control group. Most construction projects are complex and variable in their outcome, in part because the combination of players is generally unique to each individual project. Therefore, from an experimental perspective, they do not easily qualify for statistical hypothesis testing. Researchers have responded to this challenge by analyzing patterns of problems plaguing the industry, as well as successes, through statistical analysis of surveys. Although this methodology is helpful to identify ways of working that might more likely lead to successful project outcomes, it does little to generate new ways of working as yet untried. *Action Research* methodology responds to this challenge (Greenwood et al. 1993; Westbrook 1995). Unlike data gathering of pre-existing conditions, action researchers create new conditions using the Plan-Do-Check-Act (PDCA) cycle of improvement, as will be discussed in the **Appendix**. While hypothesis testing may be viewed as a form of discovery, Action Research may be viewed as a form of creation, invention or “tinkering”—one where new hypotheses are generated. It is somewhat akin to a patient with a rare tropical ailment whose treatment defies all known cures. At a loss for known solutions, the patient’s physician administers medication by trial and error, until relief is found. Another physician then discovers a patient with similar conditions. Hearing of the success of the first patient, she may then offer the same medications that cured the first patient—resulting in a repeat success. The study of each situation constitutes a case study where N=1. Over time, patterns of repeat results from similar case studies generate hunches within a research community. Once these hunches are strengthened, they may crystallize into hypotheses that can then be tested using controlled experimentation, but a hypothesis must first be built before it can be tested (Schmenner and Swink 1998). Action research fuels the circle of science. Case study analysis bridges the gap between late qualitative and early quantitative work (Eisenhardt 1989; Yin 2003).

The research methodology on Evidence-Based Design which informs **Chapter 4** strives to move the field of EBD from hypothesis-generation to hypothesis-testing by prioritizing evidence that has been pre-screened for its level of rigor. The research methodology on TVD which informs **Chapter 5**, by contrast, is primarily descriptive in nature and is intended to offer support to the evolving theory of Target Costing in construction. At some point in the future, the methods implemented in TVD might be quantified through controlled laboratory experimentation. However, the expense of conducting controlled experiments in construction needs to be justified by sound hypothesis-generation.

In other words, I believe the research methodology choices for each of the two areas of study are appropriate for where the field of Evidence-Based Design finds itself now.

2.6 Institutional Review Board approval

Human subject research for this dissertation was approved by the Office for the Protection of Human Subjects at UC Berkeley, under CPHS Protocol #2007-7-58.

Chapter 3

This chapter reviews the development of Evidence-Based Design through an in-depth literature review, notes how EBD is being adopted into legal standards, and discusses the multidisciplinary nature of the field.

3.0 Context and literature review

3.1 Development of EBD

3.1.1 Precursors to EBD

EBD is gaining momentum in the US, but the observation that human behavior is influenced by physical surroundings is not new. For example, the practice of Feng-Shui (literally “wind-water”), which prescribes the placement of urban fabric, architectural and interior design elements to ensure health and prosperity, dates back to the Zhou Dynasty 1122-256 BC. Major Chinese cities, such as Beijing, have been and often continue to be designed to conform to conventions dictated by Feng-Shui. Although sometimes considered an alternative form of wisdom by members of western societies, Feng-Shui’s principles are becoming increasingly popular in the US, Britain and Australia. Practitioners argue that a space designed according to principles of Feng Shui enhances a occupant’s sense of well-being (Jeffreys 2000; Mak and Ng 2005; Xu 1998).

In the West, nursing pioneer, Florence Nightingale, observed that individuals in a recovery ward exhibit a subconscious need for light:

> “It is a curious thing to observe how almost all patients lie with their faces turned to the light, exactly as plants always make their way towards the light; a patient will even complain that it gives him pain “lying on that side.” “Then why *do* you lie on that side?” [I ask]. He does not know–but we do. It is because it is the side towards the window. A fashionable physician has recently published in a government report that he always turns his patient’s faces from the light. Yes, but nature is stronger than fashionable physicians…Walk through the wards of a hospital, remember

> the bed sides of private patients you have seen, and count how many sick you ever saw lying with their faces towards the wall."
>
> (Nightingale 1860)

In the US, the science of environmental psychology was first formalized as a field in 1947 when researchers Roger Barker and Herbert Wright established the Midwest Field Station in Oskaloosa, Kansas, population 800. Barker and Wright observed the behavior of town residents in natural everyday settings, such as a pharmacy, worship service, grocery store, or walkway to school. The researchers called their new field "ecological psychology"—a study of "how people's behavior and development are influenced by the physical environments that are part of their everyday lives" (Holahan 1982). One of Barker and Wright's partners, Paul Gump, observed: "Two children in the same place (behave) more similarly than one child in two places" (McAndrew 1993).

Environmental psychology—an area of psychology in which the focus is the interrelationship between the physical environment, human behavior and experience—emerged from observations made at the Midwest Field Station (Holahan 1982). Future researchers extended their work, discovering, for example, that rearranging ward furniture in groups significantly encourages greater social interaction among psychiatric patients (Sommer and Ross 1958) and that long corridors or tunnels produce distortions of auditory and visual perception for these patients (Spivack 1967).

The Environmental Press Model, published by the American Psychological Association (Eisdorfer and Lawton 1973), suggests a link between the competence of an individual and the impact of an environment on that individual's ability to adapt. For example, the model's "environmental docility hypothesis" suggests there is an appropriate "fit" between an individual's competence and her ability to navigate through an environment. The less competent or frail the individual, the more vulnerable she will be to environmental demands, compared to those who are more competent. For example, the act of stepping out of a tub requires that a bather has the ability to raise her feet over the height of the tub, while maintaining balance. A designer's decision to increase friction on the tub's floor or to include handholds to help an individual maintain balance, springs from this realization (Connell 1997). The model speaks of the importance of "fit". Matching an environment to a subject's level of competence is critical because too little environmental stress—or press—is as inappropriate as too great a one, as is indicated by **Figure 11**.

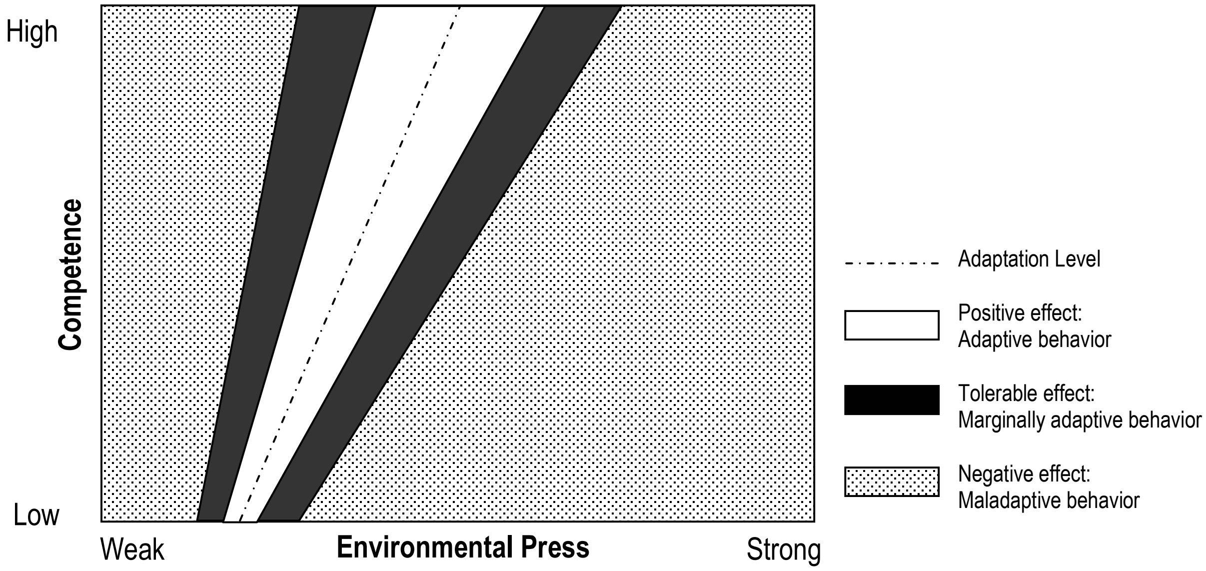


Figure 11. The Environmental Press Model

Adapted from Eisdorfer and Lawton (1973), as presented in Connell (1997)

3.1.2 Emergence of EBD

Environmental psychology and EBD share a quest for evidence regarding the impact of the environment on human beings. However, the fields flow through separate streams because they are being driven by different research cultures. For example, while environmental psychology includes various built environment typologies (Bell et al. 1996), EBD has thus far principally focused on a sub-sector of buildings—the architectural and interior design of healthcare facilities.

Although it has been variously referred to as “supportive design,” “evidence-informed” and “research-based” during its development, the 1984 publication of Roger Ulrich’s paper in *Science* is frequently heralded as the christening point of EBD (Bilchik 2002). In his paper, entitled “View through a window may influence recovery from surgery,” Ulrich, then researcher at the Department of Geography at the University of Delaware, analyzed the recovery records of forty-six surgical patients assigned to eight rooms over the course of nine years. The recovery rooms were almost identical in all ways but one. On each floor, windows of half of the rooms faced a brick wall, while half faced a natural scene (**Figure 12**). To minimize confounding factors, forty-six patients subjected to a similar surgical procedure were grouped into twenty-three pairs and matched in terms of: sex, age (within 5 years), being a smoker or non-smoker, being obese or within normal weight limits, general nature of prior hospitalization, year of surgery (within 6 years), floor level, and wall color of rooms. Comparison of recovery rates indicated statistically significant differences; patients whose windows faced foliage had shorter postoperative stays, received fewer negative evaluative comments in nurses notes, and took fewer potent analgesics than their matching counterparts (Ulrich 1984).

Ulrich’s results implied that health benefits afforded by an environment could be measured, and were therefore as tangible as administered medication. The discovery, in turn, suggests that careful design can offer determinable financial benefits.

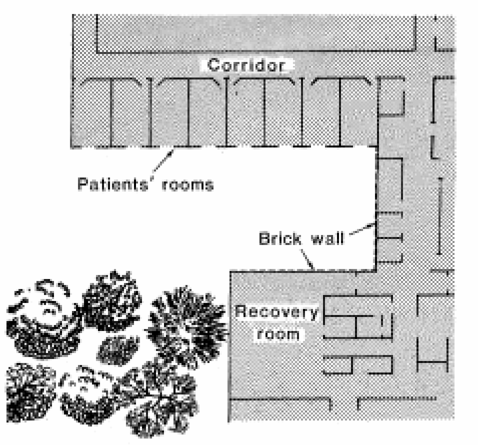


Figure 12. Recognized first study in Evidence-Based Design analysis methodology
Floor plan of hospital showing patient rooms facing foliage versus brick wall.
From Ulrich, R. (1984). "View through a window may influence recovery from surgery." *Science*, 224(4647), 420-421. Reprinted with permission from AAAS.

Two years following the publication of Ulrich's seminal paper, Wayne Ruga led the founding of the Center for Health Design (CHD), a nonprofit organization with a stated mission to "transform healthcare settings into healing environments that improve outcomes through the creative use of evidence-based design." The CHD website declares: "We envision a future where healing environments are recognized as a vital part of the therapeutic treatment; and where the design of healthcare settings contributes to health and does not add to the burden of stress" (Center for Health Design 2007a). The CHD, recognizing the need to convincingly demonstrate health benefits potentially achieved by EBD interventions within actual healthcare settings, established the Pebble Projects program, based on the metaphor that a single pebble tossed into a pond makes ripples that can have far reaching effects. The Rady Children's Hospital in San Diego was the first of four Pebble Projects. The number of healthcare facilities participating as Pebbles has since grown to 65 as of this time of writing, and continues to increase (Center for Health Design 2007c).

In addition to its role in facilitating the gathering of research data from Pebble Projects, the CHD commissioned Haya R. Rubin, Amanda Owens, and Greta Golden at Johns Hopkins University to prepare a literature review on EBD. The result, *Status Report (1998): An Investigation to Determine Whether the Built Environment Affects Patients' Medical Outcomes*, is one of the first attempts to systematically review existing studies relating to EBD topics. Researchers found 84 studies produced since 1968 that met specified criteria, assessed their scientific merit, and classified them into four primary categories: (1) randomized control trial, (2) experimental, paired, (3) observational, paired, and (4) observational, unpaired, nonrandom assignment. The team proposed a conceptual "Environment-Outcome Interface" model, suggesting three ways that features of the physical environment might impact a patient's rate of recovery (**Figure 13**). According to the model, the environment may

> (1) support or hinder a caregiver's actions and medical interventions
> (2) impair or strengthen a patient's health status and personal characteristics
> (3) protect a patient from or expose him or her to causes of illness
>
> (Rubin et al. 1998)

Figure 13. The Johns Hopkins' *Environment-Outcome Interface Model*

From Rubin, H. R., Owens, A. J., and Golden, G. (1998). "Status Report (1998): An Investigation to Determine Whether the Built Environment Affects Patient's Medical Outcomes." The Center for Health Design.
Reprinted with permission from the Center for Health Design.

Five years following publication of the Rubin report, Ann Devlin and Allison Arneill from the Department of Psychology at Connecticut College examined three areas of research: patient involvement with healthcare (the role of patient control), the impact of the ambient environment (e.g., sounds, light, art), and specialized building types for defined populations (such as Alzheimer's patients) (Devlin and Arneill 2003).

One year later, a milestone literature review on EBD appeared. The review team was jointly led by now University of Texas A&M professor, Roger Ulrich, and Georgia Tech professor, Craig Zimring, both teaching and researching professors in departments of architecture. The review, entitled, *The Role of the Physical Environment in the Hospital* *of the 21st Century: A Once-in-a-Lifetime Opportunity*, identified 600 rigorous studies and assessed their scientific merit, evaluating them using an academic letter grade scale. After assessing the literature, the team called for facility design decision-makers to:

- *Reduce staff stress, health, and safety* through environmental measures, such as improved ventilation, ergonomic design, better designed nursing stations, improved lighting, and floor plans that reduce the need for staff to walk great distances;
- *Improve patient safety* by controlling hospital-acquired infections with HEPA filters and single-patient (rather than multi-patient) rooms and with sinks and/or alcohol-based hand-rub dispensers in each room for staff use between patients, reducing medical errors by installing improved lighting, and reducing patient falls by introducing wider bathroom doors; and
- *Reduce stress and improve outcomes* by eliminating noise, improving way-finding, introducing bright light, visions of nature, positive distractions, gardens, art, and comfortable areas for families and friends to offer social support, and enhancing communication between staff and patient.

(Ulrich et al. 2004)

The Ulrich and Zimring team found evidence pointing to a number of factors that may reduce length of stay and increase patient satisfaction with the quality of care they receive. They cite data demonstrating that appealing hospital rooms lead to more positive evaluations of physicians and nurses as well as more favorable patient judgments of service (Swan et al. 2003). This is significant because environmental satisfaction has been demonstrated to substantially predict overall satisfaction, second only to perceived quality of nursing and clinical care (Harris et al. 2002).

EBD claims are being investigated outside the US as well. A team from the University of West England, Bristol, published a literature review for the Centre for Public Health Research on the impact of visual arts on patient health (Daykin and Byrne 2006). In 2008, the Health and Care Infrastructure Research and Innovation Centre in the UK (HaCIRC) published a report “The Effects of the Built Environment on Health Outcomes” (Codinhoto et al. 2008) in response to expressed goals by the UK’s Department of Health to (a) reduce waiting time, (b) reduce patient length of stay, (c) reduce use of medicine, (d) increase staff time per patient in hospitals, (e) increase staff work effectiveness, and (f) improve the national healthcare experience for patients (Department of Health 2004).

However, despite growing enthusiasm, EBD is not without its critics. An article by researchers at the University of Twente in the Netherlands (Dijkstra et al. 2006) argues that of 500 potentially relevant EBD studies, only 30 pass highly rigorous scientific criteria. They suggest that since conclusive evidence is so limited, it is premature to formulate EBD guidelines for healthcare environments. David Chambers, Director (Planning Architecture & Design) of Sutter Health criticizes EBD proponents for focusing on the patient in the bed, and recommends advocates should instead acknowledge the increasing role that ambulatory care is beginning to play (Chambers 2006). Some long-time facility design practitioners who have witnessed the rise and fall of various “flavor-of-the-month” design trends have expressed concern about the staying power of EBD (Mazurek 2007).

Nevertheless, advocacy groups have been pushing forward with the adoption of EBD (**Figure 14**). A number of papers by Anjali Joseph (Joseph 2006a; 2006b; 2006c), Director of Research of the Center for Health Design, have served as a bridge between academic research and decision-makers who seek to implement its findings.

3.2 Adoption of EBD into standards

An extensive review of the literature regarding the advantages and disadvantages of single-patient rooms versus multi-patient rooms by Habib Chaudhury at Simon Fraser University in Canada (Chaudhury et al. 2003) has resulted in the recommendation of single patient rooms over multiple occupancy rooms for acute care environments in the *AIA Guidelines for Design and Construction of Health Care Facilities* (The Facility Guidelines Institute et al. 2006).

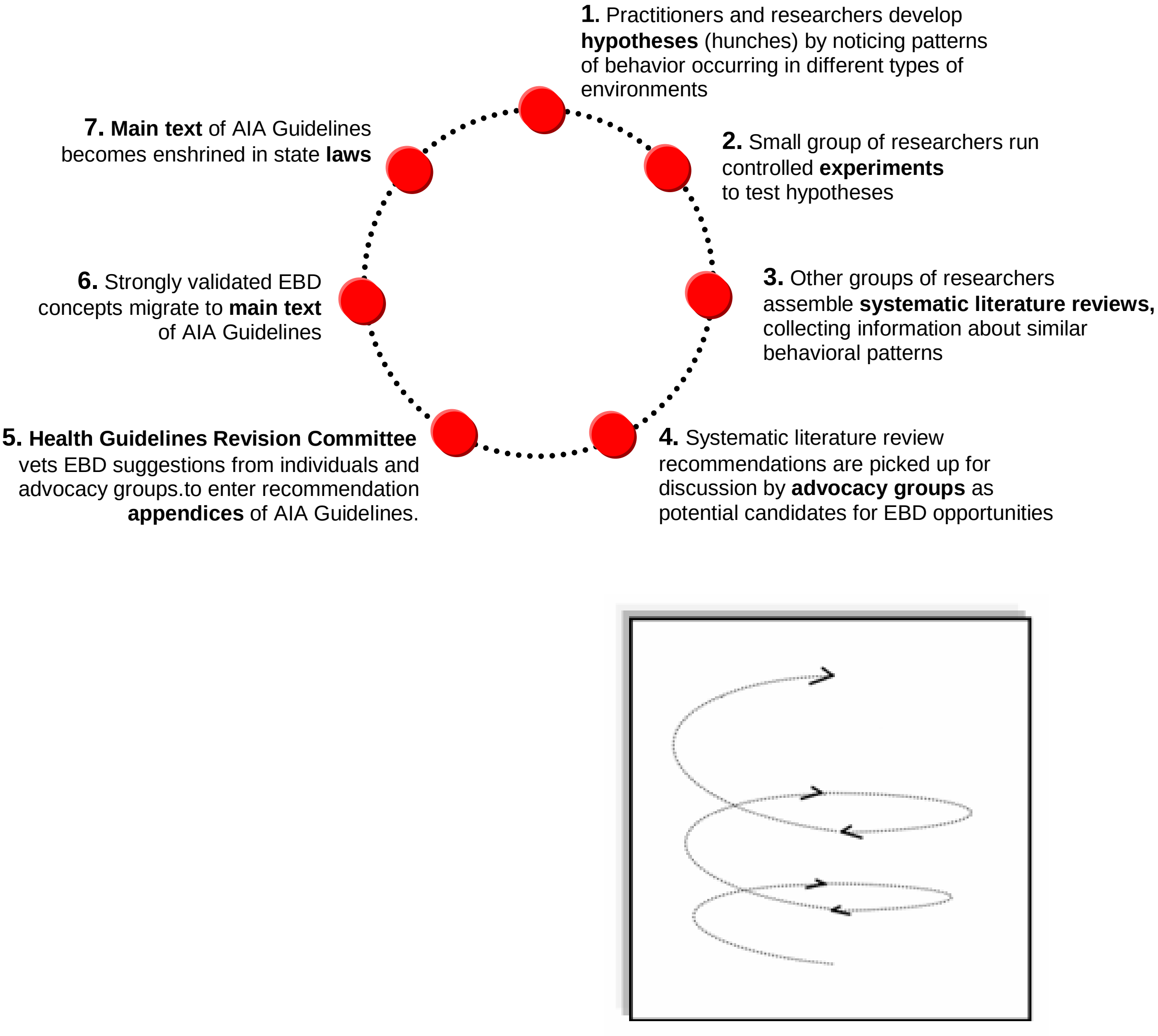


Figure 14. The iterative nature of the EBD standardization process.

(Ballard and Rybkowski 2007)

The EBD standardization process is one of continual improvement. Although more like a spiral that becomes richer as it climbs (below), the process is shown in plan view for simplicity (above).

The AIA guidelines do not, in and of themselves, carry the force of law; however many states include sections of the guidelines as part of their building codes, which *are* enforceable by law (Blumgart 2007).

3.3 Multidisciplinarity of EBD

EBD knowledge is drawn from many disciplines; researchers come from a variety of fields, including biology, psychology, architecture, sociology, anthropology, marketing, and engineering. For example, EBD reviewers Ann Devlin and Allison Arneill represent themselves as psychologists. Although Roger Ulrich earned his PhD in human/behavioral psychology and Craig Zimring defines himself as an environmental psychologist, both teach in departments of architecture, at Texas A&M and Georgia Tech, respectively. Leonard Berry is a professor of marketing; Karin Dijkstra comes from a department of marketing communication and consumer psychology. Our own Department of Civil and Environmental Engineering at UC Berkeley is also engaged in research on EBD, under the direction of Dr. Glenn Ballard.

Not yet mentioned is the work by Eve Edelstein, a neurobiologist who has been awarded the AIA College Fellows Awards 2005 Latrobe Fellowship, along with team members from academia (UC Berkeley) and industry (Chong Partners and Kaiser Permanente) to examine the physiological link between healthcare facility design and faster healing rates in patients (American Institute of Architects 2005; Edelstein 2007).

Key milestones in the development of EBD are summarized in **Figure 15**.

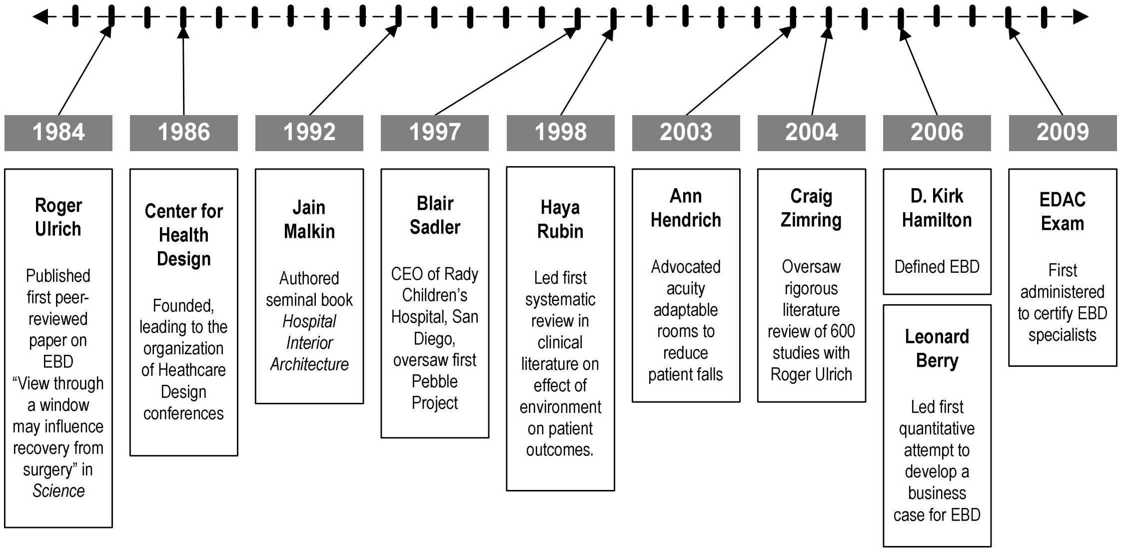


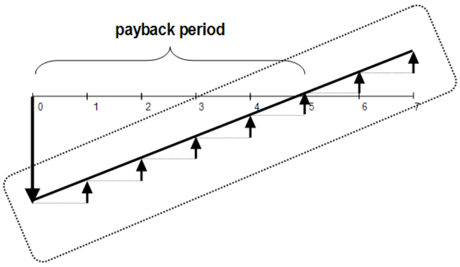
Figure 15. Milestones in the development of EBD

Compilation and graphic by author.

This chapter has set the context for Evidence-Based Design research—as a social movement as well as a science.

We will now transition to the first of my primary research questions: How might we increase accuracy of—and therefore confidence in—predictions made about long-term savings resulting from implementation of Evidence-Based Design interventions?

Chapter 4



The purpose of this chapter is to develop a framework to increase confidence in long-term cost saving predictions associated with implementation of Evidence-Based Design interventions.

This chapter links Evidence-Based Design to Root Cause Analysis used by lean thinking, tests the resulting framework with actual data and discusses its viability as a potential strategy for making financial predictions.

4.0 Part I: Long-term financial savings

4.1 The Dilemma: How much can EBD save a project long-term?

4.1.1 Overview: Link between EBD and capital budgeting

One key benefit of EBD, as suggested by its advocates, is its ability to offer potentially measurable long-term financial savings to those who adopt it.

Various scholars of building design and construction, such as Paulson (1976) and MacLeamy (MSA 2004), have suggested that the ability to influence a project is greatest during the earliest stages of deliberation and design—when costs per change are lowest.

For example, the decision about whether or not to orient a building's fenestration southward to capture the rays of the sun can substantially influence the building's energy use over the life of that building. Making this decision early in the design process costs very little. However, as consultants add details to the design and the various trade partners become increasingly involved, modifying the building's orientation becomes more expensive. The influence-cost relationship diagram has been adapted and simplified, taking several forms; one is shown in **Figure 16**. The implications of the diagram is that EBD-influenced decisions should be made as early as possible during the planning stages of a project because trying to implement changes to a design to accommodate EBD inputs later in the process is more costly.

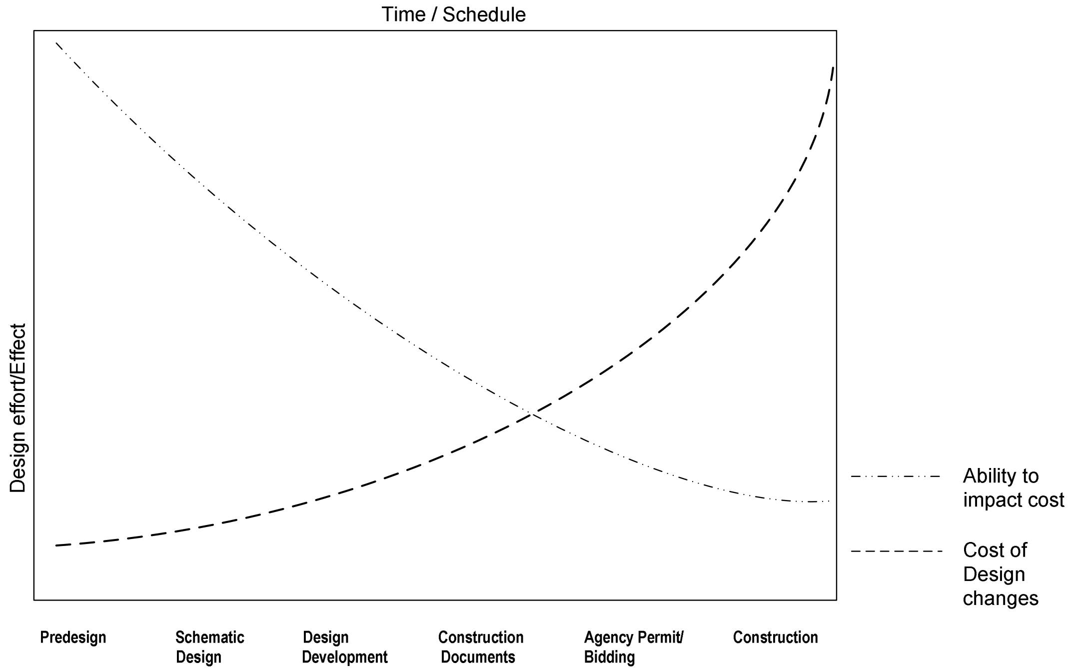


Figure 16. Simplified relationship between ability to impact cost, cumulative cost commitment and time

Adapted from Paulson (1976); Barrie and Paulson (1992) and MacLeamy (MSA 2004).

Capital budgeters wishing to implement EBD need to weigh the additional incremental capital costs—if any—associated with EBD interventions against potential incremental savings over the life cycle of the building. In this chapter, we explore the potential financial benefits of EBD, and link them to the use of Life Cycle Cost Analysis (LCCA) or Benefit-Cost Analysis (BCA) models.

4.1.2 Early financial case for EBD

In 2004, a multi-disciplinary team of academics and practitioners published “The Business Case for Better Buildings” (Berry et al. 2004). The paper represented an early attempt to financially quantify incremental benefits and costs associated with EBD, based on data from early Pebble Project case studies. The team created a “Fable Hospital, a composite of recently built or redesigned healthcare facilities that have implemented facets of evidence-based design.” The imaginary $240 million facility has 300 beds and provides a comprehensive range of inpatient and ambulatory services, including medical/surgical, obstetrics, pediatrics, oncology, cardiac and emergency.

Included in the fable hospital are features based on EBD principles:

- Larger private patient rooms
- Acuity-adaptable rooms
- Larger windows
- Larger patient bathroom with double-door access
- Hand-hygiene facilities
- Decentralized nursing substations
- Additional HEPA filters
- Noise-reduction measures
- Additional family/social spaces on each patient floor
- Health information resource center for patients and visitors
- Meditation rooms on each floor
- Staff gym
- Art for public spaces and patient rooms
- Healing gardens (interior and exterior)

By the authors' calculations, the investment required above a typical hospital's construction cost totals approximately $12 million, or 5% of the facility's capital cost.

Using actual metrics from Pebble Project case studies, the authors claim EBD interventions benefit the Fable Hospital in the following ways:

- Patient falls (reduced)
- Patient transfers (reduced)
- Hospital-acquired infections (reduced)
- Drug costs (reduced)
- Nursing turnover (reduced)
- Market share (increased)
- Philanthropy (increased)

Berry et al. (2004) estimate these interventions can lead to a total increase in revenue and savings of nearly $11,500,000 within 12 months after opening. Thus, by the author's calculations, the additional investment of $12 million would likely be paid for with the incremental savings in just a little over a year.[2] After the payback period, long term financial savings then begin.

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[2] The Berry et al. article uses an undiscounted cost-benefit analysis estimation of value to make its argument. Although discounting is considered standard practice for engineering economy calculations, the authors' decision is probably appropriate given that the financial costs and benefits are rough estimates and occur approximately within a year, rendering time-value-of-money concerns negligible.

4.1.3 Life Cycle Cost Analysis (LCCA) and EBD

Kirk and Dell'Isola (1995) estimated that the long-term costs associated with a hospital throughout its life may represent just 6% of its total costs, as shown in **Figure 17**.

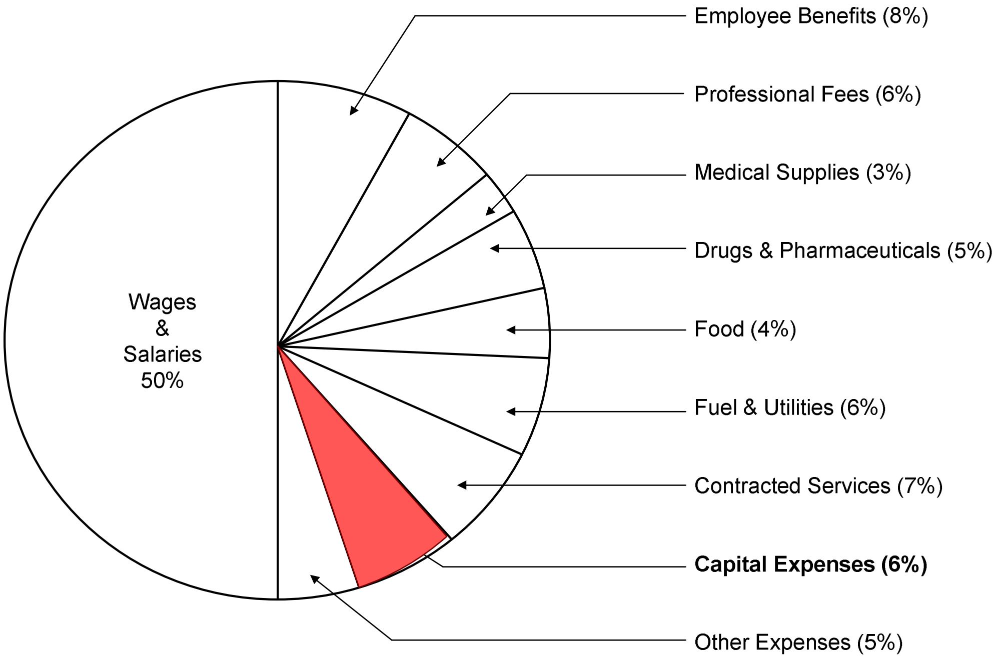
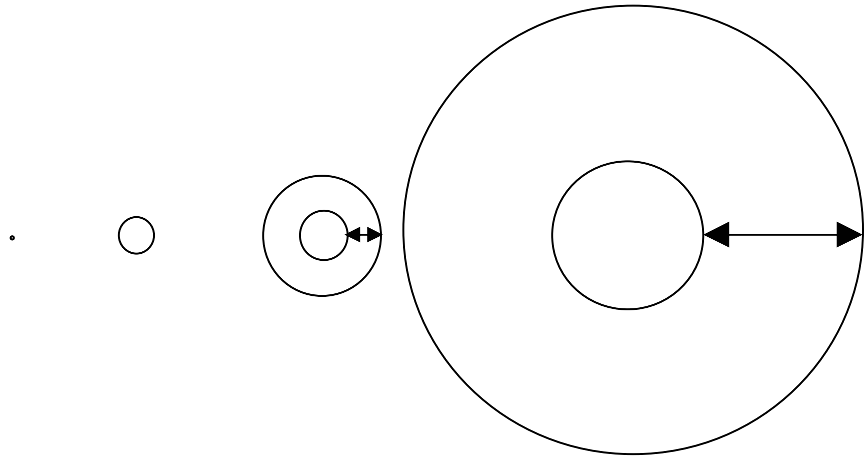


Figure 17. Total cost of ownership for a typical hospital
Adapted from Figure 1-3, Kirk and Dell'Isola (1995).

In a similar spirit, the Royal Academy of Engineering suggested that the ratio, (Construction)☹Maintenance Building and Building Operating Costs)☹Business Operating Expenses), should be considered on the order of 1 : 5 : 200 (Evans et al. 1998). The precise magnitude of this ratio has been disputed (Ive 2006). Nevertheless, because total cost of ownership is undeniably greater than the capital expenses associated with the project, there is growing support that life cycle costs should be considered when making capital budgeting decisions (**Figure 18**) (Boussabaine and Kirkham 2004; Kirk and Dell'Isola 1995; Langston 2005; Saxon 2005; U.S. Department of Transportation 2002).



Design cost	**Construction cost**	**Maintenance & building operating costs**	**Business operating costs**	*Citation*
0.1	1	5	200	(Evans et al. 1998)
0.1	1	1.5	15	(Ive 2006)

Figure 18. The long term costs of owning and using buildings

Adapted and adjusted from Ive (2006) and Evans et al. (1998).
The double-headed arrows represent the range of total costs per category proposed.

Calculating life cycle costs requires an understanding of the concept of value. Definitions of value are varied (Thomson et al. 2003). The one adopted during this research was offered by Richard Saxon in *Be Valuable: A Guide to Creating Value in the Build Environment* (2005):

$$\text{Value} = \frac{\text{What you get}}{\text{What you give}} \qquad \text{(Saxon 2005)}$$

This definition is similar to that of Life Cycle Cost Analysis (LCCA), Benefit-Cost Analysis (BCA) and the Savings-to-Investment Ratio (SIR), the latter ratio being most useful when savings are a primary benefit. The rationale behind these tools has been defined by ASTM, as well as by a number of authors (ASTM April 2006a; Boussabaine and Kirkham 2004; Bull 1993; Kirk and Dell'Isola 1995; Langston 2005).

4.1.3.1 LCCA and resistance from industry to use LCCA

Despite the fact that the LCCA methodology has been relatively well developed, industry members are still reluctant to use it. A number of reasons for this are summarized in **Table 2**. It is my impression, through informal discussions with practitioners in the field, that the first two items listed—uncertainty of forecasted costs and the barrier of first cost regardless of magnitude of long-term benefits—are two significant reasons for not using LCCA. The uncertainty argument may seem intuitively obvious. As for the concern regarding barrier to first cost, even if LCCA calculations suggest long-term investment might be favorable, the first cost expense must initially be met in order for the investment to take place at all.

Table 2. Reasons industry decision-makers do not currently use LCCA

• Forecasting of future costs as well as categories of costs is uncertain (data difficulties)	(Ashworth 1993; Clift and Bourke 1999)
• Higher first cost is a considerable hurdle (despite excellent IRR)	(Moore 2001)
• Life expectancy of building and its parts is uncertain	(Ashworth 1993)
• Technological changes may render building, and/or its parts, obsolete	(Ashworth 1993)
• Fashion changes may make building obsolete	(Ashworth 1993)
• Cost and value change over time (inflation varies as well as prices—i.e., petroleum)	(Ashworth 1993)
• Policy and decision-making changes (i.e., tax structures)	(Ashworth 1993; Clift and Bourke 1999)
• Capital cost estimations, also needed for LCCA, are frequently inaccurate	(Ashworth 1993)
• Capital and operating budgets are often separate	(Al-Hajj and Horner 1998; Cole and Sterner 2000)
• First costs are certain, seem real and easy to calculate	(Clift and Bourke 1999; Flanagan et al. 1987)
• Design team will not volunteer to undertake LCCA unless a client is willing to pay for it	(Cole and Sterner 2000)
• If an owner decides on a project, she will usually remain committed to it, regardless of the results of LCCA	(Cole and Sterner 2000)
• Intangible factors often influence a decision (i.e., Perception of good will may be more important than cost, as with healthcare)	(Clift and Bourke 1999)
• LCCA software is not standardized	(Clift and Bourke 1999)

A number of strategies have been proposed to encourage greater usage of LCCA. Two of these include: (1) Enhanced education about the merits of LCCA, and (2) improved availability of cost and performance data (Clift and Bourke 1999; Cole and Sterner 2000).

4.1.3.2 Addressing industry concerns

Although future forecasts cannot be predicted with absolute accuracy, uncertainty can be addressed using (a) sensitivity analysis, or (b) probabilistic LCCA software. The former approach indicates how much the result is affected by changes in critical economic variables; the latter helps indicate if the ranking of two alternatives is conclusive (Cole and Sterner 2000).

4.2 The Proposed Solution: Quantification of EBD

In order to quantify long-term financial benefits associated with EBD, it is first necessary to understand how these benefits may be quantified. For this we turn the discussion to Evidence-Based Medicine (EBM).

Manipulating the environment is a form of medical treatment; we therefore need to understand EBM in order to achieve the requisite rigor and quantification of benefits attained. In response to this, the following sections will explore the development of EBM literature reviews, for the purpose of determining how EBD might benefit from EBM lessons learned.

4.2.1 Harnessing lessons learned about literature reviews from Evidence-Based Medicine (EBM)

The well-designed research experiment resides at the heart of EBM. However, it is unreasonable to expect practitioners and policy-makers to unearth, read and digest the vast number of primary research articles published each year. In 1987 alone, it was reported that 2,000,000 articles were published in 20,000 journals (Ad Hoc Working Group for Critical Appraisal of the Medical Literature 1987).

Literature reviews help bridge the gap and solve this dilemma. Once results are reported in peer-reviewed journals and industry publications, the reviewer is able to draw together an accumulated understanding from research results on a similar topic. There are various types of reviews; **Figure 19** summarizes these, emphasizing their differences graphically. While anecdotal observations are not considered reviews, per se, they might be considered the first form of generalization as they represent an individual's observation of repeated patterns of behavior or outcome.

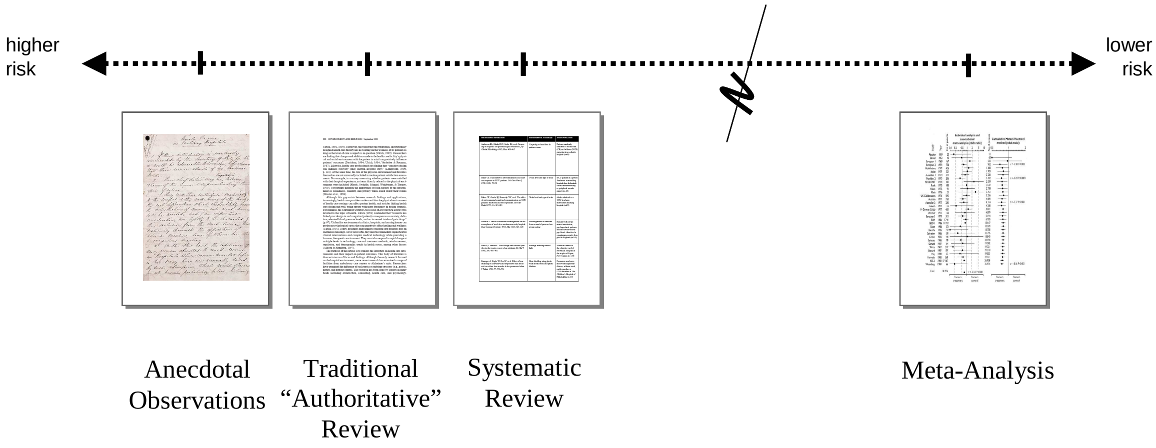


Figure 19. Types of literature review according to acknowledged level of rigor

Historically, “authoritative reviews” were conducted by invitation only. Editors engaged recognized experts to survey the literature of a field. On the surface, this assumption seems reasonable. However, in reality, the correlation between reviews by multiple experts has been poor (r=0.19-0.54) (Oxman and Guyatt 1993). In the rest of this report, this type of authoritative review will be referred to as the *traditional review*.

Systematic reviews, by contrast, evolved as a reaction against traditional reviews, which tend to represent ad hoc compilations of past research reflecting the bias of the individual reviewers.

Mulrow (1994) cites a number of reasons why the scientific community should collaboratively focus on constructing systematic reviews. Her reasons include:

- Since quality of experiments and results vary, decision-makers need integrated knowledge to make prudent decisions. Once experimental results are integrated systematically, it is possible to make generalizations about a topic.

- A well-conducted review, although expensive, is less costly than many scientific experiments, and ensures that funds are not wasted by reproducing existing knowledge.

Systematic reviews help to overcome the shortcomings of traditional reviews that can be haphazard and reflect the personal bias of the reviewer.

4.2.1.1 Conducting a systematic review

Systematic reviews share certain procedural traits. A number of authors recommend specific methodologies. For example, Mullen and Ramírez (2006) recommend a nine-step strategy for a proper systematic review:

1. Specify the study's aims
2. Set inclusion criteria for participants/evidence
3. Design the recruitment/search strategy
4. Screen potential participants/evidence against inclusion criteria
5. Decide on measures and design the data collection protocol
6. Select an appropriate metric to represent the magnitude of the findings and assess the likelihood that these findings could be the result of chance
7. Collect the data/code the primary studies
8. Analyze and display the data using appropriate methods, and
9. Draw conclusions based on the data and discuss alternate interpretations in view of the study's strengths and limitations.

(Mullen and Ramírez 2006)

It is helpful to discuss a few hallmarks of a systematic review in greater detail:

- Because there are so many articles with varying characteristics, Carl Counsell (1997) suggests that inclusion criteria be established with a properly formulated question. This question should comprise four specific parts, labeled (a), (b), (c) and (d). They include the type of: (a) *intervention*, (b) *outcome* anticipated, (c) *person* involved, and (d) *control* to which the exposure is being compared. In EBD research, an appropriate screening question might therefore be written as follows: Does (a) regular hand washing by caregivers (b) reduce incidence of nosocomial infection in (c) ICU patients compared to (d) situations where hand washing is not enforced? This type of question establishes criteria against which reviewers can decide whether or not an article qualifies for inclusion in a review.

- To guard against variability and personal bias during the review process, it is suggested that researchers enlist at least two independent screeners who develop explicit inclusion criteria, and evaluate articles based on the same criteria. They should compare results and achieve consensus. There is also a danger that reviewers may unknowingly express screening bias by recognizing an article’s author. To mitigate this potential bias, researchers might consider coding authors’ identities. Screeners should look for quality, quantity, consistency, and coherence of evidence when evaluating articles (Mullen and Ramírez 2006).

- Reviewers also need to guard against publication bias. A number of researchers warn against the tendency to restrict a search to articles published in peer reviewed journals and only in the English language (Dickersin and Min 1993; Mullen and Ramírez 2006). Also, there is a tendency for journals to publish only positive results. Much good work exists outside of these boundaries.

Reviewers should search article databases extensively and internationally, seeking out "fugitive literature." One researcher suggests a literature search should include mining databases such as MEDLINE, EMBASE, BIOSIS, CINAHL, PsychLit, CancerLit, Dissertation Abstracts, and SIGLE (for unpublished literature). A thorough search should also include a manual page-by-page examination of conferences and journals because many articles are not properly indexed (Counsell 1997). Sources of information may come from human and non-human research, as well as from prior literature reviews (Mulrow et al. 1997).

4.2.1.2 Levels of evidence

A fundamental assumption of evidence-based design is that not all evidence is considered to be of equal merit. The U.S. Preventative Services Task Force ranks evidence according to the following categories:

- Level I: Evidence from one or more randomized controlled trials
- Level II-1: Evidence from controlled trials, but no randomization
- Level II-2: Evidence from cohort or case-control studies
- Level II-3: Evidence from multiple time series
- Level III: Expert opinion based on clinical experience

(U.S. Preventive Services Task Force 1996)

Level I evidence—that which comes from randomized controlled trials—is deemed the most reliable because a control group eliminates confounding variables, and double blind randomization removes potential bias of both experimenter and subjects. Level III—expert opinion—is considered the lowest level of evidence because judgments have been shown to vary between individuals. Between these two extremes exists a spectrum of varying certainty. Level II evidence, for example, is considered less rigorous than Level I but is often necessary for ethical or practical reasons. Level II-1 evidence exists because it is not always possible to randomly assign characteristics, such as gender, to experimental subjects. Similarly, Level II-2 evidence acknowledges that it would be unethical to randomly assign research subjects to partake in certain types of behavior, such as smoking cigarettes. Therefore, another type of experimental study—a case control study—compares subjects who already embody a condition of interest against those who do not. While cohort studies identify a study group before a characteristic such as a disease or smoking tendency emerges, a case control study identifies and compares subjects who have already developed a phenomenon of interest against those who have not. A cohort study offers greater certainty than a case control study since information is recorded as it happens (case control studies, by contrast, rely on the potentially faulty memories of subjects). But, case control studies are less expensive than cohort studies; researchers study a phenomenon retrospectively—after it has already occurred. Level II-3 evidence introduces an intervention at a point in time and observes if there is a concurrent alteration to the population under investigation. This level of evidence is common for infection control studies, especially during an epidemic. Level II-3 evidence is not considered to be of the same level of rigor as the levels of evidence previously discussed because changes in outcome may be coincidental, e.g., drops in infection rate may be due to natural seasonal variations of the bacteria being studied.

Categorizing evidence according to rating levels may seem simple. But highly rated evidence is not easy to obtain. For example, a recent comprehensive integrative review of 1120 articles on hand hygiene and its impact on healthcare-associated infections yielded inconclusive results (Backman et al. 2008b) because reviewers found many of the published experiments riddled with confounding variables, as shown in **Table 3**.

Table 3. Example of fatal flaws in quasiexperimental before and after studies

1. Unblinded intervention or prospective study with 1 or more of the fatal flaws sufficient to weaken confidence in the study’s conclusions
2. Unblinded intervention or prospective study with 1 or more other flaw, but none is fatal to negate the conclusions
3. Intervention or prospective observational study with no fatal or other flaws not accounted for by study authors
4. Blinded randomized controlled trial (RCT) with no fatal or other flaws

Fatal flaws:

I. Inadequate sample size
II. Uncontrolled bias or confounding (e.g., No evidence or interrater reliability, unclear participant inclusion criteria, data collection unblended)
III. Unclear operational definitions or description of intervention
IV. Inadequate (or no) statistical analysis
V. Lack of evidence that intervention was actually implemented

(Backman et al. 2008b)

Despite the challenges, however, sorting through publications and rating the quality of available evidence is central to the Evidence-Based decision-making as it is currently practiced in Medicine (Cochrane Collaboration 2007).

4.2.1.3 Challenges of reviews

Systematic reviews have been adopted slowly by the scientific community in many areas of medical research. Some of the challenges involved with the preparation of a systematic review are:

- The time required to prepare a review is usually grossly underestimated. Because of this, many well-intentioned reviewers have neither the time nor the resources to prepare a high quality review (Chalmers 1993).

- The heterogeneity of data sources makes it difficult to combine evidence (Counsell 1997; Mulrow et al. 1997). Identifying, downloading and screening thousands of articles often requires time and resources far beyond those available. Therefore, a number of researchers have recommended standardizing the format of data reporting—including the abstract—so that methodologies and results can be more efficiently subjected to collective statistical analyses (Mullen and Ramírez 2006; Sandercock 1993). However, this type of experimental design and data reporting requires a level of collaboration that is not always easy in a culture that tends to value research independence.

In other words, just as not all experiments are equally meritorious, not all literature reviews are equally useful and reliable. EBM derives its impetus from the methodological precision of the systematic review; EBD would benefit by heeding lessons learned by EBM.

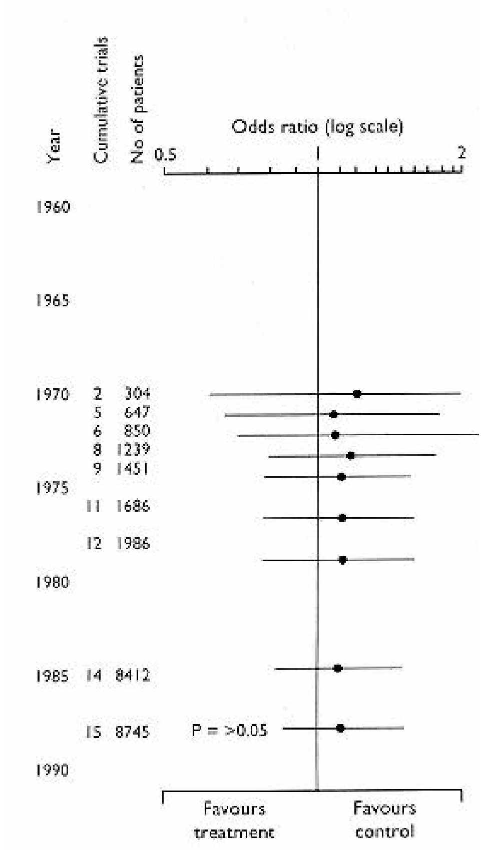
4.2.1.4 The diamond of literature reviews: The Cumulative Meta-Analysis

A subcategory of systematic review is the *cumulative meta-analysis*. Although now generally a stabilized term, nomenclature for this type of review has varied from “meta-evaluation,” and “research synthesis,” to “integrative review” (Mullen and Ramírez 2006).

A meta-analysis can be defined as “the statistical combination of studies to produce a single estimate of the healthcare intervention being considered” (Buendia-Rodriguez and Sanchez-Villamil 2006; Mullen and Ramírez 2006). Because it represents the quantitative compilation of numerous primary studies, a meta-analysis has been called a “tower of statistical power” (Mulrow 1994). By combining results from various sources, one is able to determine statistical significance with greater accuracy, thus rendering the final result more meaningful.

Mulrow (1994) cites Antman et al. (1992) as an exemplary case where traditional literature review recommendations lagged far behind the current state of research on a medication, prophylactic lidocaine, administered to patients with acute myocardial infarction. In 1990, data collected from 15 randomized trials and subjected to statistical meta-analysis demonstrated no mortality benefit associated with prophylactic lidocaine for acute myocardial infarction. However traditional reviews continued to recommend the administration of prophylactic lidocaine, despite statistical evidence to the contrary (**Figure 20**). By contrast, a cumulative meta-analysis of 33 trials indicates that another medication, streptokinase, is effective in treating cases of acute myocardial infarction.

Mulrow argues streptokinase’s effects were determined to be statistically significant (within a 95% confidence interval) as early as 1973—20 years before it was approved by the US Food and Drug Administration and its use generally adopted (**Figure 21**). Because of this misjudgment in the traditional review literature, more effective treatments to reduce myocardial infarction mortality, such as streptokinase, were not recommended as often as they might have been—likely resulting in unnecessary health complications or deaths.



Textbook/review recommendations for giving lidocaine

	Routine	*Specific*	*Rare/Never*	*Experimental*	*Not mentioned*	
		17			4	1966
		4			1	
	2	7	1		1	1970
		3				
		8			2	1974
	1	4			2	
	4	2		1	1	1978
	4	8			1	
	5	6			2	1982
	3	5			3	
M M	4	2		1	3	1986
M	5	9	4		6	
	1	3	2		1	1990

Figure 20. Cumulative meta-analysis versus traditional review

Results of the meta-analysis done by Antman et al. (1992). The meta-analysis indicates that the prophylactic lidocaine served no mortality benefit in cases of myocardial infarction (left). This was not the result that had been suggested by the traditional review (right). "M" indicates that meta-analyses appeared in the literature from 1986-1987.

From Antman, E. M., Lau, J., Kupelnick, B., Mosteller, F., and Chalmers, T. C. (1992). "A comparison of results of meta-analyses of randomized control trials and recommendations of clinical experts: Treatments for Myocardial Infarction." *JAMA*, 268(2), 240-248. Reprinted with permission.

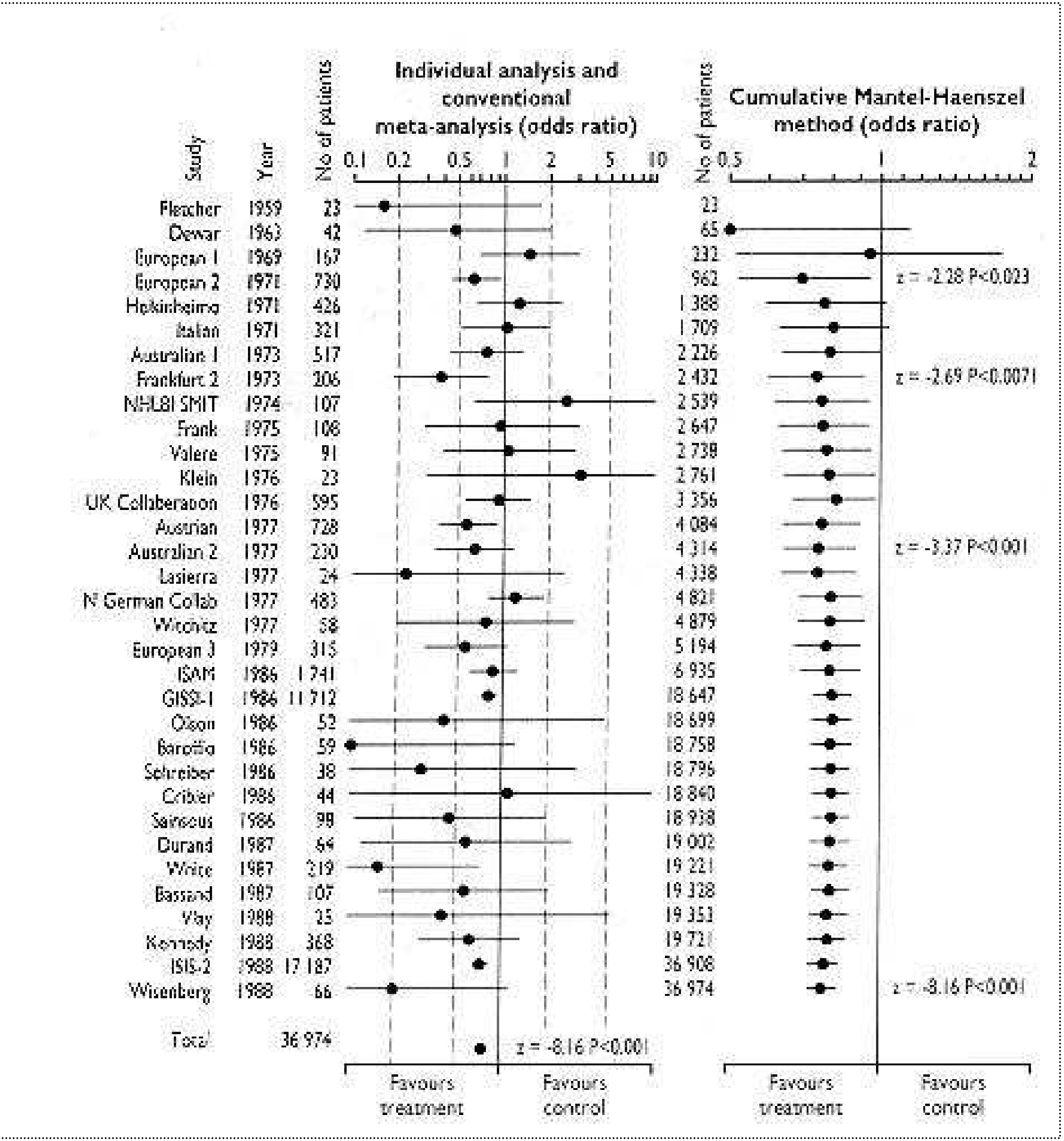


Figure 21. Conventional meta-analysis versus cumulative meta-analysis

A meta-analysis demonstrating the advantages inherent in pooling cumulative results from homogeneous randomized controlled trials.
Treatment was shown to be favored as early as 1973.

Reproduced from Mulrow, C.D. (1994). “Systematic reviews: rational for systematic reviews.” *BMJ*, 309, 597-599, with permission from BMJ Publishing Group Ltd.

Meta-analyses are done on the causal relationship between a single feature of the designed environment and desired outcomes. In the best of all worlds, EBM and EBD meta-analyses would exist for all causal relationships, and scored reviews could then evaluate the various studies done on specific relationships using quantitative methods. Where such quantitative methods cannot be applied, qualitative evaluation is the next best option and can also be included in scored reviews, with evaluation criteria made explicit.

4.2.1.5 Building literature review synergies: The Cochrane Collaboration

In order to comprehend why cumulative meta-analyses are so important to Evidence-Based Medicine, it is helpful to understand what spurred the genesis of a key organization responsible for their preparation—the Cochrane Collaboration.

An extensive effort in meta-analysis formed as a response to Archie Cochrane's call to improve accuracy of collected information by systematizing the review process. Cochrane's book, *Effectiveness and Efficiency, Random Reflections on Health Services*, published in 1972, set forth straightforward principles, which included developing reviews from randomized controlled trials (RCTs). His principles resulted in the formation of the Cochrane Collaboration, an international not-for-profit organization, that sets a highly rigorous standard for meta-analyses (Cochrane Collaboration 2007). The meaning of the group's logo, the stylization of an actual, historic, meta-analysis of seven RCTs (**Figure 22**), is explained by Iain Chalmers: "Each horizontal line represents the results of one trial (the shorter the line, the more certain the result); and the diamond represents their combined results. The vertical line indicates the position around which the horizontal lines would cluster if the two treatments compared in the trials did not differ in their effects; and if the horizontal line touches the vertical line, it means that that particular trial found no clear difference between the treatments. The position of the diamond to the left of the vertical line indicates that the treatment studied in the trials is beneficial" (Chalmers 1993). In fact, the logo of the Cochrane Collaboration represents actual data from seven RCTs testing an inexpensive corticosteroid's impact on the mortality of fetuses expected to be born prematurely. Chalmers writes: "Because no systematic review of these trials had been published until 1989, most obstetricians had not realized that this treatment was so effective. As a result, tens of thousands of premature babies have probably suffered and died unnecessarily (as well as costing the health services more than was necessary). This is just one of many examples of the human costs resulting from failure to perform systematic, up-to-date reviews of RCTs of healthcare" (Chalmers 1993).

Figure 22. Cochrane Collaboration logo

(Cochrane Collaboration 2007)

Reprinted with permission from the Cochrane Collaboration.

In the same publication, Iain Chalmers wrote about the then-forming Cochrane Collaboration. A lengthy quote is included here because it describes a potential collaborative model to which EBD researchers and reviewers might look should they seek ways to synergistically enhance collaboration.

> “Although the Cochrane Collaboration is still at an early stage of its development, its basic structure and methods of working have been established. Each reviewer is a member of a collaborative review group, which consists of individuals sharing an interest in a particular topic (stroke, for example). Collaborative review groups have often grown out of an ad hoc meeting of people who have recognized that they share an interest in preparing and maintaining systematic reviews of RCTs within a particular field. But review groups have also emerged in other ways. Members of the review group seek funding and other support for their activities from whichever specific sources they consider appropriate. Each of the collaborative review groups is coordinated by an editorial team. The editorial team is responsible for preparing an edited module of the reviews prepared by members of the review group for dissemination through the Cochrane Database of Systematic Reviews…
>
> The pregnancy and childbirth collaborative review group, for example, comprises about 30 reviewers who, collectively, are currently responsible for maintaining between 500 and 600 systematic reviews of RCTs, and for dealing with between 200 and 300 new reports of trials every year. The group includes reviewers in Australia, Canada, Ireland, the Netherlands, South Africa, the United Kingdom, and Zimbabwe. The individual reviewers are responsible for obtaining the resources (of which their time is often the most important) which are needed to prepare and maintain the reviews that fall within their respective areas of expertise. The editorial team coordinating the group consists of four editors, an administrator and administrative secretary, and the work of the team is supported by a grant from the Department of Health for England. Together with members of the collaborative review group, the editorial team is responsible for preparing an edited Pregnancy and childbirth Module for incorporation in the Cochrane Database of Systematic Reviews.”
>
> (Chalmers 1993)

In addition to the Cochrane Collaboration, other organizations dedicated to bringing together collaborators to prepare meta-analyses have emerged in the field of Evidence-Based Medicine. For example, the Evidence-Based Practice Centers program, developed under the wing of the Agency for Healthcare Research and Quality, has established centers at universities and other institutions such as Duke University, Johns Hopkins University, McMaster University, Oregon Health Sciences University, the University of California at San Francisco, Stanford University, Research Triangle, the RAND Corporation and Blue Cross and Blue Shield Association (Institute of Medicine 2001).

The advantage of establishing organizations such as the Cochrane Collaboration and the Evidence-Based Practice Centers program is that they draw reviewers together into a community that maps and maintains knowledge about a specific area of study.

4.2.1.6 Classification of EBD reviews

There is considerable overlap between EBD as applied to healthcare facility design and EBM, as was implied by **Figure 8**. In order to better understand the developing nature of EBD literature reviews, I have classified EBD reviews along a spectrum ranging from qualitative to quantitative review methodologies, diagramed in **Figure 7**. The spectrum is intentionally roomy, allowing for the future insertion of review typologies that may develop as the EBD field matures. The double-headed arrow signifies that these additional types of reviews may evolve at and beyond either end of the spectrum. Each of these categories—as it specifically relates to EBD—will now be discussed in greater detail.

Because EBD is still a developing field with boundaries yet to be fully defined, it has been necessary for reviewers to create rough classifications of collected information. These categories of knowledge first emerged and continue to appear as traditional literature reviews, as described earlier (Devlin and Arneill 2003; Joseph 2006a; 2006b; 2006c; Joseph and Ulrich 2007).

As the field matures, systematic scored reviews have begun to emerge with greater frequency. For example, Rubin et al. restricted their literature review to experimentation that fell within one of four primary areas: (1) Randomized controlled trial, (2) Experimental, paired, (3) Observational, paired, and (4) Observational, unpaired (Rubin et al. 1998). By comparison, Ulrich and Zimring assessed primary research on a typical academic scale, awarding grades that ranged from "A" to "D" (Ulrich et al. 2004). Both review teams reported on recurring patterns of results within categories of EBD-related experimentation. Additionally, Dijkstra et al. argue that of over 500 EBD-related studies found, only 30 met the stringency of their one permissible category—the well-conducted controlled trial (Dijkstra et al. 2006).

As larger numbers of randomized controlled trials start to appear, highly rigorous meta-analyses on EBD topics will emerge. For example, Rabie and Curtis (2006) published a paper on the impact of hand washing on respiratory infections. The review is structured as a meta-analysis. The abstract itself is cleanly organized into the categories of Objective, Methods, Results and Conclusions. The authors pool the results of seven homogenous studies to discover that, on average, hand washing lowers the risk of respiratory infection by 16%. Although the authors specifically exclude studies conducted in hospitals and caution that the pooled studies are of poor quality and limited geographic scope, they also affirm that the "results show a coherent and significant pattern of impact of hand cleansing on (respiratory) infection." For the purpose of understanding how meta-analyses can help healthcare capital budgeters make decisions, let us imagine the study had demonstrated that hand washing reduced nosocomial infections in hospitals (as well as in the community) by 16%, with a 95% confidence interval between 0.11 and 0.21. We could then suggest that equipping sinks or alcohol dispensers in every patient room in a way that demonstrably encourages hand washing can reduce nosocomial infection rates by approximately 16% (Rabie and Curtis 2006). A reported confidence Interval (CI) of 95% means that we would be 95% confident that the actual level of nosocomial infection reduction lies between 11% and 21% (**Figure 23**).

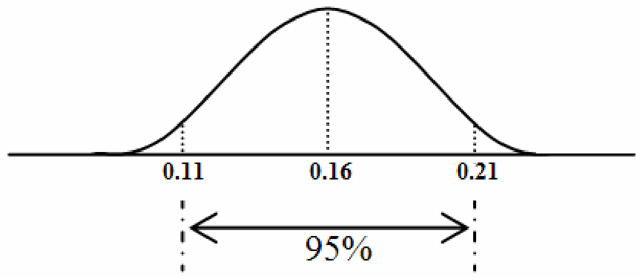


Figure 23. Range of expected results for reduction of respiratory infections associated with hand washing at 95% confidence interval

Adapted from Rabie and Curtis (2006)

Once the quantification of information becomes available and reliable, this information, along with information on the investment required and the costs of infections, can be used by the decision-maker during capital budgeting. Quantifying the link between cause and effect enables estimation of payback periods. For example, in the hand washing example, one could then multiply the outer bounds (11% and 21%) of respiratory infection reduction by the average annual cost of treating respiratory infections in one's own facility, to determine the likely payback period, as well as the range of financial savings expected over the life of that facility.

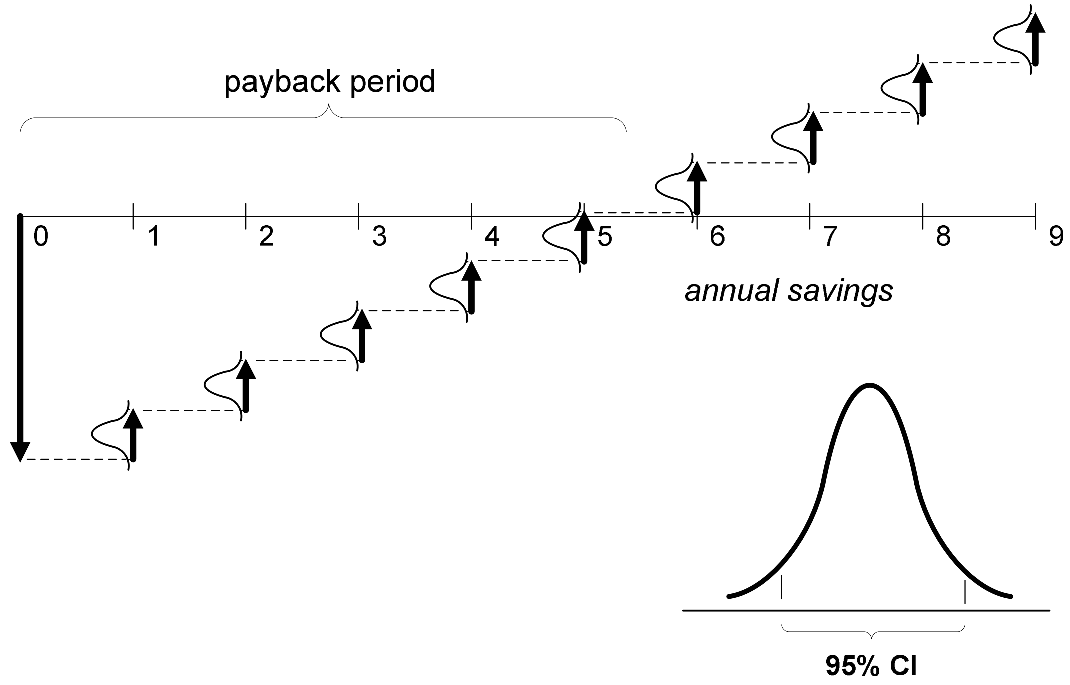


Figure 24. Conceptual application of cost saving using 95% confidence intervals (CI) to a cumulative cash flow diagram

4.3 Need to build a tool

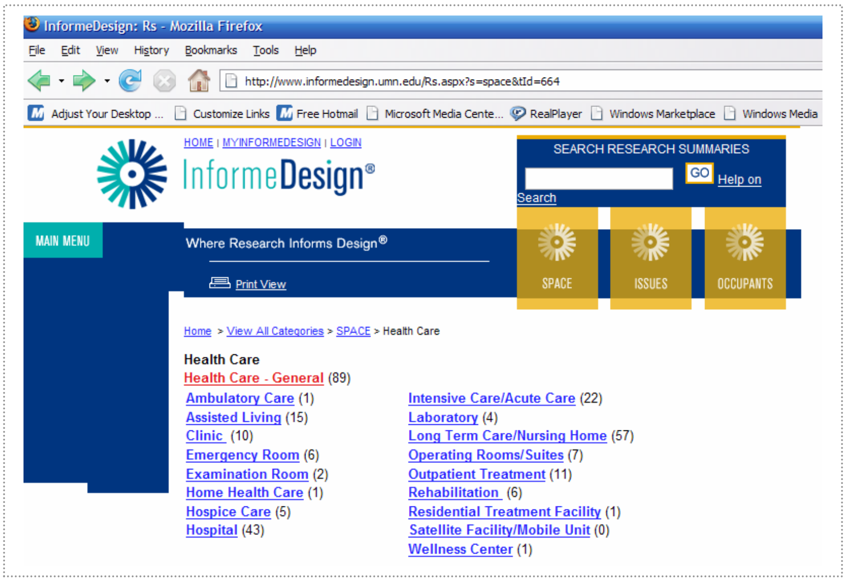
4.3.1 Pre-existing tools

Despite growing interest in EBD and its potential to improve healthcare quality, some owners and designers have expressed frustration over the difficulty of communicating EBD recommendations to their budgeting and design staff. Sorting through research articles can be unwieldy and time consuming. Traditionally, owners and designers have little formal training in scientific research methodology and so are unequipped to make judgments about the validity of published experimental results.

To address these concerns, members of the EBD research community are developing tools to systematize findings and to render recommended EBD interventions easier to comprehend and implement.

Four tools currently in existence or under development are described below:

- *InformeDesign:* Initiated in the fall of 2000 by Denise Guerin, Ph.D. and Caren Martin, Ph.D. of the Department of Design, Housing, and Apparel in the College of Human Ecology, University of Minnesota, this website is constructed as a collaboration between the American Society of Interior Designers and the University of Minnesota. It serves as a searchable clearinghouse for human behavior research. The professed mission of this website is to “facilitate designers’ use of current, research-based information as a decision-making tool in the design process, thereby integrating research and practice.” (InformeDesign 2009). **Figure 25** depicts the website.



Health Care
Health Care - General (89)
Ambulatory Care (1)
Assisted Living (15)
Clinic (10)
Emergency Room (6)
Examination Room (2)
Home Health Care (1)
Hospice Care (5)
Hospital (43)
Intensive Care/Acute Care (22)
Laboratory (4)
Long Term Care/Nursing Home (57)
Operating Rooms/Suites (7)
Outpatient Treatment (11)
Rehabilitation (6)
Residential Treatment Facility (1)
Satellite Facility/Mobile Unit (0)
Wellness Center (1)

Figure 25. The InformeDesign searchable website

Screen print from InformeDesign (2009)

- *EBD Wheel:* Lyn Geboy, PhD, Director of Research and Education of the architectural firm Kahler Slater, depicted the mnemonic in **Figure 26** to assist consultants designing a healthcare facility. Geboy grouped twelve categories of EBD research reviewed by Ulrich et al. (2004) as well as other "high impact studies" (Geboy 2007).

The twelve categories Geboy includes in the wheel are as follows:

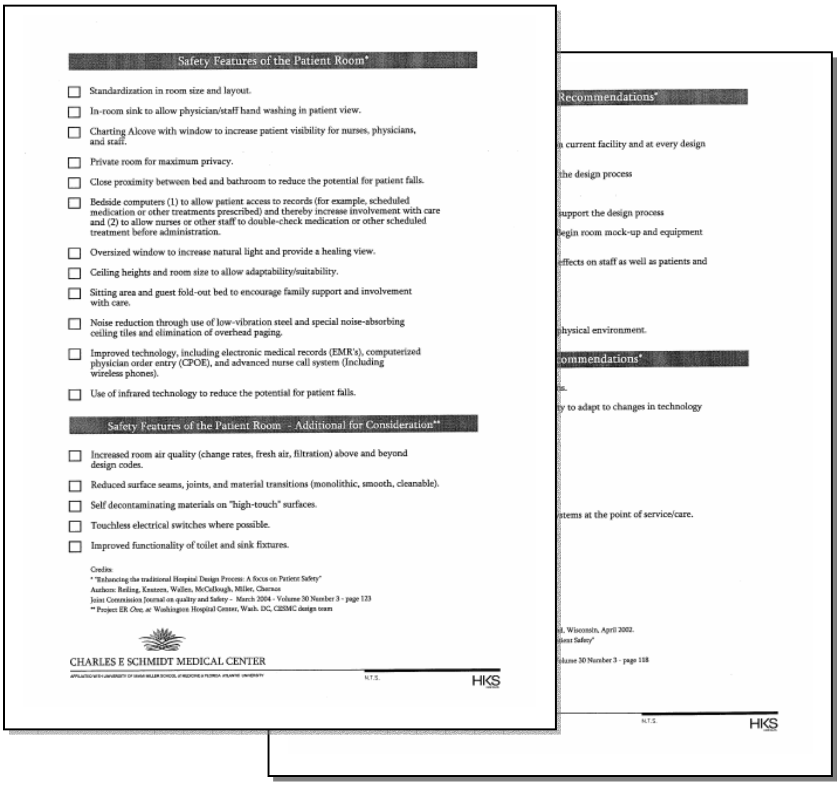
1. Single patient rooms
2. Noise
3. Windows
4. Light
5. Access to nature
6. Positive distractions
7. Furniture arrangements
8. Air quality
9. Flooring materials
10. Wayfinding
11. Building layout
12. Ergonomics

Geboy argues that the wheel has been “very helpful in our efforts to increase designers’ and clients’ knowledge of EBD issues and in fostering clients’ understanding of the negotiated complexities that must be navigated in the course of the healthcare design process. In addition, the wheel has been useful in talking with clients about shortcomings in existing facilities, highlighting responsive features in our own designs, and focusing discussions throughout the design process.” (Geboy 2007).

Figure 26. The EBD Wheel

from Geboy, L. (2007). "The evidence-based design wheel: A new approach to understanding the evidence in evidence-based design." *Heathcare Design*, 7(2), 41-42; reprinted with permission from the author and Kahler Slater Architects.

- *John Reiling's Checklist*: This tool by former CEO of St. Joseph's Hospital in Westbend Wisconsin, was presented and distributed at the Healthcare Design'06 conference in Chicago, IL. A work in progress, it is included here not so much to imply the form was intended to serve as a completed and polished tool, but to illustrate the checklist type of response to EBD that is becoming increasingly common. The list shown in **Figure 27** includes: Safety Features of the Patient Room, Safety Features of the Patient Room (Additional for Consideration), Facility Design Process Recommendations, and Design Principle Recommendations. Some items on the checklist include:
    - Sitting area and guest foldout bed to encourage family support and involvement with care
    - Noise reduction through the use of low vibration steel and special noise-absorbing ceiling tiles and elimination of overhead paging
    - Self-decontaminating materials on "high touch" surfaces
    - Design for maximum standardization



Safety Features of the Patient Room*

☐ Standardization in room size and layout.

☐ In-room sink to allow physician/staff hand washing in patient view.

☐ Charting Alcove with window to increase patient visibility for nurses, physicians, and staff.

☐ Private room for maximum privacy.

☐ Close proximity between bed and bathroom to reduce the potential for patient falls.

☐ Bedside computers (1) to allow patient access to records (for example, scheduled medication or other treatments prescribed) and thereby increase involvement with care and (2) to allow nurses or other staff to double-check medication or other scheduled treatment before administration.

☐ Oversized window to increase natural light and provide a healing view.

☐ Ceiling heights and room size to allow adaptability/suitability.

☐ Sitting area and guest fold-out bed to encourage family support and involvement with care.

☐ Noise reduction through use of low-vibration steel and special noise-absorbing ceiling tiles and elimination of overhead paging.

☐ Improved technology, including electronic medical records (EMR's), computerized physician order entry (CPOE), and advanced nurse call system (Including wireless phones).

☐ Use of infrared technology to reduce the potential for patient falls.

Safety Features of the Patient Room - Additional for Consideration**

☐ Increased room air quality (change rates, fresh air, filtration) above and beyond design codes.

☐ Reduced surface seams, joints, and material transitions (monolithic, smooth, cleanable).

☐ Self decontaminating materials on "high-touch" surfaces.

☐ Touchless electrical switches where possible.

☐ Improved functionality of toilet and sink fixtures.

Credits:
* "Enhancing the traditional Hospital Design Process: A focus on Patient Safety"
Authors: Reiling, Knutzen, Wallen, McCullough, Miller, Chernos
Joint Commission Journal on quality and Safety - March 2004 - Volume 30 Number 3 - page 123
** Project ER *One*, at Washington Hospital Center, Wash. DC, CHSMC design team

CHARLES E SCHMIDT MEDICAL CENTER

N.T.S.

HKS

Recommendations*

n current facility and at every design

the design process

support the design process

Begin room mock-up and equipment

effects on staff as well as patients and

physical environment.

commendations*

ts.

ty to adapt to changes in technology

stems at the point of service/care.

d, Wisconsin, April 2002.
tient Safety"

olume 30 Number 3 - page 118

N.T.S.

HKS

Figure 27. A checklist for safety features

by John Reiling, former CEO of St. Joseph’s Hospital (West Bend, Wisconsin)
(Reiling 2006)

- *A Visual Reference for Evidence-Based Design*, by Jain Malkin: The president of Jain Malkin Inc., a San Diego California interior architecture firm which specializes in healthcare facilities authored this book to serve as a “snapshot in time.” Malkin’s work is intended to inform healthcare facility decision-makers about recent developments in healthcare facility design as well as to help designers visualize what an EBD-inspired healthcare facility might look like. The book is amply illustrated and captioned according to room function, to make visualization easier. A sample illustration is included in **Figure 28**.

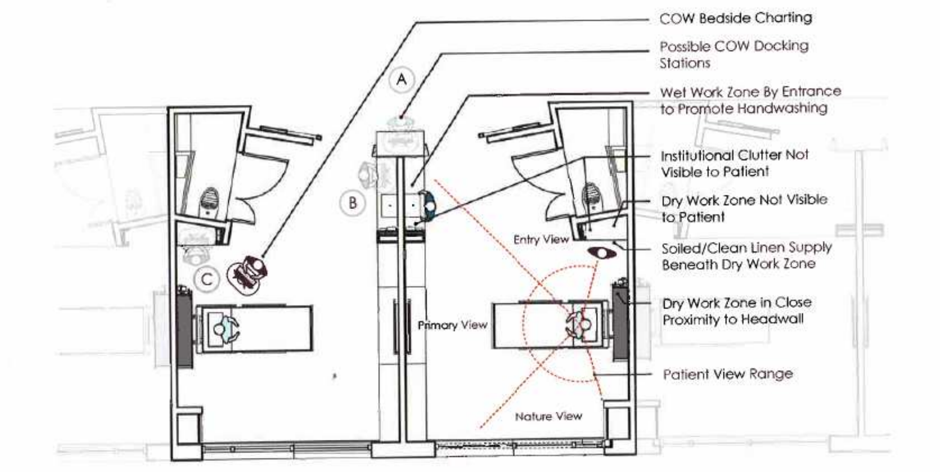


Figure 28. Example illustration from *A Visual Reference for Evidence-Based Design*, by Jain Malkin

Patient's Unit Prototype, Clemson University and Spartanburg Regional Healthcare System Collaboration

From from Malkin, J. (2008). *A visual reference for evidence-based design,* Center for Health Design, Concord, CA;
reprinted with permission from the Center for Health Design.

4.3.2 Assessment of EBD tools currently under development and criteria for new tool development

Each illustrated tool serves an important function in its own right.

However, this research seeks to develop a framework to heighten confidence in financial savings predicted by implementation of EBD interventions. To this end, this dissertation seeks to situate EBD within an array of potential solutions which may or may not involve the design of the facility itself. This purpose is very different from that of the above-mentioned tools.

Therefore, in light of this defined need and after interviews with owners and capital budgeters, as described in **Section 2.4**, I developed criteria for a new tool based on the following questions:

- *Searchable:* Are research findings fast and easy to locate?
- *Expandable:* Can new findings be easily added as fresh research results become published?
- *Inclusive of non-architecture-oriented solutions:* Are non-architectural, as well as architectural, solutions to medical problems included as potential options?
- *Visually strong and clear:* Is the graphic interface easy to understand and use?
- *Input-Output correlations obvious:* Are the correlations between EBD inputs and outputs clear?
- *Rate-able:* Can the research findings be easily evaluated by users, and can those evaluations be readily shared?
- *Benchmark-able to national indicators:* Can users benchmark their facility's performance against national indicators?
- *Transition-able to LCCA or BCA:* Can the tool easily transition to capital budgeting uses as increasingly reliable data becomes available?

I have also assessed the adequacy of existing tools according to the above criteria, as shown in **Table 4.** The ratings given to each tool are subjective; they are based on my own judgment. However, they offer a starting point for the development of a tool.

Table 4. Assessment of a sample of EBD tools currently under development

	Assessment (weak = 1 ←…..→ 5 = strong)							
	S	**E**	**I**	**V**	**R**	**C-E**	**B**	**L**
InformeDesign http://www.informedesign.umn.edu/ *(website)*	5	4	1	1	5	3	1	1
Lyn Geboy: EBD Wheel *(graphic nemonic)*	1	1	1	4	1	1	1	1
Jain Malkin *(book)*	1	1	1	5	1	3	1	1
John Reiling *(checklist)*	1	1	5	1	1	1	1	1

S	Searchable
E	Expandable
I	Inclusive of architecture and non-architectural solutions
V	Visually strong and clear
R	Rate-able
C-E	Cause-effect correlations obvious
B	Benchmark-able to national indicators
L	Transition-able to LCCA

To develop a tool that can respond to the above criteria—especially that which includes a full range of both architectural and non-architecture solutions—the next section will introduce Root Cause Analysis.

4.4 Proposed Framework for a New Tool

4.4.1 Structure of the New Tool

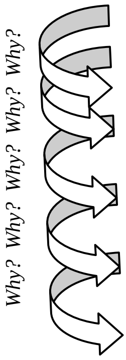
4.4.1.1 Root Cause Analysis: the Five Whys

The Joint Commission is the largest and best known non-profit body that accredits 16,000 healthcare organizations and programs in the US. Responding to the growing influence of

EBD and to ensure that the sets of recommendations proffered by EBD consultants are appropriate and effective, the Joint Commission has recommended that Root Cause Analysis to be undertaken as a response to Evidence-Based Design (Feldbauer et al. 2008; The Joint Commission 2009). This section will examine one form of Root Cause Analysis and discuss how it can be used as the basis for an EBD-decision-making framework.

The intent of Root Cause Analysis is to drill down to the root of a problem. The assumption is that, by eliminating the root cause of problem, the problem itself becomes resolved. Lean Construction borrows heavily from lean manufacturing, described by Jeffrey Liker in *The Toyota Way* (Liker 2004). Liker offers an example of Root Cause Analysis in the form of a “Five Why” chart (Liker 2004), after presenting a challenge: “there is a puddle of oil on the shop floor.” If we ask, “Why is this so?”, the answer may be: “because the machine is leaking oil.” If we are to again ask, “Why is *this* so?”, the response may be “because the gasket has deteriorated.” Each time we reach a new level of causal understanding, we decide whether or not to take action at that point or to continue with our line of inquiry. For example, a reasonable response following the discovery of leaky oil is to clean up the oil. Upon realizing that the gasket has deteriorated, we may elect to replace the gasket. Each level of causal analysis brings with it a new potential solution. However, note that first level solutions are often temporary. Cleaning up the oil will not arrest the leak; the oil will likely need to be cleaned up again. Although replacing the gasket will stop the leak from reoccurring for a while longer, a poor quality gasket replaced by another poor quality gasket only forestalls another leak.

In other words, each successive level of inquiry brings with it a longer term solution, as is depicted in **Figure 29.** Not until we reach the final level of the Liker figure do we arrive at a solution of some permanence.



Level of Problem	Corresponding Level of Countermeasure	Result if take action at this point
There is a puddle of oil on the shop floor	Clean up the oil	Short-term solution
Because the machine is leaking oil	Fix the machine	”
Because the gasket has deteriorated	Replace the gasket	Midterm solution
Because we bought gaskets made of inferior material	Change gaskets specifications	”
Because we got a good deal (price) on those gaskets	Change purchasing policies	”
Because the purchasing agent gets evaluated on short-term cost savings	Change the evaluation policy for purchasing agents	Long-term solution

Figure 29. Example of Root Cause Analysis using “5-Whys”

Adapted from Liker 2004, Figure 20-1, p. 253.

The logic behind the Five-Whys is that short-term solutions require that fixes must be repeated multiple times over a given period, while a long-term solution demands a singular fix. Despite its sometimes larger first cost, the Five-Whys solution argues the long-term resolution is often less expensive than the short-term one in the long run—and should therefore be preferred.

The question then may be, at what stage in the cascade of questioning does one stop a Root Cause Analysis? The Five-Whys technique is not intended to literally suggest stopping after asking “why” five times, but rather after reaching “an actionable cause.” Ideally, one should take action at the moment when the number of repeated fixes matches the needs of the situation at hand. For example, in the case of the oil leak, the short-term solution might be most appropriate if the machine needs to be fixed only long enough to use it for two hours (as opposed to two years).

4.4.1.2 Clarifying the scope of Root Cause Analysis as applied to healthcare

The logic of Root Cause Analysis can be applied to any problem. However, this research is about resolved problems associated with healthcare.

Therefore, a word of caution is in order here; Root Cause Analysis may seem to lead to a seemingly endless chain of causal events. For example, in the case of healthcare, Ferlie and Shortell (2001) and Reid et al. (2005) define four nested levels:

(1) the individual patient
(2) the care team (including professional care providers, clinicians, pharmacists and other), the patient and family members
(3) the organization (hospital, clinic, nursing home, etc.)
(4) the political and economic environment (regulatory, financial, payment regimes and markets, conditions under which organizations, care teams, individual players and care providers operate.

While all levels certainly need to be considered in some respect, only two of the four reside within the scope boundaries established for this dissertation in **Section 2.2**, and perhaps more importantly within the boundaries of a hospital design project. If (4) and possibly (3) are givens, then the root cause analysis must stop at level (2) in order to have workable root causes in which to work.

4.4.1.3 Root Cause Analysis and EBD

The next sections will look to ways in which EBD can be applied to Root Cause Analysis of challenges associated with healthcare dilemmas.

Evidence-Based Design research identified in the Ulrich et al. literature reviews is certainly critical (Ulrich et al. 2004; Ulrich et al. 2008) to this endeavor. However, this research focuses first and foremost on architectural solutions to healthcare challenges but excludes other means to help patients recover faster. While this approach is reasonable and useful, undertaking root cause analysis and situating architectural solutions within an array of solution possibilities lends additional credibility to EBD claims (Feldbauer et al. 2008). When a patient takes longer to recover than others faced with similar ailments, Root Cause Analysis in the form of the Five Whys directs seekers to the source of the difference.

4.4.1.4 Link between the Hopkins Medallion and Ulrich/Zimring's Literature Reviews

One way to link Root Cause Analysis to Evidence-Based Design is through the inner workings of a recovering patient. This is logical because the value system of EBD is based on patient-centered care.

By way of analogy, a recovering patient's body is similar to a city under siege. To recover from a wartime siege (illness), a city (body) must become engaged in three ways: (1) prevent further destruction of the city (body), (2) make sure the workers (immune system) rebuilding the city (body) are kept strong and healthy enough to repair the damage, and (3) ensure that supply lines (hospital staff) are given adequate support to assist the city's (body's) own rebuilding efforts. The authors of the Johns Hopkins literature review (Rubin et al. 1998) recognized these three categories of need for patient-centered care. In **Figure 30**, the patient is situated at the center of the Environment-Outcome Interface Model medallion, and surrounded by three categories of influence: (1) Protecting from or exposing to causes of illness, (2) Impairing or strengthening patient's health status and personal characteristics, and (3) Supporting or hindering medical interventions. For convenience, I have renamed these three categories: (1) Safety; (2) Healing and (3) Caregiving.

One measure of success of a healing process is the rate at which a patient recovers. I have expressed the central role the Rate of Recovery plays by depicting it as the central axis.

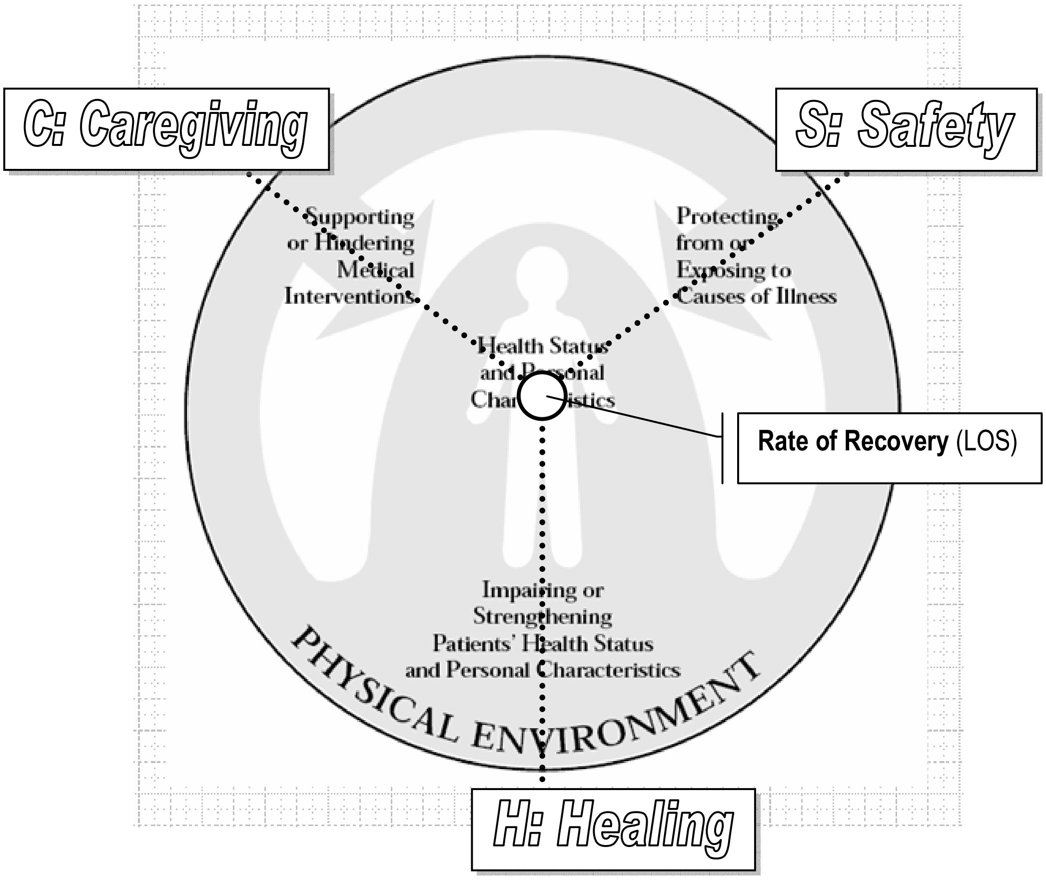


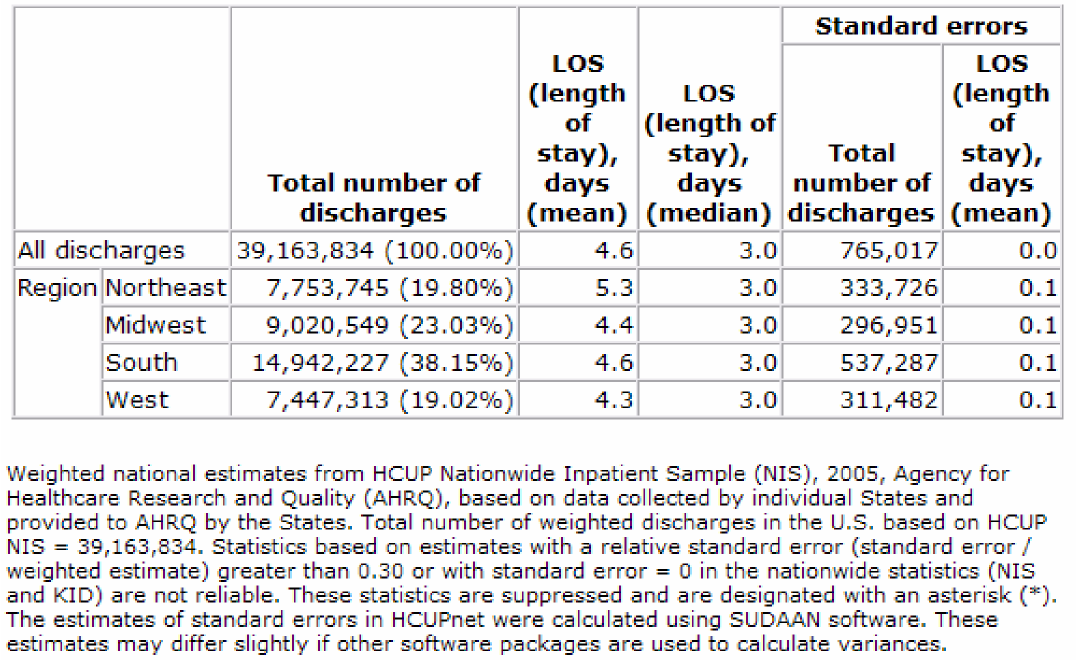
Figure 30. Categories of the Johns Hopkins Environment-Outcome Interface Model
Adapted from (Rubin et al. 1998)

4.4.1.5 The centrality of Length of Stay (LOS)

The Johns Hopkins' Environment-Outcome Interface model identifies branches or categories of factors that are needed to ensure that a patient resides at the center of a healthcare facility's focus. Although the indicator, Length of Stay (LOS) is not a perfect proxy for Rate of Recovery, the metric is commonly used by healthcare facilities to benchmark their performance against that of other facilities or their own prior performance, as suggested by a chart from the Agency for Health Research and Quality. LOS metrics are available to healthcare organizations as well as to the general public through the AHRQ website, as shown in **Table 5** (Agency for Healthcare Research and Quality 2007).

Table 5. Length-of-Stay (LOS) indicators for all discharges sorted by region

(Agency for Healthcare Research and Quality 2007)



					Standard errors	
		Total number of discharges	**LOS (length of stay), days (mean)**	**LOS (length of stay), days (median)**	**Total number of discharges**	**LOS (length of stay), days (mean)**
All discharges		39,163,834 (100.00%)	4.6	3.0	765,017	0.0
Region	Northeast	7,753,745 (19.80%)	5.3	3.0	333,726	0.1
	Midwest	9,020,549 (23.03%)	4.4	3.0	296,951	0.1
	South	14,942,227 (38.15%)	4.6	3.0	537,287	0.1
	West	7,447,313 (19.02%)	4.3	3.0	311,482	0.1

Weighted national estimates from HCUP Nationwide Inpatient Sample (NIS), 2005, Agency for Healthcare Research and Quality (AHRQ), based on data collected by individual States and provided to AHRQ by the States. Total number of weighted discharges in the U.S. based on HCUP NIS = 39,163,834. Statistics based on estimates with a relative standard error (standard error / weighted estimate) greater than 0.30 or with standard error = 0 in the nationwide statistics (NIS and KID) are not reliable. These statistics are suppressed and are designated with an asterisk (*). The estimates of standard errors in HCUPnet were calculated using SUDAAN software. These estimates may differ slightly if other software packages are used to calculate variances.

LOS may therefore serve as an indicator for quality of care until a more accurate indicator becomes readily available.

4.4.1.6 Extruding the three branches

To set up working planes onto which Root Cause Analysis diagrams can be drawn, the three dotted arms of the Environment-Outcome Interface Model medallion shown in **Figure 30** can be extruded into three dimensions, as shown in **Figure 31.**

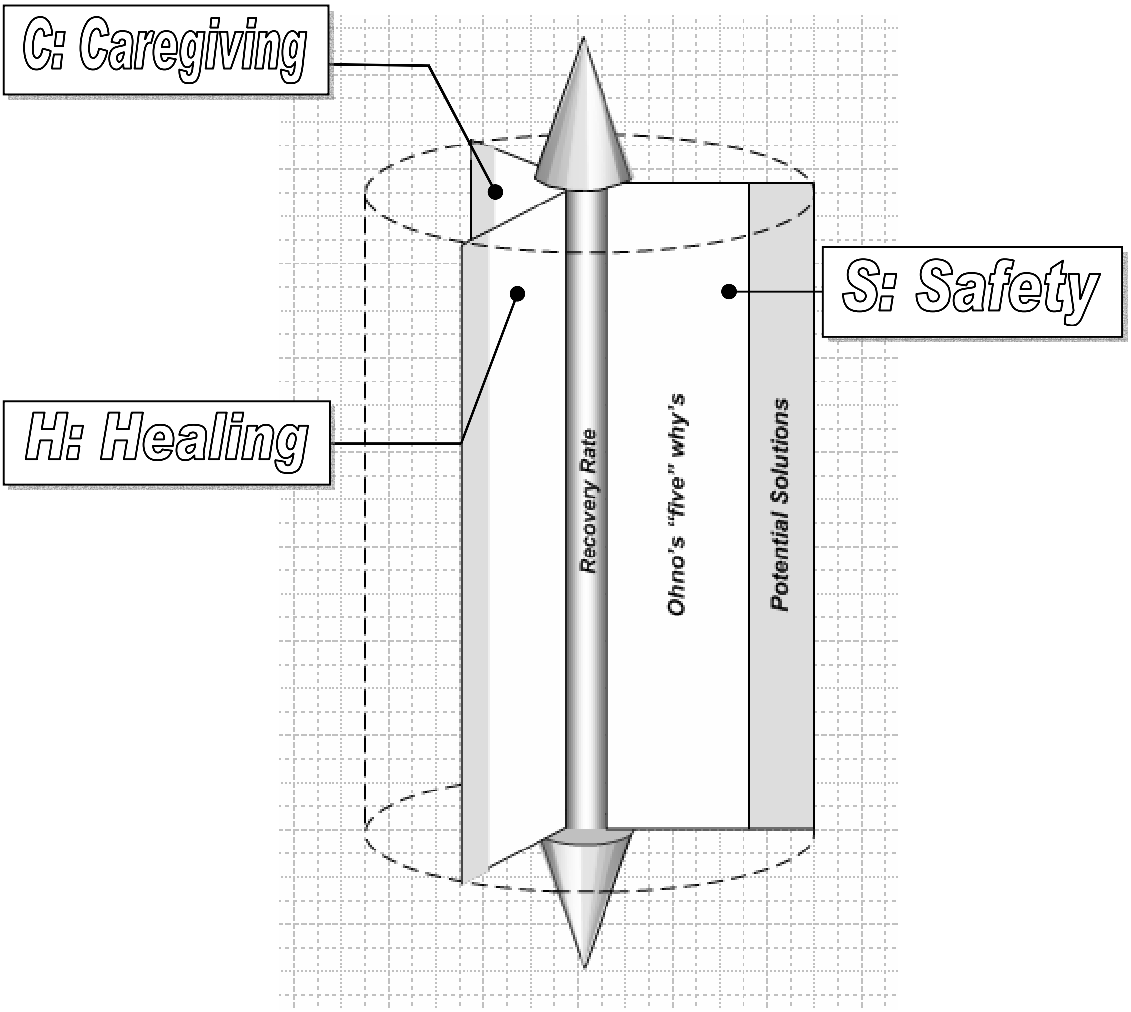


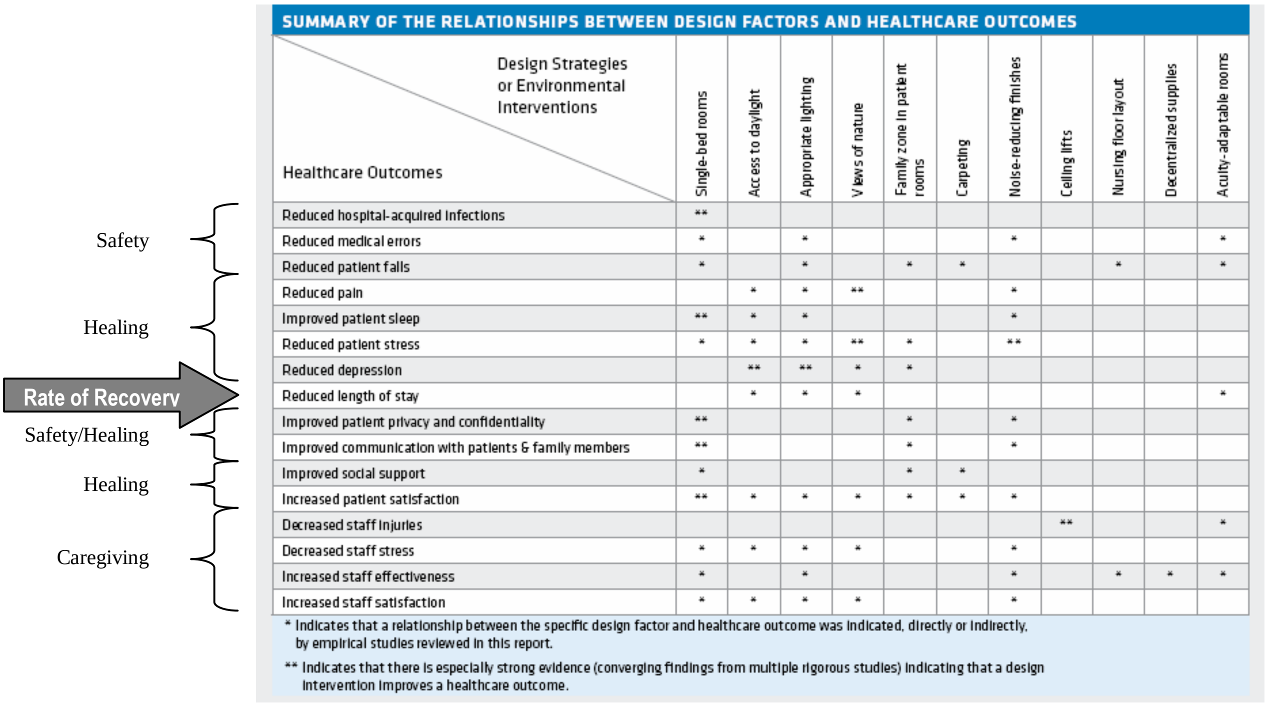
Figure 31. Three-dimensional extrusion from the Johns Hopkins Environment-Outcome Interface Model

An example of Root Cause Analysis as it relates to **Figure 31** will be presented in **Section 4.5.3.3**. However, it is necessary to first introduce the role of literaure reviews as they relate to the tool.

4.4.1.7 Relationship between framework and EBD literature

The operational concerns a healthcare facility must face can be staggering. In response to these concerns, the EBD research community has identified a number of challenges that may be assisted through better quality facility design. Each of the three categories of patient-centered care—safety, healing and caregiving—can in turn be investigated more deeply. For example, assaults to patient *Safety* include hospital-acquired infections, medical errors, patient falls, (mis)communication between staff, patient and family members. Rate of patient *Healing* is impacted by that patient's response to pain, sleep, stress, loneliness and depression. The ability of staff members to offer a patient assistance during *Caregiving* is influenced by their own injuries, stress, effectiveness, and satisfaction. EBD literature reviews reveal that each of these frustrations can be minimized through more sensitively designed spaces.

The EBD outcomes discovered by Ulrich et al. (2004, 2008) can be grouped into the same categories identified by Rubin et al. (1998). To bring the results of both research teams into alignment, I have relabeled the Ulrich et al. (2004, 2008) categories as I did those of Rubin et al. (1998), i.e., (1) Safety, (2) Healing, and (3) Caregiving. **Figure 32** shows these three categories, as they are applied to Ulrich et al.'s work.



SUMMARY OF THE RELATIONSHIPS BETWEEN DESIGN FACTORS AND HEALTHCARE OUTCOMES

Design Strategies or Environmental Interventions / Healthcare Outcomes	Single-bed rooms	Access to daylight	Appropriate lighting	Views of nature	Family zone in patient rooms	Carpeting	Noise-reducing finishes	Ceiling lifts	Nursing floor layout	Decentralized supplies	Acuity-adaptable rooms
Reduced hospital-acquired infections	**										
Reduced medical errors	*		*				*				*
Reduced patient falls	*		*		*	*			*		*
Reduced pain		*	*	**			*				
Improved patient sleep	**	*	*				*				
Reduced patient stress	*	*	*	**	*		**				
Reduced depression		**	**	*	*						
Reduced length of stay		*	*	*							*
Improved patient privacy and confidentiality	**				*		*				
Improved communication with patients & family members	**				*		*				
Improved social support	*				*	*					
Increased patient satisfaction	**	*	*	*	*	*	*				
Decreased staff injuries								**			*
Decreased staff stress	*	*	*	*			*				
Increased staff effectiveness	*		*				*		*	*	*
Increased staff satisfaction	*	*	*	*			*				

* Indicates that a relationship between the specific design factor and healthcare outcome was indicated, directly or indirectly, by empirical studies reviewed in this report.

** Indicates that there is especially strong evidence (converging findings from multiple rigorous studies) indicating that a design intervention improves a healthcare outcome.

Figure 32. Summary of healthcare outcomes related to metrics
(Ulrich et al. (2008))

Reprinted with permission from the Center for Health Design.

The only outcome from Ulrich et al. (2008) which does not fall into one of these three groups is reduced *Length of Stay (LOS)*. However, reduced LOS—as introduced earlier—differs from the other metrics in that it may be considered as an overall indicator of healing success into which all other categories feed. For example, patients who are kept safe from further harm, whose bodies are assisted in the healing process and who have access to good caregiving should heal more quickly and should therefore be able to leave a hospital sooner.

4.5 Testing the Framework

4.5.1 Background on Hospital-Associated Infections and MRSA

This dissertation uses Root Cause Analysis to address one especially costly safety problem; it investigates the control of nosocomial infections, also known as Hospital-Associated Infections (HAIs)—thus testing in a pilot application the rough prototype of the tool presented in the last section. More specifically, this research investigates the spread of methicillin-resistant *Staphylococcus aureus* within a hospital facility and proposes ways in which its spread can be minimized. The intent is to explore one problem in depth so that it may serve as an example for ways other patient-centered challenges might be addressed.

4.5.1.1 The challenge of Hospital-Associated Infections

According to the Center for Disease Control, there are approximately 1.7 million hospital-associated infections per year in the US. Of these, 99,000 result in death (Centers for Disease Control and Prevention 2009).

Infections visit healthcare facilities at the following rates:

- Urinary tract: 32%
- Surgical Site Infections: 22%
- Pneumonia (Lung Infections): 15%
- Bloodstream Infections: 14%

(Centers for Disease Control and Prevention 2009)

Hospital-associated infections are caused by viruses, bacteria and (more difficult to treat) fungi. The Society for Healthcare Epidemiology of America and Infectious Diseases Society of America (2008) focus on six HAIs, in particular.

- Central Line-Associated Bloodstream Infections
- Ventilator-Associated Pneumonia
- Catheter-Associated Urinary Tract Infections
- Surgical Site Infections
- Methicillin-Resistant *Staphylococcus aureus*
- *Clostridium difficile*

Many of these infections share similar modes of transmission. For example, the first four of these six infection types are device-associated; i.e., they travel into a patient’s body via an inserted medical device, such as a catheter.

However, the modes of transmission of some of the infections also differ. Therefore, the scope of this study is limited to one strain of bacteria in particular, methicillin-resistant *Staphylococcus aureus* (MRSA). MRSA is classified as a gram-positive bacteria, which means that gram stain colors it dark blue or violet (**Figure 33**).

At the time of this writing, MRSA has become difficult to control.

When it first appears on a human body, a staph infection may resemble a small red pimple or spider bite. An initially mild infection can quickly penetrate surgical sites, bones, joints, the blood stream, heart valves and lungs, develop into painful abscesses and potentially contribute to the patient’s death (Mayo Clinic Staff 2009a) (**Figure 34**).

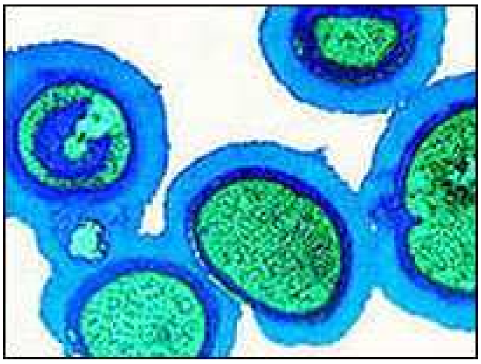


Figure 33. MRSA bacteria
from Church (2009)

Figure 34. Appearance of methicillin-resistant *Staphylococcus aureus*
from its early pimple-like appearance to puss accumulation (Logical Images Inc. 2009). The final image (eCanadaNow 2009) depicts a case that resulted in the patient’s death.

Not everyone colonized by MRSA develops an active infection. A number of individuals are, unknowingly, carriers of the *S. aureus* bacterium. These individuals serve as reservoirs and can transmit the bacteria to those in a weakened state.

Those most at risk for becoming infected by MRSA include those who:

- are in a weakened immune state, such as the elderly, AIDS patients, those in Intensive Care Units (ICUs), burn units, or those receiving organ transplantation or surgery
- stay in a hospital longer than 14 days or who have recently been hospitalized (within previous the three months)
- have been transferred from another acute-care facility, chronic-care facility or nursing home
- are penetrated with an invasive device (those on dialysis, with catheters or feeding tubes).
- have recently been treated by antibiotics

--(Mayo Clinic Staff 2009b; Rubinovitch and Pittet 2001)

In reservoir individuals—those who carry the bacterium without presenting symptoms—the bacterium generally colonizes the nasopharynx, perineum (area bounded by the urogenital passages and the rectum), or skin (Chambers 2001), as depicted in **Figure 35**. These areas are significant because sensitivity of location—especially in the case of the perineum—can make comprehensive patient screening for MRSA expensive and complicated (Swartzberg 2008). Because human reservoirs can unknowingly transfer MRSA to those in a weakened immuno-compromised state, the clinical literature repeatedly discusses attempts to decolonize the nares (nasal passages) of reservoir individuals in healthcare facilities with the antibiotic mupirocin (Hudson 1994; Miller et al. 1996).

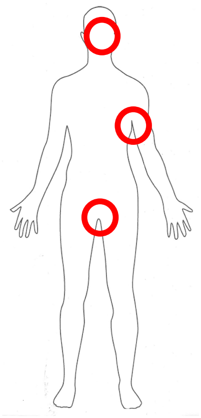


Figure 35. Common MRSA colonization locations in reservoir carriers

4.5.1.2 The global rise of Hospital-Associated Infections

The increasing number of hospital-related infections is alarming. Within the six year stretch from 1999 to 2005, infections in the US rose from approximately four to eight MRSA-related hospitalizations per 1,000 (Figure 36). Various reasons have been suggested for the rising magnitude of MRSA infections, including the increasing numbers of elderly and immuno-compromised patients worldwide.

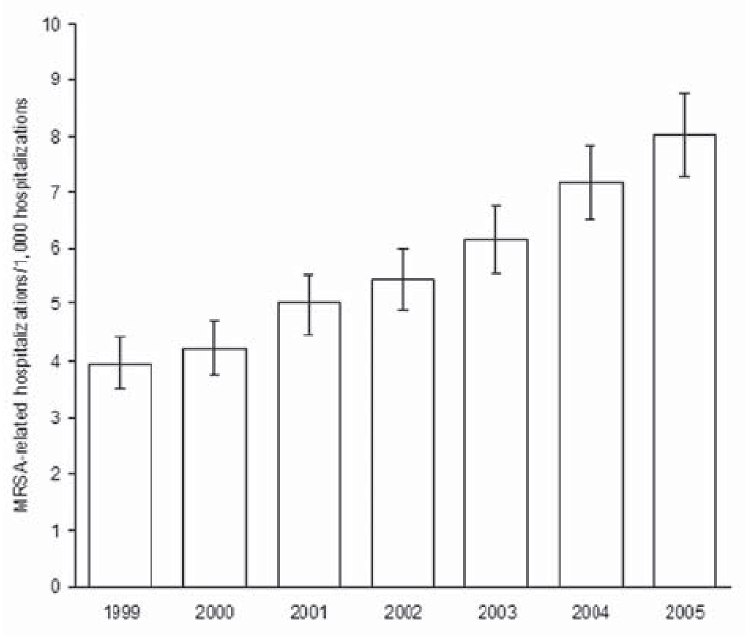


Figure 36. MRSA–related hospitalization rates in the US from 1999–2005

MRSA-related discharges/1,000 hospitalizations, with error bars bracketing 95% confidence intervals.

Reproduced from Klein, E., Smith, D.L., and Laxminarayan, R. (2007). "Hospitalizations and deaths caused by methicillin-resistant *Staphylococcus aureus*, United States, 1999-2005." *Emerging Infectious Diseases*, 13(12), 1840-1846.
No permission to reprint necessary; image in public domain.

Especially disconcerting is the bacteria's rising resistance to existing antibiotics. In fact, methicillin-resistance has increased among *Staphylococcus aureus* isolates among all hospital infections, ICU patients and skin and soft tissue infection patients during the five-year period depicted in **Figure 37**.

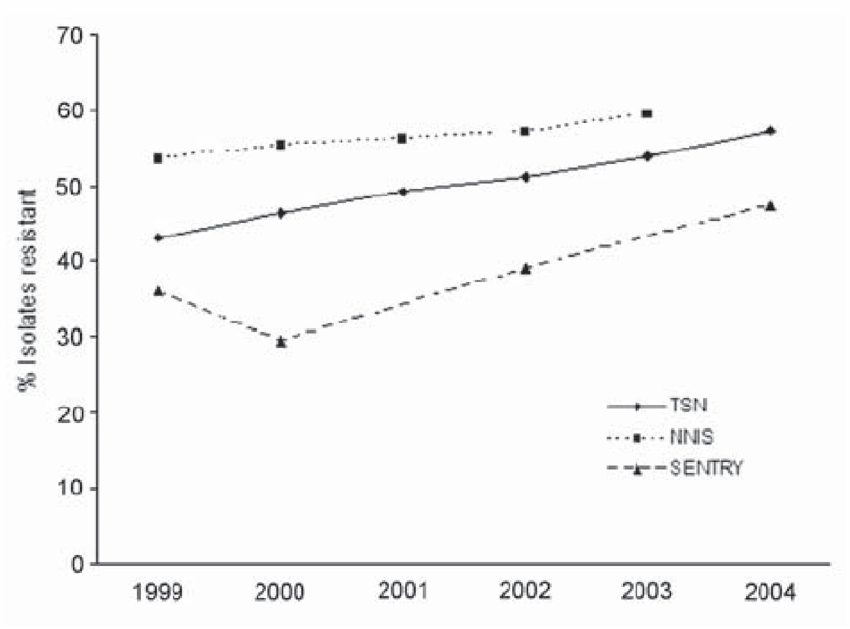


Figure 37. The percentage of *Staphyloccocus aureus* resistant to methicillin in the US as indicated by three surveys

TSN, The Surveillance Network (includes all hospital infections); NNIS, National Nosocomial Infections Surveillance System (includes only intensive care units); SENTRY (includes only skin and soft tissue infections))

Reproduced from Klein, E., Smith, D.L., and Laxminarayan, R. (2007). "Hospitalizations and deaths caused by methicillin-resistant *Staphylococcus aureus*, United States, 1999-2005." *Emerging Infectious Diseases*, 13(12), 1840-1846;
No permission to reprint necessary; image in public domain.

4.5.1.3 MRSA in the community

Containment of MRSA is increasingly complicated because its incidence is no longer limited to healthcare facilities; of concern is the discovery that MRSA has emerged in the community. The precise origin of community-acquired MRSA is still a topic of speculation (Chambers 2001) and has led to investigations to determine if MRSA is colonizing surfaces common to urban environments, such as handholds of trolleys, trams and buses (Stepanović et al. 2008).

Designing public spaces to reduce the spread of community-acquired MRSA is a topic worthy of further investigation in its own right. However, the scope of this study is limited to investigating ways to reduce the spread of this bacteria within healthcare facility settings.

4.5.1.4 The controversy over controlling MRSA

Containing the spread of MRSA in healthcare facilities has been controversial. Some argue that controlling the bacteria is unrealistic; control is expensive, consumes resources that might be better spent elsewhere, and is sometimes unsuccessful. Critics assert that MRSA is now endemic to healthcare facility settings and should instead be considered as part of the regular hospital flora (Boyce 1991; Farrington et al. 1998; Folorunso et al. 2000; Teare and Barrett 1997).

Nevertheless, as resistance to methicillin increases, there is concern the bacteria will become resistant to Vancomycin as well. This development would present a worrying turn of events since Vancomycin is traditionally considered the antibiotic of last resort; once S. aureus can no longer be treated by Vancomycin, there are few other options available for treatment at this time (Herwaldt 1999). Therefore, despite the controversy, there is growing agreement among members of the scientific community that spread of MRSA should be restrained (Herwaldt 1999).

4.5.1.5 Cost of treating MRSA infections

The cost of controlling MRSA infections is currently high, as shown in **Table 6**. This has led to significant interest in controlling the spread of the bacteria.

Table 6. Cost of nosocomial infections as reported by hospitals

Year	Cost to treat each infection (US $)	Citation
2001-2006	12,197	(Kilgore et al. 2008)
2005	13,973	(Stone et al. 2005)
2005	153,871	(Pennsylvania Health Care Cost Containment Council 2006)
2001-2002	3,306	(Chen et al. 2005)
1996-2000	50,896	(Evans et al. 2007)
1998	15,275	(Roberts et al. 2003)

The range of costs to treat each infections represented in the table is fairly large ($3,306-$153,871 per infection) and the studies are of varying quality. However, the Kilgore et al. study is the largest of its kind to provide rigorous analysis of costs, with N=1,355,437 admissions from over 55 hospitals. The study period began in March 30, 2001 and ended in January 31, 2006. The average cost result of $12,197 is bounded by a 95% Confidence Interval (CI) of $4,862-$19,533 and is considered statistically significant ($p<0.001$).

4.5.2 Applying Root Cause Analysis and its implications for design

4.5.2.1 Call for Root Cause Analysis and prior attempts

One premise of this thesis is that the healthcare community is not able to significantly reduce MRSA infection rates because it may not be considering the full picture of the virus' transmission path. Constructing such a path analysis for the spread of MRSA infections is the goal of undertaking Root Cause Analysis.

In 2007, Carrico and Ramirez (2007) published fishbone diagrams for sentinel event analysis of Healthcare Associated Pneumonia (**Figure 38**). Certainly, causal links found in the diagram such as "medical staff unaware of prevention protocols" and "lack of consistent hygiene" are likely; and the diagram can assist a time-strapped infection-control professional by offering a ready-made checklist. However, the author of the diagram appears to have clustered various potential causes for infection without asking "Why?" more than once. Also, responses appear to imply that an appropriate reaction to violations of protocol is to simply reinforce pre-existing protocols. From an Evidence-Based Design perspective, a better solution might instead be to design the problem away entirely. This is the logic of Poka Yoke—a design strategy which will be introduced in **Section 4.5.2.2**.

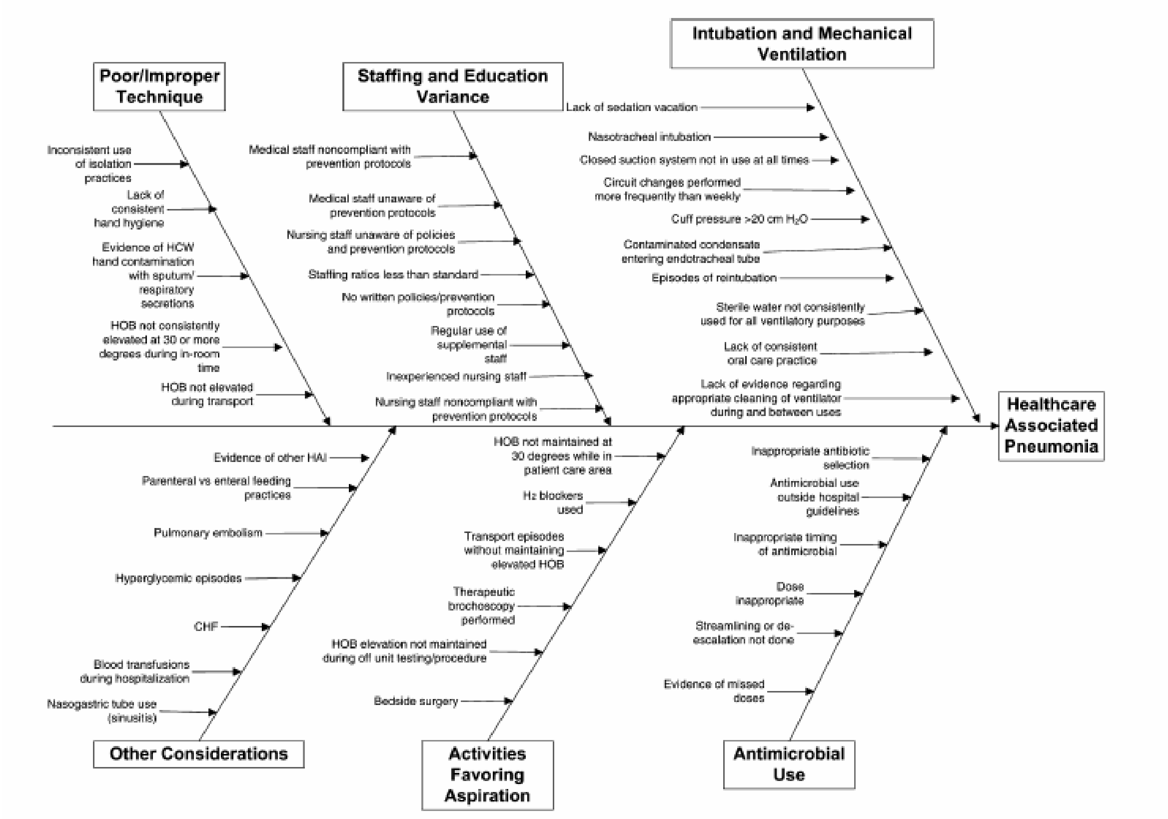


Figure 38. Sentinel event analysis for Healthcare Associated Pneumonia

From Carrico, R., and Ramirez, J. (2007). "A process for analysis of sentinel events due to healthcare-associated infection." *American Journal of Infection Control*, 35(8), 501-507. Reprinted with permission.

4.5.2.2 Applying mistake-proof design to Root Cause Analysis

The ability to reduce healthcare infections—and medical errors in general—by policy enforcement alone is limited. This constraint was recognized in Grout's (2007) publication "Mistake-Proofing the Design of Health Care Processes," where the author presents examples of *poka yoke*—or mistake-proofing applied to hospital facilities. Grout argues that, given the complexity of medical treatment requirements and the nature of human error, it is unrealistic to mistake-proof human performance. Rather, he suggests, healthcare facility decision-makers should seek ways to build solutions into their design and thus entirely eliminate the need for quality control.

The concept of poka yoke was initially postulated by Toyota's industrial engineer, Shigeo Shingo (Shingo 1985). To encourage its application to healthcare, Grout collects examples of poka yoke that have been applied outside the hospital environment: filing cabinets that prevent opening more than one drawer at a time to avoid the danger of overturning, tooth brushes with colored bristles oriented to alert owners that it is time for replacement, safety belts colored in such a way that users can tell if the belt is buckled incorrectly. In the foregoing examples, poka yoke helps individuals identify an error when it occurs. However, an ideal poka yoke design eliminates the error completely. In the following hypothetical example of a poka yoke (**Figure 39**), the need to inspect the orientation of two interlocking pieces on an assembly line is eliminated.

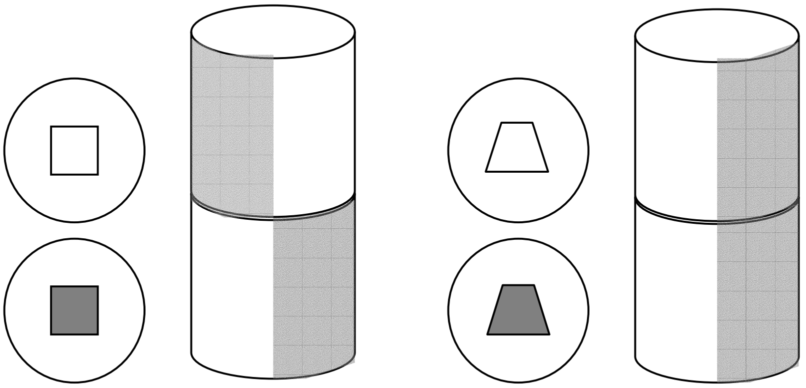


Figure 39. Poka yoke: design as a means to eliminate errors

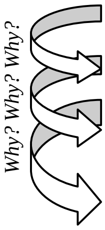
An example of a poka yoke solution; male and female parts are designed to connect in only one way (right).

Grout’s report throws down a gauntlet to the healthcare design community to seek mistake-proofing design strategies whenever possible. Interestingly, Grout’s challenge is especially suited to EBD.

4.5.3 Linking Root Cause Analysis and EBD

4.5.3.1 Constructing a Root Cause Analysis framework for MRSA

In order to prevent error, it is necessary to understand what is causing that error. This is the role of Root Cause Analysis. **Figure 40** applies Root Cause Analysis to the spread of MRSA in the form of Five-Whys.



Level of Problem	Corresponding Level of Countermeasure	Result if take action at this point
Patient has MRSA	Administer antibiotics	Short-term solution
Because MRSA was on HANDS of staff contacting patient	Wash hands before touching patient	”
Because staff HANDS were in contact with SURFACE (with MRSA)	Wash surface before touching with hands	Midterm solution
Because OTHER PATIENT (with MRSA) touched that surface	Screen and isolate patients for MRSA before entry	Long-term solution

Figure 40. Example of Root Cause Analysis using “5-Whys”

Adapted from Liker 2004, Figure 20-1, p. 253.

Figure 40 offers one path for the transmission of MRSA from patient to patient. However, unlike the singular path of the Root Cause Analysis diagram for the oil leak discussed in **Section 4.4.1.1**, MRSA can potentially travel along multiple paths, such as via hands, surfaces or fomites, or droplets in the air. Therefore, rather than present a chart with a singular path, a more accurate Root Cause Analysis chart should include a number of potential causal branches. For example, a patient may have contracted MRSA via contract with a surface or fomite (any inanimate object that can transfer infection from one person to another), with staff or visitor hands or through contact with an invasive medical device. Each of these vectors, in turn, received MRSA colonies from contact with another vector, such as a colonized surface or fomite, hands or other colonized patient, and so on. The branching nature of the Five Whys is represented in **Figure 41**. The challenge for a medical facility is to determine the most likely path and find the appropriate corresponding level of countermeasure.

4.5.3.2 Characteristics of the tool

It is worth reminding ourselves that the purpose of the proposed tool is to enhance the confidence of healthcare facility decision-makers regarding the most cost effective ways to solve patient-centered care problems.

Recall from **Section 4.3.2** that, to address this purpose, several criteria underlie the development of this tool. I have listed a proposed response to each criterion.

- *Searchable:* Are research findings fast and easy to locate?

  Tool development response: make tool computer-based with search function

- *Expandable:* Can new findings be easily added as fresh research results become published?

  Tool development response: make tool a wiki so new information can be easily added over time

- *Inclusive of non-architecture-oriented solutions:* Are non-architectural, as well as architectural, solutions to medical problems included as potential options?

  Tool development response: use Root Cause Analysis to first identify root cause and then arrive at potential solutions, be they architectural or non-architectural in form.

- *Visually strong and clear:* Is the graphic interface easy to understand and use?

  Tool development response: use branching, tree-like graphic to support tracing to root cause.

- *Input-Output correlations obvious:* Are the correlations between EBD inputs and outputs clear?

  Tool development response: use graphically separate zone to indicate connection between the cause and corresponding countermeasure.

- *Rate-able:* Can the research findings be easily evaluated by users, and can those evaluations be readily shared?

  Tool development response: organize quantitative data so only the most highly regarded (most rigorously screened) results are included.

- *Benchmark-able to national indicators:* Can users benchmark their facility's performance against national indicators?

  Tool development response: hyperlink indicators, such as Length of Stay (LOS) to national databases, such as those compiled by the Agency for Healthcare Research and Quality, as described in **Section 4.4.1.5**.

- *Transition-able to LCCA or BCA:* Can the tool easily transition to capital budgeting uses as increasingly reliable data becomes available?

  Tool development response: determine an average value and 95% confidence interval for impact of countermeasure from cumulative meta-analyses so that capital budgeters can determine a likely range for long-term cost savings.

Once the framework for the tool is developed, based on the collective wisdom of numerous problem solvers, it is necessary to populate the framework with evidence. Therefore, the purpose of this section is not to specifically solve the MRSA spread problem, but instead to test how the tool might be populated with pre-screened evidence.

The chart in **Figure 41** diagrams possible paths of MRSA spread as identified by healthcare facilities and published in peer-reviewed journals. Each category is identified by an icon label such as "H" for Hands or "S/F" for Surface/Fomite or "OP" for Other patients. These icons indicate a hyperlink to "drill down" to the next level of questioning. I have darkened the circles for categories that I prescreened during this test run. The final link is between the cause and one or more recommended actions that can be taken to address the cause. Note that an uncommitted item has been inserted at the bottom of each drill-down diagram. The intention is to symbolize the additive wiki nature of the tool; new solutions will continuously emerge over time.

4.5.3.3 Trial run

For the test run, I selected representative links in three drill down charts (H, S/F and P), as shown in **Figures 42** through **44**. I then populated the representative links with results from systematic literature reviews for *handwashing*, *disinfecting surfaces* (floors and walls), and *screening* and *isolation*. The literature had been prescreened for quality of evidence and published in peer-reviewed journals. The specific search strategies the authors used, the screens they applied, as well as the final results of their searches can be found in **Tables 7-10**.

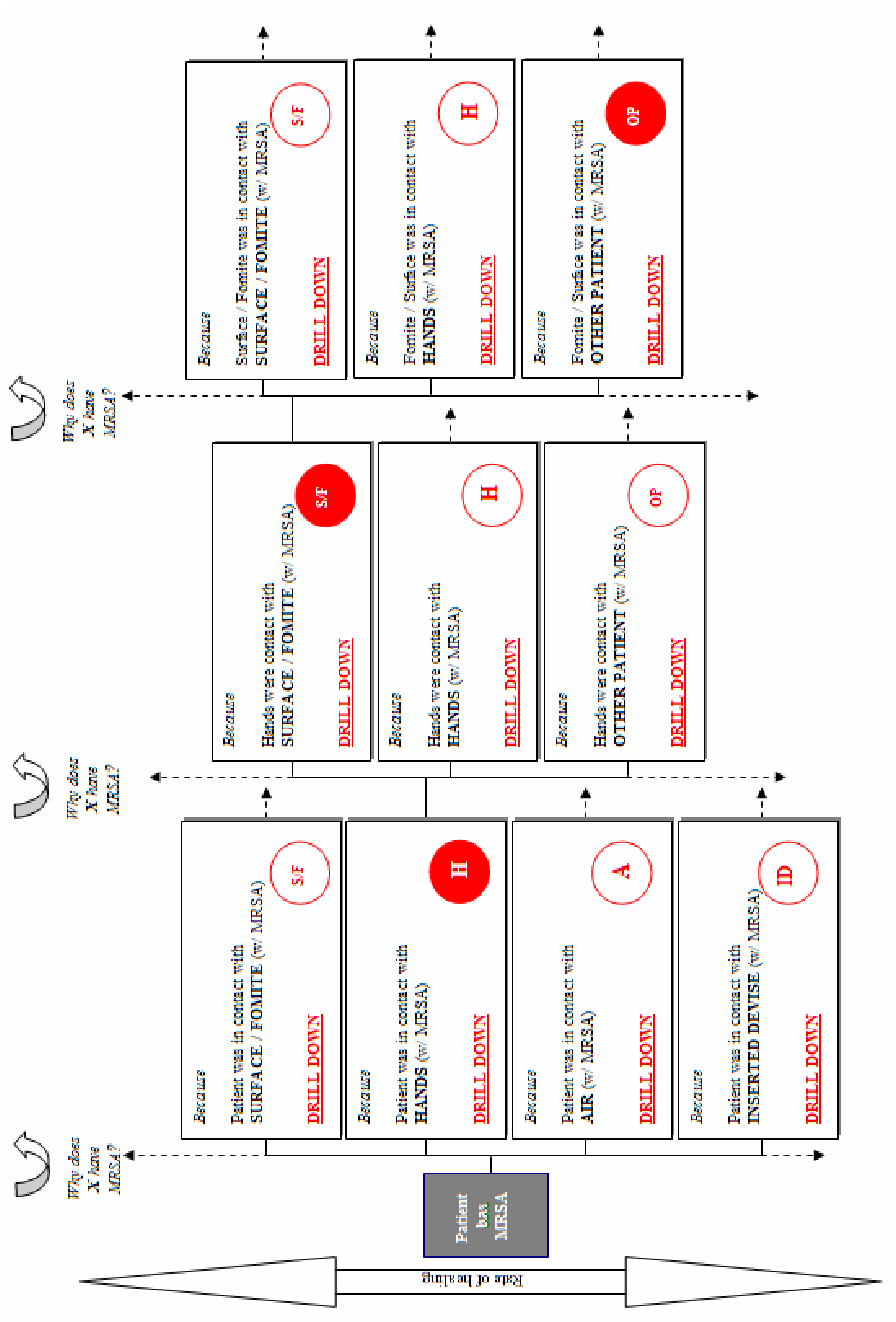


Figure 41. Example of Root Cause Analysis of spread of MRSA

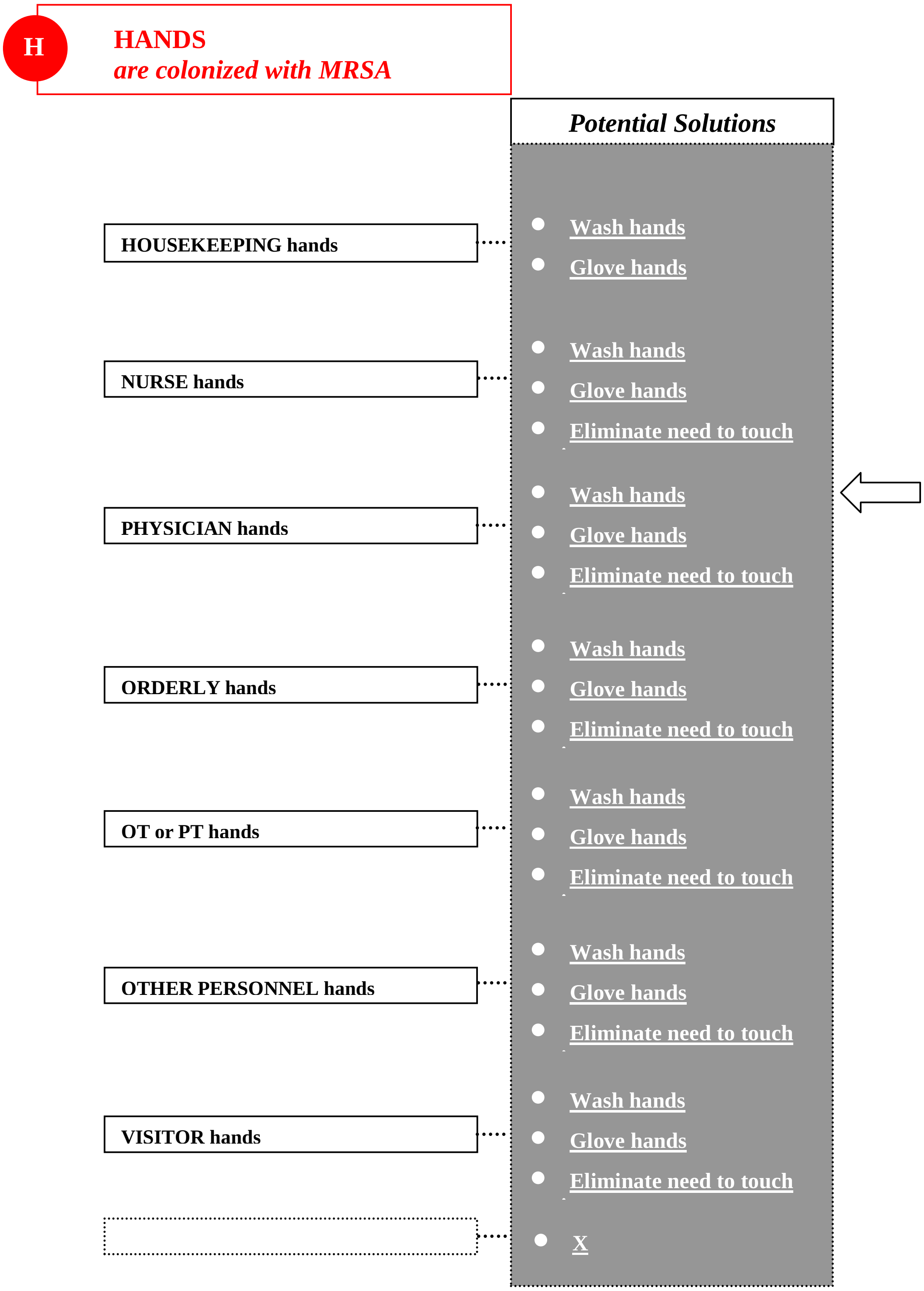


Figure 42. Potential Solutions for reducing MRSA by washing hands

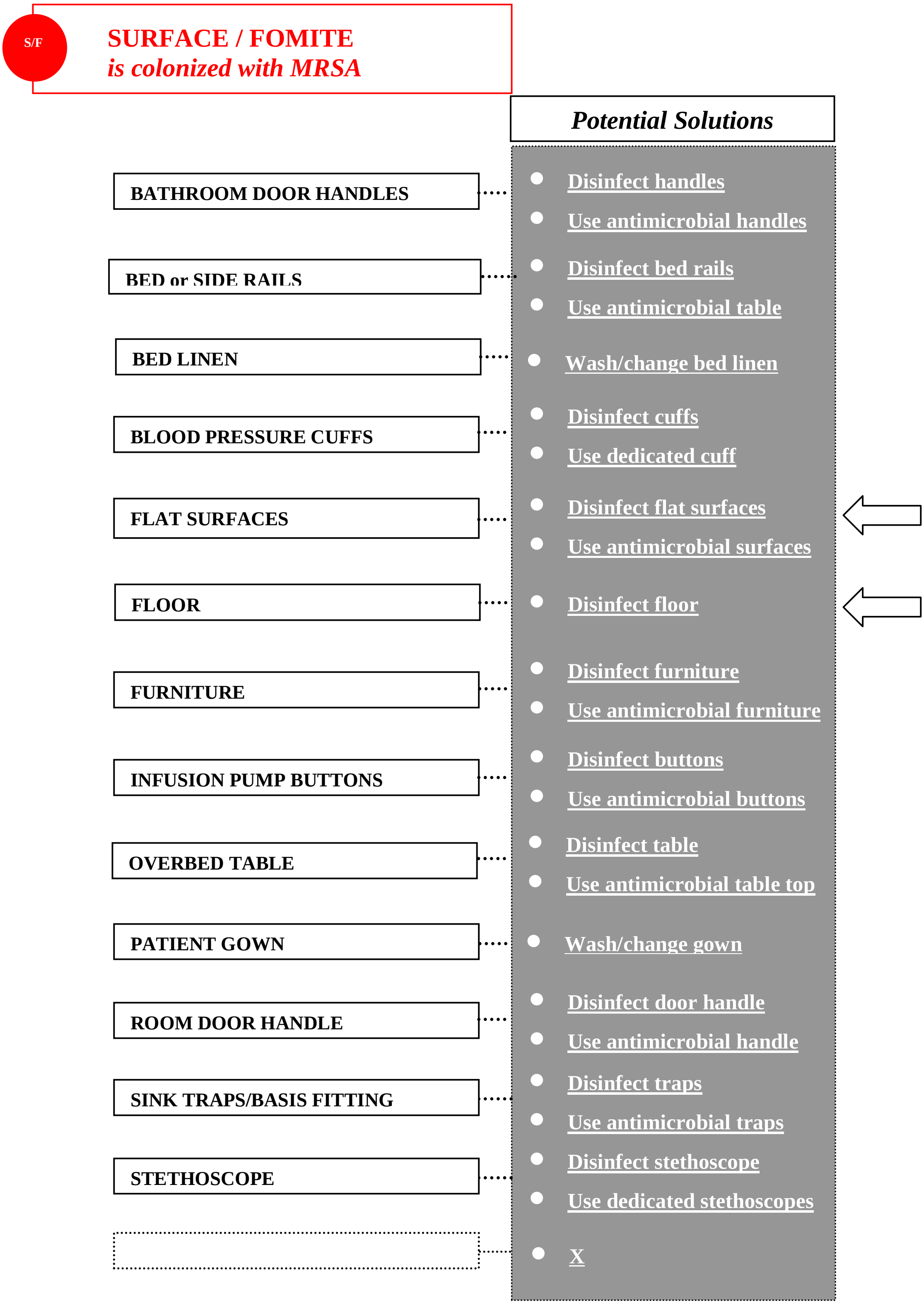


Figure 43. Potential Solutions for reducing MRSA by cleaning surfaces and fomites

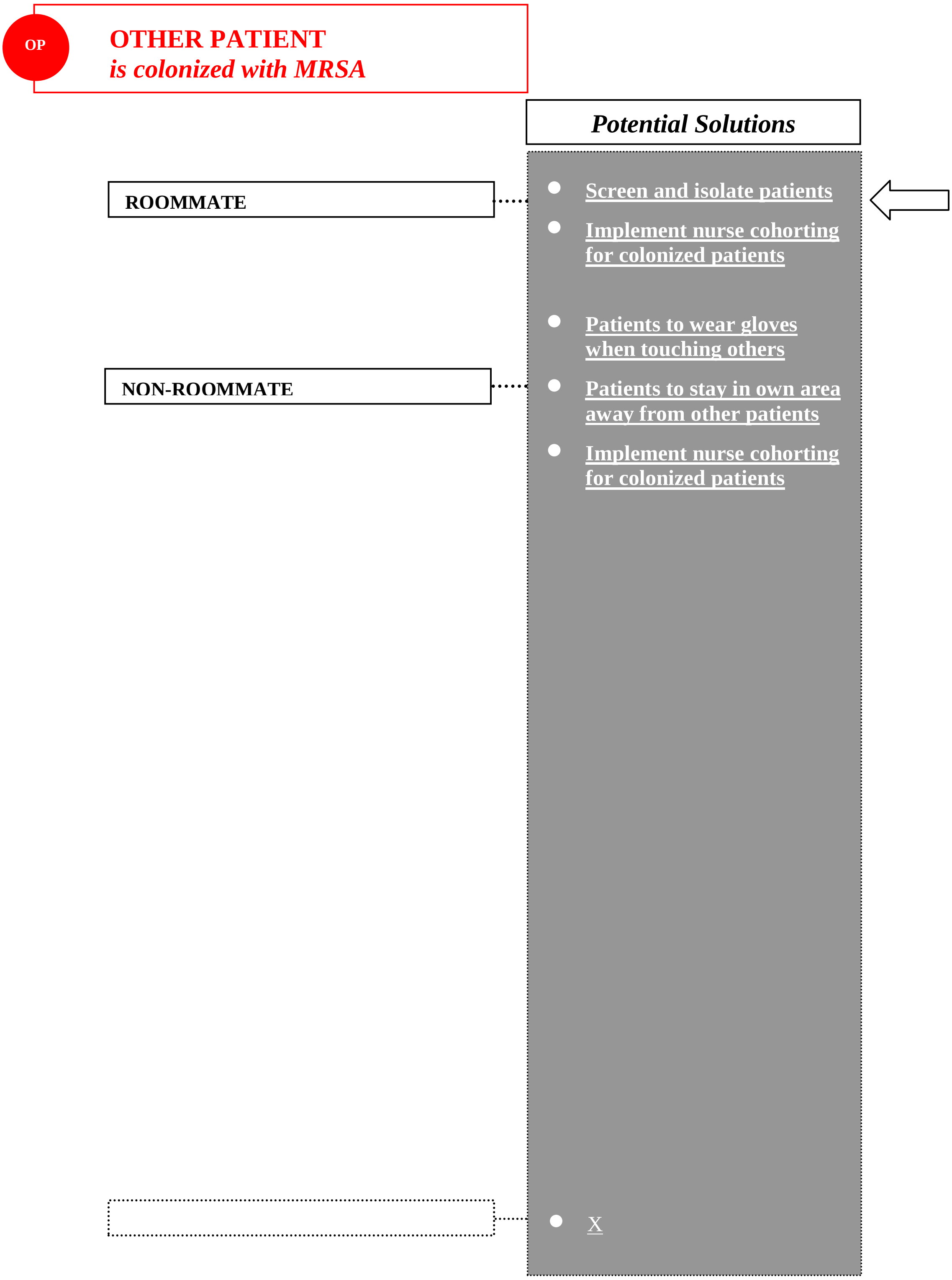


Figure 44. Potential Solutions for reducing MRSA by cleaning surfaces and fomites

Table 7. Search methodology used by systematic reviewers

TOPIC	Article	Databases Searched	Dates Searches	Keywords searches
Handwashing	(Backman et al. 2008a)	Medline CINAHL EMBASE Cochrane Library PubMed	Jan. 1, 1996 -July 31, 2006 (10 year)	*Handwashing* (MESH headings): hand + disinfection + antisepsis + disinfectants + antiinfective agents + local + antiviral agents + soaps + detergents + ethanol + alcohols *Titles:* (hand$ adj5 wash$) handwashing$ hand hygiene (hand$ adj5 wash$ [saniti$ or disinfect$ or decontaminat$ or gel$]) + cross infection + infection control + nosocomial + nosocomial$ + (educe$ adj3 spread$) + disease transmission + (healthcare associated or healthcare associated or hospital acquired)
Disinfecting Surfaces	(Dettenkofer et al. 2004a)	Biological Abstracts/BIOSIS Previews Cochrane Library Cochrane Clinical Trials Register HECLINET: HealthCare Literature Information	1980-1988/1989-2001 (2001, Issue 4) (1969-2000)	contaminat* cross infect* decontaminat* detergent* disinfect* environment* equipment floor* furnishing health facility housekeep* hospital* hygien*

		Network Medline (Ovid) Science Citation Index SwetScan Web of Science (Science Citation Index Expanded) EMBASE EMBASE alert Somed Internet	 (1966-2001) (1991-1996) (1997-2001) (1997-2001) (1974-2001) (1978-2000) 	inanimate* infect* control surface*
Screening & Isolation	(Cooper et al. 2004)	Medline Embase CINAHL SIGLE Cochrane Library	1966-Dec. 2000 1980-Dec. 2000 1982-May 2000 1980-May 2000 until Dec. 2000	MRSA screening isolation of patients control of infection

Table 8. Numbers of articles located and passing authors' inclusion criteria

Systematic Review	Author or systematic review	Total # of articles located	# of articles passing inclusion criteria	Final # of articles passing most rigorous screen
Handwashing	(Backman et al. 2008a)	1120	35	12
Disinfecting Surfaces	(Dettenkofer et al. 2004a)	2035	80	4
Screening & Isolation	(Cooper et al. 2004)	4382	46	4 [a]

[a] Although Faogali (1992) and Farrington (1998) were also cited in the final articles selected by Cooper et al., 2004, I did not include them in this analysis because experimental conditions appeared to suggest incomplete isolation.

Table 9. Inclusion screens applied by systematic reviewers

Intervention	***Hand hygiene***	***Cleaning***	***Screening and Isolation***
Systematic Review	(Backman et al. 2008a)	(Dettenkofer et al. 2004b)	(Cooper et al. 2004)
Screens applied (most rigorous) ↓ (least rigorous)	Experimental study Randomized Controlled Trial Experimental study without randomization Observational study with control group Cohort study Case control study Observational study with control groups Cross-sectional study Before-and-after study Case series Reviews of research (only if they clearly defined the parameters of their search strategy, including inclusive dates of the review, databases searched, and search terms used)	Meta-Analysis based on Randomized controlled trials Nonrandomized concurrent cohort comparison between contemporaneous patients who did and did not receive an intervention Nonrandomized historical cohort comparison between current patients who did receive an intervention and former patients who did not Case-control study Case series without control Exert judgment, consensus statements, reports	Prospective interrupted time series Retrospective interrupted time series Hybrid retrospective and prospective time series Retrospective cohort study Non-comparative (one phase) studies
	Minimum requirement: accepted studies should include a component of prospective data collection		

Table 10. Articles that passed the most selective criteria of systematic reviewers

Topic	Article	% Reduction of MRSA	Citation
Handwashing	(Backman et al. 2008a)	0.01% ↓	(Pittet 2000)
		17% ↓	(Aragon et al. 2005)
		57% ↓	(Johnson et al. 2005)
		11% ↓	(Ng et al. 2004)
		68% ↓	(Brittain 2005)
		21% ↓	(Gordin et al. 2005)
		0.9% ↓	(MacDonald et al. 2004)
		2.14% ↓	(Schelenz et al. 2005)
		6.8% ↓	(Kac et al. 2000)
		8.1% ↓	”
		2.01% ↓	(Stone et al. 1998)
		0 % ↓	(Larson et al. 2000)
	Average	**~21% ↓**	-
Disinfecting Surfaces	(Dettenkofer et al. 2004a)	~0%	(Dharan et al. 1999) (Danforth et al. 1987) (Daschner et al. 1980) (Mayfield et al. 2000)
	Average	**~0 % ↓**	-
Screening & Isolation[a]	(Cooper et al. 2004)	98% ↓	(Coello et al. 1994)
		90% ↓	(Cosseron-Zerbib et al. 1998)
		67% ↓	(Duckworth et al. 1988)
		60% ↓	(Harbarth et al. 2000)
	Average	**~79% ↓**	-

[a] Although Faogali (1992) and Farrington (1998) were also cited in the final articles selected by Cooper et al., 2004, I did not include them in this analysis because experimental conditions appeared to suggest incomplete isolation.

4.6 Discussion of results

4.6.1 Results

The screens used by the systematic review authors differ. However, they are also relatively similar in their assignment of hierarchy. Backman et al. (2008a) and

Dettenkofer et al. (2004b) both use randomized controlled trials as their most rigorous screen. Cooper et al. (2004) relied on a time series rigor screen because most hospitals will not conduct randomized control trials during a time of outbreak, for ethical reasons (it would be ethically questionable to ask some staff members to not wash their hands). However, as was discussed in **Section 4.2.1.2**, time series results are usually not considered to be of the same level of rigor as randomized controlled trials, since a drop in infection rates may not be due to handwashing, but rather to coincidentally-occurring seasonal variations.

According to the systematic reviewers, screening and isolation appear to offer the best opportunities for cost saving (approximately 80%), handwashing comes in second place (approximately 21%), and cleaning of surfaces in third (0%). Please note that the Dettenkofer et al. (Dettenkofer et al. 2004a) have clarified that they focused on cleaning of walls and floors in their articles, and not high contact surfaces.

Assuming the results are relatively accurate, the significant drop in infection rate following isolation is perhaps not surprising because quarantine (which is, in effect, isolation) is one of the most effective methods traditionally used to control infection outbreaks. It appears that increased efforts in handwashing result in some infection control, but not as much as one might expect. There may be a number of reasons for this, including: (a) staff and visitors are not washing hands as required, and (b) MRSA is also being passed through other means, such as via the air or by contact with high contact objects, such as bedrails and doorknobs.

4.6.2 Handwashing and the second layer of Root Cause Analysis

Root Cause Analysis does not necessarily stop with the cause and effect diagram. For example, even if the primary method of spreading MRSA is via hands of staff and visitors and the proposed countermeasure is to ask these individuals to clean their hands more fastidiously between touching patients, they may not comply. For example, in the case of handwashing, compliance has been shown to be poor; doctors are some of the worst offenders, as shown in **Table 11**.

Table 11. Compliance with MRSA precautions

Adapted from from (Afif et al. 2002)

Type of Healthcare Worker	*Compliance with all glove gown and hand hygiene precautions (%)*
Nurses	40
Physician	22
OT or PT	89
Orderly	18
Housekeeping personnel	4
Other personnel	24
Visitor	11

The implication is that it may be necessary to apply Root Cause Analysis—ask multiple "whys"—yet again to determine how to most effectively apply the proposed solution. For example, the following responses have been given when staff members are asked why they do not wash their hands:

- Hand hygiene agents cause irritation and dryness
- Sinks are inconveniently located or insufficient in number
- Insufficient soap, paper and towels
- Caregiver is too busy/has insufficient time

- Caregivers are understaffed
- Wards are overcrowded
- Patient needs take priority
- Hand hygiene interferes with HCW-patient relationship
- Perception there is a low risk of acquiring infection from patients
- Belief that wearing gloves substitutes for hand hygiene
- Lack of knowledge of guidelines/protocols
- Forgetfulness
- No role model from superiors or colleagues
- Skepticism about the effectiveness of hand hygiene
- Disagreement with the recommendations
- Lack of scientific information showing a definitive impact of improved hand hygiene on hospital-associated infection rates.

Adapted from Pittet (2001), Table 1, p. S41

Both inconvenience and drying of skin may explain why hand washing compliance appears to increase when hospitals make alcohol dispensers readily available to staff.

4.6.3 Making sense of the cleaning results

It is also reasonable to ask why cleaning surfaces should make so little difference to reducing incidence of MRSA, especially given that MRSA has been found to colonize surfaces and fomites as shown in **Table 12**.

Table 12. Proportions of environmental sites positive on high contact surfaces

(from highest to lowest, on average)

Reported values are from the following articles: (A) (Rampling et al. 2001), (B) (Boyce 1997), (C) (Sexton et al. 2006), (D) (Lemmen et al. 2004), (E) (French et al. 2004). Adapted from Dancer (2008)

	(%)					
	Outbreak	**Endemic**				**Site estimated** (mean)
Contact Surface	**(A)**	**(B)**	**(C)**	**(D)**	**(E)**	
Bed linen	-	38-54	44	34	-	41
Patient gown	-	40-53	-	34	-	40.5
Overbed table	-	18-42	64-67	24	-	40
Average quoted	11	27	49	25	74	37
Floor	9	50-55	44-60	24	-	34.5
Bed or side rails	5	1-30	44-60	21	43	27
Furniture	11	-	44-59	19	-	27
Sink traps or basis fitting	-	-	-	14	33	23.5
Room door handle	11	4-8	-	23	59	21.5
Flat surfaces	7	-	32-38	-	-	21.5
Blood pressure cuff	13	25-33	-	-	-	21
Infusion pump button	13	7-18	-	30	-	19
Bathroom door handle	-	8-24	-	12	-	14

However, recall that the systematic review primarily addressed the cleaning of floors and walls. These are areas that with which contaminated human hands do not often come into contact.

4.6.4 Results from isolation and their manifestation when applied

In the case of single room isolation, the results support that which has been observed in Holland and a number of Scandanavian countries, as is apparent from MRSA rates reported by Gould (2007) in **Table 13**.

Table 13. MRSA infection rates in the Scandinavian countries and the rest of Europe

Adapted from Gould (2007), table 3, p. S67

MRSA rates	(%)
Netherlands	0.93
Iceland	0
Norway	1
Sweden	1
Denmark	1.7
Estonia	2
Finland	2.9
Slovenia	10
Czech Republic	13
Slovakia	19
Hungary	19
Germany	21
France	27
Spain	27
Italy	37
UK	44
Portugal	47
Romania	61

Interestingly, MRSA appears to have been brought under control in Holland and the Scandinavian countries, Also, **Figure 45** suggests that the number of *S. Aureus* bacterium resistant to Methicillin in Denmark has dropped over time—something which enables infections to be treated via currently available antibiotics. The Dutch have institutionalized a "Search and Destroy" strategy; they place incoming patients in single patient rooms, and use barrier precautions (caps, masks, gowns and gloves when entering a room) after screening and preemptively isolating patients that come from situations with endemic MRSA (Vandenbroucke-Grauls 1996; Verhoef et al. 1999). Remarkably, incidence of MRSA in the Netherlands has been maintained to less than 0.5% (Vriens et al. 2002).

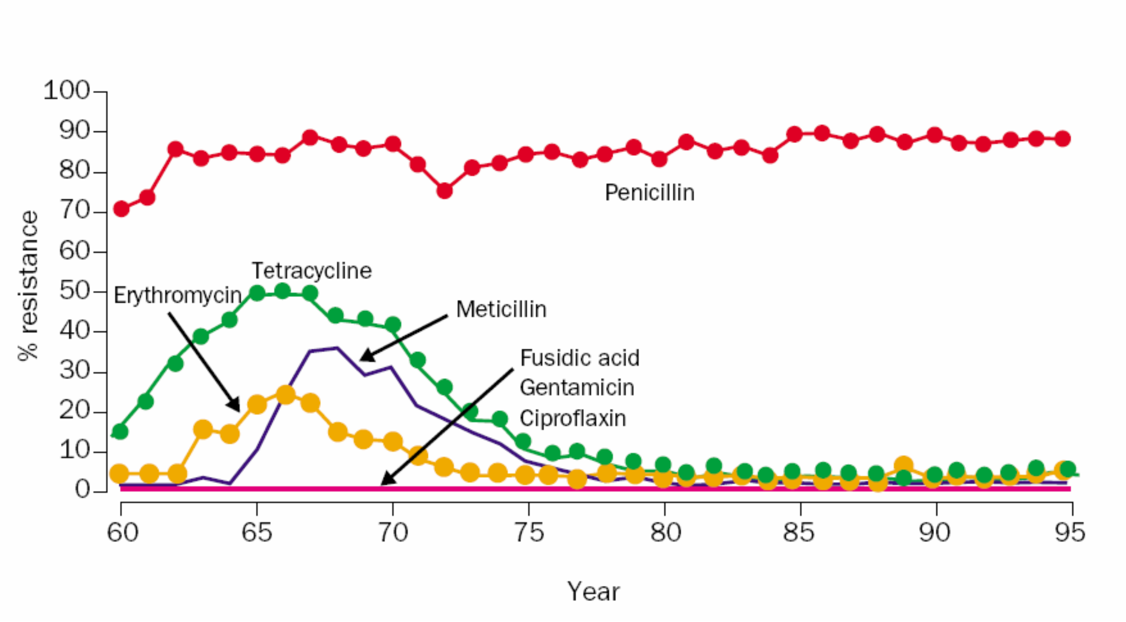


Figure 45. Percentage of S. aureus blood resistant to antimicrobials in Denmark: 1960-1995

Source: DANMAP Report, 1997
From *The Lancet Infectious Diseases*, 1, Farr, B.M. Salgado, C.D., Karchmer, T.B., and Sherertz, R.J. "Can antibiotic resistant nosocomial infections be controlled?" 38-45, Copyright 2001. Reprinted with permission from Elsevier

The success enjoyed by Scandinavian countries in reducing incidence of MRSA has been watched by healthcare facility operators in other countries because it suggests that the strategy of screening and isolation can and does work.

4.6.5 Call to conduct proper experiments

Testing the tools suggests that hand washing makes some difference (>= 21%), environmental cleaning makes no difference (>=0%) and screening and isolation makes a great deal of difference (>=79%) to rates of hospital-acquired infections.

But can the results be trusted?

A cursory interpretation would suggest that a facility should focus on building single–patient rooms, ignore cleaning walls and floors and spend only moderate energy on asking staff to wash their hands. Is this the appropriate strategy healthcare facilities should use? Perhaps it is, but there are also limitations that need to be acknowledged:

(1) Despite the level of screening to which each study was subjected by the systematic reviewer, very few included true randomized controlled trials.

(2) Buried beneath a specific quantitative result may be a story attached to the specific functioning of that facility itself. For example, if thorough cleaning of walls and floors truly makes no difference to the incidence of MRSA, it may be because (a) MRSA does not colonize facility surfaces, (b) floor and wall surface areas are so large that any transfer of MRSA to them is negligible by comparison, (c) MRSA does colonize wall and floor surfaces but they are relatively untouched by the hands of those who might transfer colonies, or (d) walls and surfaces are so heavily and frequently colonized by MRSA that any attempts to clean them are not frequent enough to make a difference.

My experience is that populating the chart with pre-screened evidence, as described in Section 4.2.1.1, takes a considerable amount of effort. Screening between 1000 and 4000 articles for inclusion and then level of rigor relies on the availability of teams of scientists or at least highly trained technicians. Interpreting the results must also be done carefully. In other words, there are fundamental questions about the behavior of MRSA that still need to be addressed. There are easier and more reliable ways to answer the questions then through screening scientific articles of dubious quality.

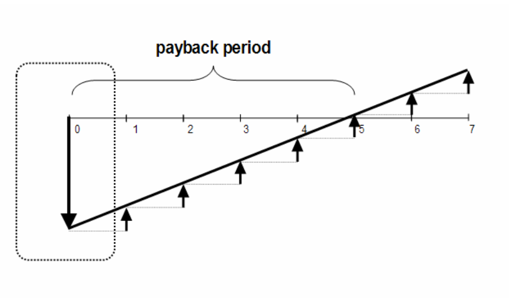
For example, while it is understandably unacceptable to conduct RCTs about MRSA on human subjects, it is perhaps ethically more acceptable to undertake RCTs on immuno-compromised laboratory rats or mice. Such types of experiments are relatively simple to conduct. For example, an air tube connecting two groups of mice and measuring the rate of transmittance from infected to uninfected mice offers an indication of the strength of MRSA transferal through air pathways. Similarly contact passage of MRSA via exposed contaminated surfaces versus uncontaminated surfaces, or colonized mouse skin versus uncolonized mouse skin would presumably require a relatively simple experimental setup. A search through the medical literature suggest that these types of experiments are currently *not* being done with any rigor. Why is this so? The practice may reflect insufficient federal research funding in recent years, or the separation between medical practice and research, for example. Although laboratory findings are not identical to experimentation with human subjects, they can offer a strong indication of the behavior of a particular pathogen in a healthcare setting.

4.6.6 Application to EBD

Designers respond to a given program, but they also create spaces that influence the types of programs that can easily be realized. One way to approach EBD research is to collect examples of spaces that appear to support a patient's rate of recovery. Another way to approach EBD research is identify solutions to recovery problems and then to design spaces that support faster recovery.

Much EBD research has thus far focused on the former approach. This dissertation has explored one way to approach the latter.

Chapter 5



In some instances, the cost of EBD interventions can exceed an owner's ability to finance them.

This chapter examines two case study projects that lowered the hurdle of first cost by applying Target Costing and Target Value Design.

5.0 Part II: First cost

5.1 The Dilemma: How can EBD overcome the hurdle of increased first cost?

5.1.1 Overview: Making Evidence-Based Design more affordable

Higher quality facilities can lead to long-term cost savings. This is the underlying assumption of Life Cycle Cost Analysis (Berry et al. 2004; Saxon 2005). The methodology is already being used by the sustainable design community to argue that reduced use of resources, reduced operation and maintenance costs, or enhanced productivity of staff can generate a positive net present value (NPV) of investments in buildings (Boussabaine and Kirkham 2004; Bull 1993; Evans et al. 1998; Ive 2006; Kirk and Dell'Isola 1995; U.S. Department of Transportation 2002). Such attempts to bolster the quality of decision-making based on long-term savings have merit; it makes intuitive sense that improved facility quality can lead to reduced need for maintenance and replacement over time. However, skeptics argue that a number of hurdles must be overcome in order to construct a higher quality building. For example, the pay-now-save-later expectation of LCCA is limited in its applicability because building owners wishing to construct a higher quality facility are still constrained by their ability to finance the project, a reality with which they must contend, irrespective of long-term benefits. In other words, *first cost*—or the capital investment cost that is expended on a facility when it is constructed—can become a significant challenge that may trump positive NPV calculations (Ashworth 1993; Cole and Sterner 2000; Moore 2001). Simply put, the ROI is irrelevant if you can not afford the investment in the capital (first) cost.

5.1.2 Target Costing and Target Value Design as a means to lower first cost

Leaders of lean construction have suggested that first cost can be made more manageable if building design teams apply principles of *Target Value Design* (TVD) during the design process (Ballard and Reiser 2004; Macomber et al. 2008; Nicolini et al. 2000). An emerging concept, the definition of TVD is in flux. Since TVD applies Target Costing to building construction, it helps to first define Target Costing.

According to Cooper and Slagmulder (1997), “Target Costing is a disciplined process for determining and realizing the total cost at which a proposed product with specified functionality *must* be produced to generate the desired profitability at its anticipated selling price in the future.” It is perhaps simplest to illustrate Target Costing as it applies to product design and then highlight how Target Costing differs from traditional product costing. In traditional product costing, a manufacturer may add a profit markup to a product’s production cost to establish its selling price. The problem with this method is there is no guarantee that buyers will be willing to pay the asking price. The process of Target Costing, by contrast, implements a reverse strategy; the market price is *first* established by determining how much buyers might be willing to pay (using focus group research or looking to similar products on the market, for example). A desired profit is then subtracted to give product designers the cost to which they must design the final product:

Target cost = Target Price – Target Margin (Clifton et al. 2004)

The word "must" is emphasized in the definition of Target Costing, suggesting that, if the product cannot be designed and produced at the required cost, the project must be abandoned (Clifton et al. 2004). This stipulation is the only way to ensure that the product will ultimately be profitable. The fundamental idea behind Target Costing is that customer constraints (time, cost, location, etc.) are conditional for delivery of value to the customer, and so constrain acceptable designs.

The concept of Target Costing, as applied to product design, can also be envisioned diagrammatically, as shown in **Figure 46**.

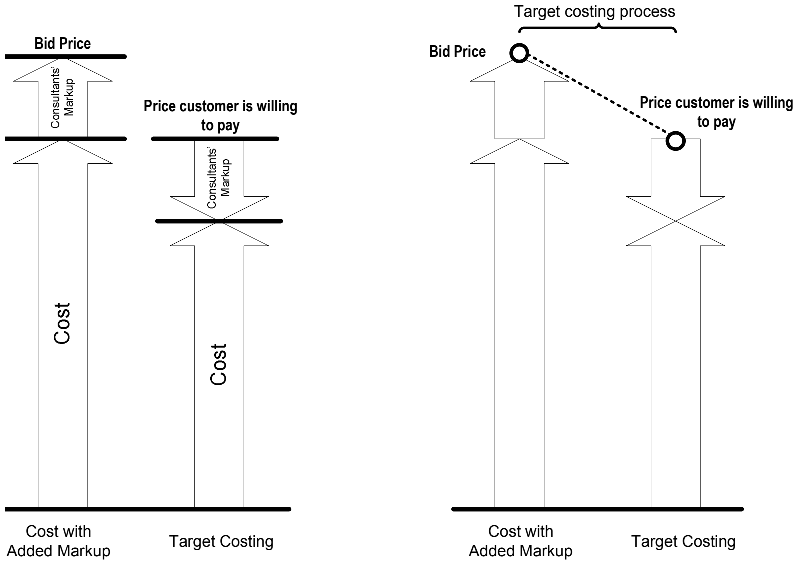


Figure 46. Cost with Added Markup versus Target Costing

Cost with an added markup is often used in to determine price in traditional design-bid-build delivery systems.

TVD builds on the above concept of Target Costing but represents Target Costing applied to construction rather than product design. While it is helpful to understand the genesis of Target Costing in product development, the terms used by the TVD community differ somewhat in their meaning and include four distinct components, as defined by Glenn Ballard: *Market Cost*, *Allowable Cost*, *Expected Cost*, and *Target Cost*. They are defined as follows:

Market Cost is a benchmark cost; it consists of the cost per square foot that would be expected for comparable construction projects. *Allowable Cost* represents the maximum cost that must not be exceeded; if the project team cannot design to allowable cost, the project must be cancelled because it would, by definition, become financially unfeasible. *Expected cost* is the estimated cost of the project in its current state during the TVD process; the expected cost is continually recalculated with each new iteration of design. *Target Cost* is the stretch goal for the project, meaning it is usually set below Allowable Cost (Ballard 2009a). For clarity, these terms are represented diagrammatically in **Figure 47**.

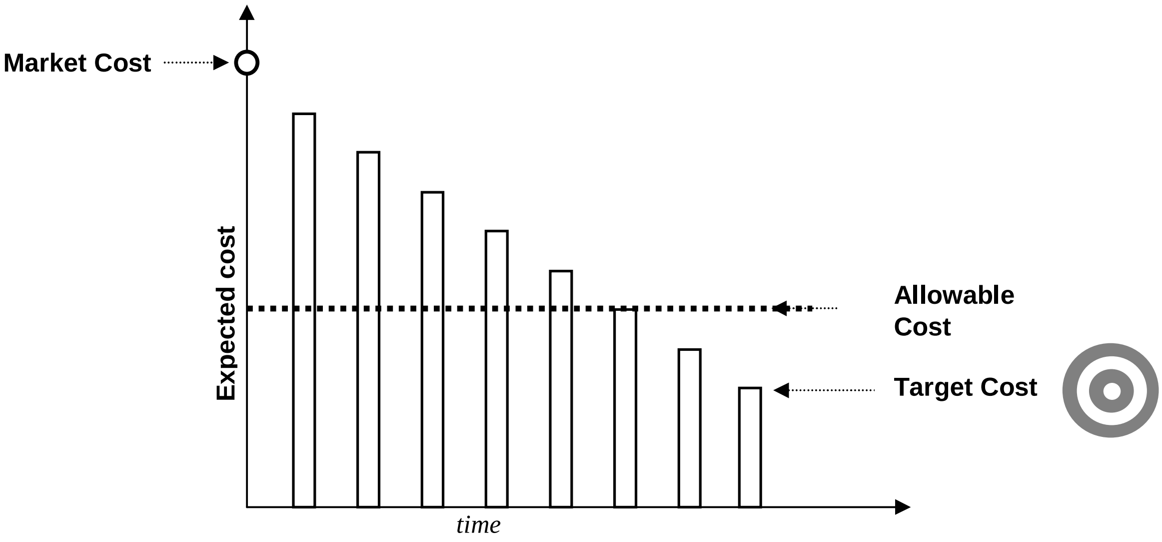


Figure 47. Costing terms associated with TVD

Target Costing involves *value engineering*—but performed the way value engineering was originally intended. The dubious reputation of value engineering is a result of applying cost saving measures to a completed design, too often stripping the project of those elements that make it interesting or unique and sacrificing the functionality or durability of one or more subsystems of the building. By contrast, Target Costing processes are applied throughout the design of a project, ensuring that waste is eliminated and value added continuously. Applying value engineering in this way ensures that total savings are generated and shared by each of the subsystems, as shown in **Figure 48**.

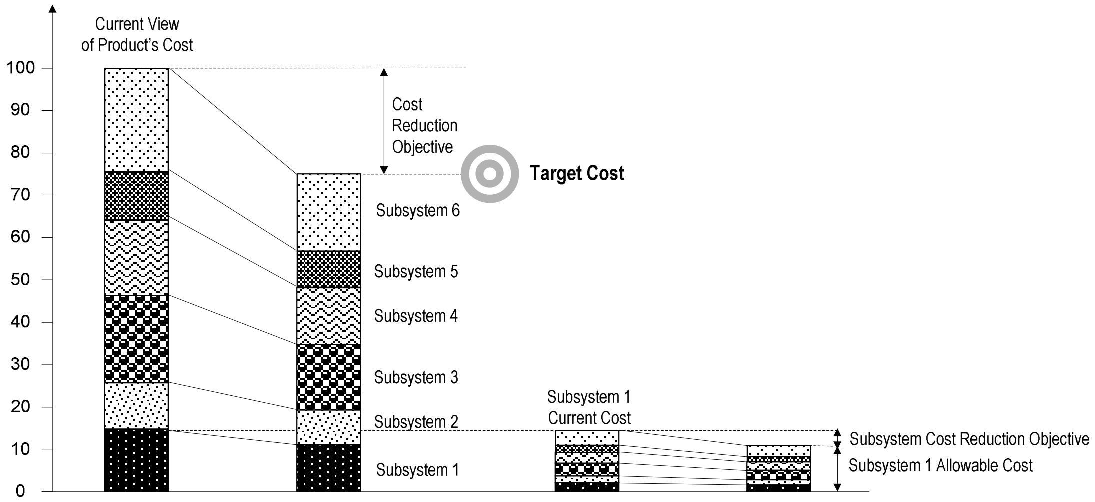


Figure 48. Cost savings shared by subsystems, as a result of Target Costing exercises
Adapted from Clifton et al. (2004)

5.2 TVD—Target Costing within the culture of Lean

Appendix 9.1 discusses many of the problems associated with a typical design-bid-build delivery system, including: inter-team conflict, construction defects, and extensive litigation. Because of the challenges facing the construction industry, lean construction officially entered the mix in 1993 when the International Group for Lean Construction was founded, promising a means to ameliorate many of these of these challenges (International Group for Lean Construction 2009). The **Appendix** introduces fundamental concepts informing the lean construction process.

Lean construction has already attained considerable successes, as is evidenced by the burgeoning numbers of industry and academic participants in lean construction organizations such as the Lean Construction Institute, the International Group for Lean Construction, and the Project Production Systems Laboratory (International Group for Lean Construction 2009; Lean Construction Institute 2009; P2SL 2005).

TVD has emerged from a culture of lean and lean construction was the delivery method of choice for the case study projects documented in this chapter. Therefore, discussion about Lean Construction has been included to provide a necessary backdrop for the discussion that follows.

TVD is Target Costing adapted from product development for construction. Since Target Costing central to TVD, this section will now focus on the emergence of Target Costing—a practice central to TVD.

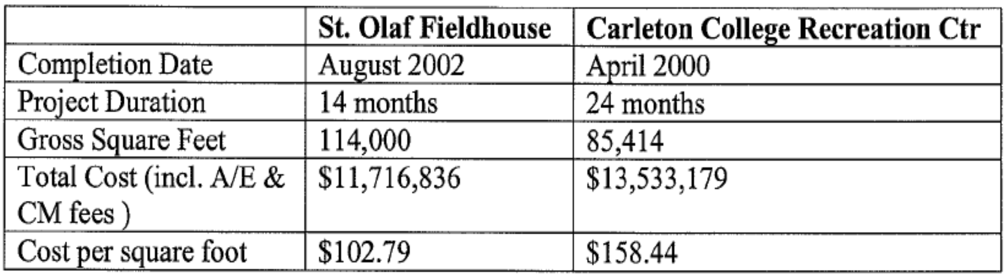
Target Costing was defined, as the term is used in product manufacturing, in **Section 5.1.1.2**. Once the price a client is able and willing to pay has been established, the design team subtracts a reasonable profit markup. In product design, the remainder is called the Target Cost—the project cost to which a design team must aspire and never surpass. However, terms such as “target cost” have assumed a slightly different meaning within the lean construction community.

In 2000, Nicolini et al. published one of the first research papers on Target Costing for the construction industry. The authors argued that setting a price by adding a markup to costs, as is often done on traditional design-bid-build systems, is problematic—and not only because it generates projects that exceed a client's capacity to finance it; the method also set suppliers and service providers against the owner, removing any incentive to streamline costs early on. The authors argue that by openly establishing constraints upfront and engaging participants in a collaborative delivery process Target Costing, by contrast, encourages participants to work in the best interest of the project itself (Nicolini et al. 2000).

Clifton et al. (2004) published a workbook-style textbook on TVD with recommended workshops to help transform the traditional culture of industrial designers and engineers

5.2.1 Prior experiments in Target Costing

Soon afterward, Ballard and Reiser (2004) published results following the Target Costing exercises of the Tostrud Fieldhouse at St. Olaf College in Minnesota. The authors compared the project duration and cost per square foot of Tostrud with that of a similar project. They credited the savings obtained in the project budget and schedule to the Target Costing process used by the team (**Figure 49**). Because Target Costing is consistent with lean philosophy and because it worked, Ballard and Reiser incorporated Target Costing into lean construction methodology at this point. In fact, several papers have since appeared on Target Costing in the *Proceedings of the International Group for Lean Construction* (Granja et al. 2005; Robert and Granja 2006). For example, Granja et al. (2005) related Target Costing to the process of *kaizen*—or continuous improvement—a process fundamental to lean construction, as has already been discussed.



	St. Olaf Fieldhouse	**Carleton College Recreation Ctr**
Completion Date	August 2002	April 2000
Project Duration	14 months	24 months
Gross Square Feet	114,000	85,414
Total Cost (incl. A/E & CM fees)	$11,716,836	$13,533,179
Cost per square foot	$102.79	$158.44

Figure 49. Comparison of two similar projects using different project delivery systems

The St. Olaf Fieldhouse was constructed using Target Costing and resulted in a lower cost per square foot and shorter project duration than a comparable project.

From Ballard, G., and Reiser, P. (2004). "The St. Olaf College Fieldhouse Project: a Case Study in Designing to Target Cost." *12th Annual Conference of the International Group for Lean Construction*, Elsinor, Denmark, 234-249. Reprinted with permission.

The Project Production Systems Laboratory at the University of California, Berkeley, published a current best practice guide to Target Costing in November 2005 (P2SL 2005). The recommended process steps were:

1. The client evaluates the business case and decides whether or not to fund a feasibility study.
2. The feasibility study involves all key members (designers, constructors, and client stakeholders) of the team that will deliver the project if the study findings are positive.
3. The client is an active and permanent member of the project delivery team.
4. The feasibility study produces a detailed budget aligned with scope.
5. All team members understand the business case and stakeholder values.
6. A cardinal rule is agreed upon by all performers: the Target Cost cannot be exceeded.
7. Cost estimating and budgeting is done continuously (i.e., “over-the-shoulder estimating”) through intimate collaboration between design professionals and cost modelers.
8. The Last Planner system is used to coordinate the actions of team members (the Last Planner will be described in Section 9.1.5.2).

(P2SL 2005)

Of note is Item 4 that recommends that a feasibility study be produced to provide a detailed budget aligned with scope.

Meanwhile, P2SL tested Target Costing processes on two additional projects: the ARC Project, completed in 2005, and Shawano Clinic, completed in 2006 (Ballard 2009b).

The term TVD began to enter the literature when Macomber et al. (2005) used it to refer to Target Costing in construction. The authors published a list of seven foundational practices in TVD and then updated that list to include nine (Macomber et al. 2008). Macomber et al. reinforced the importance of continually designing to a detailed estimate and stated this in Item 3. The practices suggested by Macomber et al. are listed in **Table 14**.

Table 14. TVD foundational practices

From Macomber et al. (2008)

1. *Engage deeply with the client to establish the target value*. Both designers and clients share the responsibility for revealing and refining concerns, for making new assessments of what is value, and for selecting how that value is produced. Continue engaging with the client throughout the design process continue to uncover client concerns.
2. *Lead the design effort for learning and innovation*. Expect that the team will learn and produce something surprising. Establish routines to reveal what is learned and innovated in real time. Also expect that surprise will upset the current plan and require more replanning.
3. *Design to a detailed estimate*. Use a mechanism for evaluating design against the budget and the client's target values. Review how well you are achieving the targets in the midst of design. When budget matters, stick to the budget.
4. *Collaboratively plan and replan the project*. Use planning to refine practices of coordinating action. This will avoid delay, rework, and out-of-sequence design.
5. *Concurrently design the product and the process in design sets*. Develop details in small batches (lot sizes of one) in tandem with the *customers* (engineer, builders, owner, users, architect) of the design detail. Adopt a practice of accepting (approving) completed work as you design.
6. *Design and detail in the sequence of the customer who will use it*. This maintains attention to what is valued by the customer. Rather than doing what you can do at this time, do what others need to do what they need to do next. This leads to a reduction in negative iterations.
7. *Work in small and diverse groups*. Learning and innovation arises socially. The group dynamics of small groups—eight people or less—is more conducive to learning and innovating: trust and care for one another are established faster; and communication and coordination are easier.
8. *Work in a big room*. Colocating design team members is usually the best option. Design is messy. Impromptu sessions among design team members are a necessary part of the process. So are regular, short codesign sessions among various specialists working in pairs.
9. *Conduct retrospectives throughout the process*. Make a habit of finishing each design cycle with a conversation for reflection and learning. Err on the side of having more retrospectives, not less. Use plus/deltas at the end of meetings. Use more formal retrospectives that include the client at the end of integration events. Instruct all team members to ask for a retrospective at any time, even if they just have a hunch that it might uncover an opportunity for improvement.

Then in 2008, Ballard outlined the key steps projects were taking during P2SL TVD exercises, as shown in **Figure 50**. The Ballard diagram illustrates TVD as part of the overall project delivery process. It is interesting to note the reconceptualization of an independent Project Definition phase which involves establishing the allowable cost and target cost. The eventual need to create a separate phase makes sense because, to be successful, TVD relies on an accurate understanding of the Owner's financial capabilities. Recall that, unlike a traditional design-bid-build delivery system which presents an owner with a price after design parameters have already been established, Target Costing first establishes the allowable price an owner can afford (allowable cost); then the design team resolves not to exceed it.

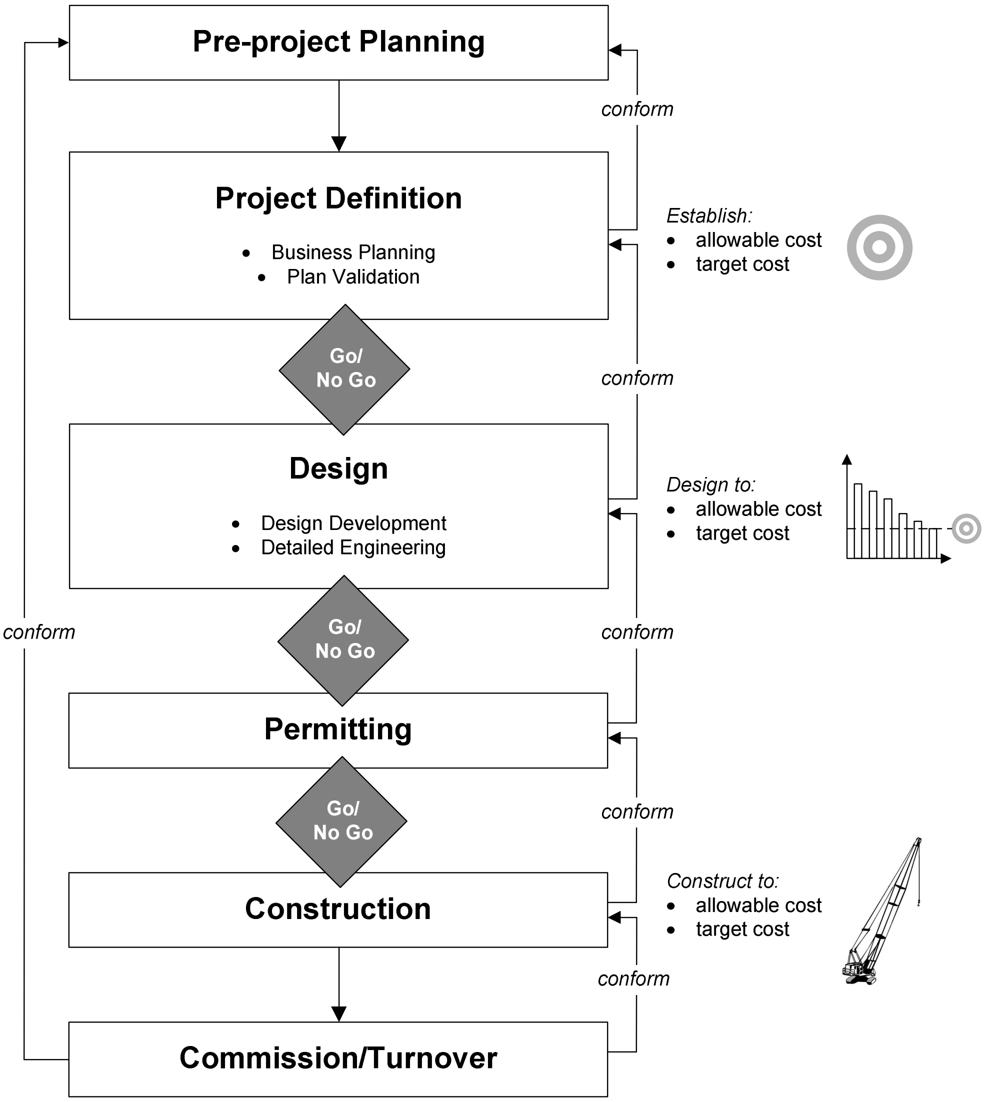


Figure 50. The TVD process as developed by P2SL.

Adapted from Ballard (2008).

5.2.2 Case Study 1: Medical Office Building in Fairfield, CA

5.2.2.1 Project overview

In 2005, civil and environmental engineering professors, Glenn Ballard and Iris Tommelein founded the Project Production System Laboratory (P2SL) at the University of California, Berkeley. P2SL facilitated the application of Target Costing to several projects financed by the hospital network, Sutter Health, including a three storey, 69,000 SF medical office building in Fairfield, CA. I was first exposed to Target Costing methodologies as an observer on this project, beginning in January 2006. Most Target Costing meetings included representatives from the following participants: the general contractor (the Boldt Company), the architect (HGA Inc.), the mechanical contractor (Southland Industries), the electrical contractor (Rosendin Electric, Inc.), and the financing organization (Sutter Health). The owner's representative continually re-estimated the cost of the project as the design changed and deepened in detail.

5.2.2.2 First-timer resistance & the Tesmer Diagram

The owner had no prior experience with Target Costing. It is therefore not surprising that TVD was challenged only three months into the exercise. Because TVD requires bringing professional consultants onto a project team early on (a practice which differs from traditional design-bid-build delivery), the owner began receiving professional service invoices earlier than they had anticipated. Also, the estimated cost of the project, at that time, was higher than the owner's allowable cost. There was talk the owner might cancel the Target Costing exercises and revert to traditional project delivery methods. In a dramatic moment, Mike Tesmer, Director of Preconstruction Services, Boldt Company, and facilitator at the Fairfield meetings, calmly explained to the owner's representative that while early estimates of most design-bid-build projects tend to be low, the costs later increase as details are added to the design. By contrast, Tesmer argued, the high estimates on the Fairfield project would likely drop over time because the team could minimize its contingency fund as more design details became settled. Furthermore, he added, having a fully loaded professional team early in design would allow progressive value engineering trade-offs to take place. To stress his point, Tesmer sketched a diagram on the board and explained how the two project delivery systems differed. Tesmer's diagram has been reproduced in **Figure 51**.

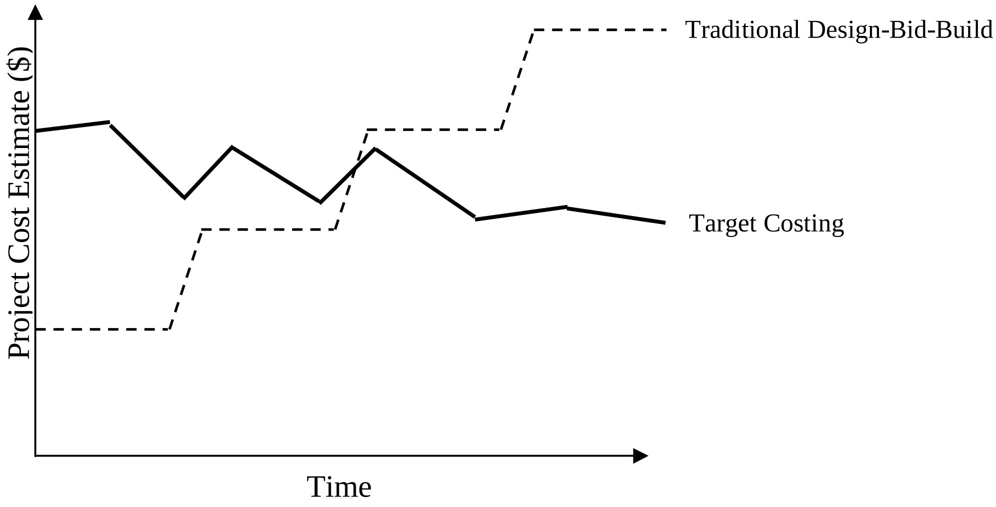


Figure 51. The Tesmer Diagram

(Tesmer 2006)

5.2.2.3 Results of estimated cost saving due to Target Costing

The estimated costs of the Sutter Fairfield project decreased steadily over the course of collective design, as shown in **Figure 52**.

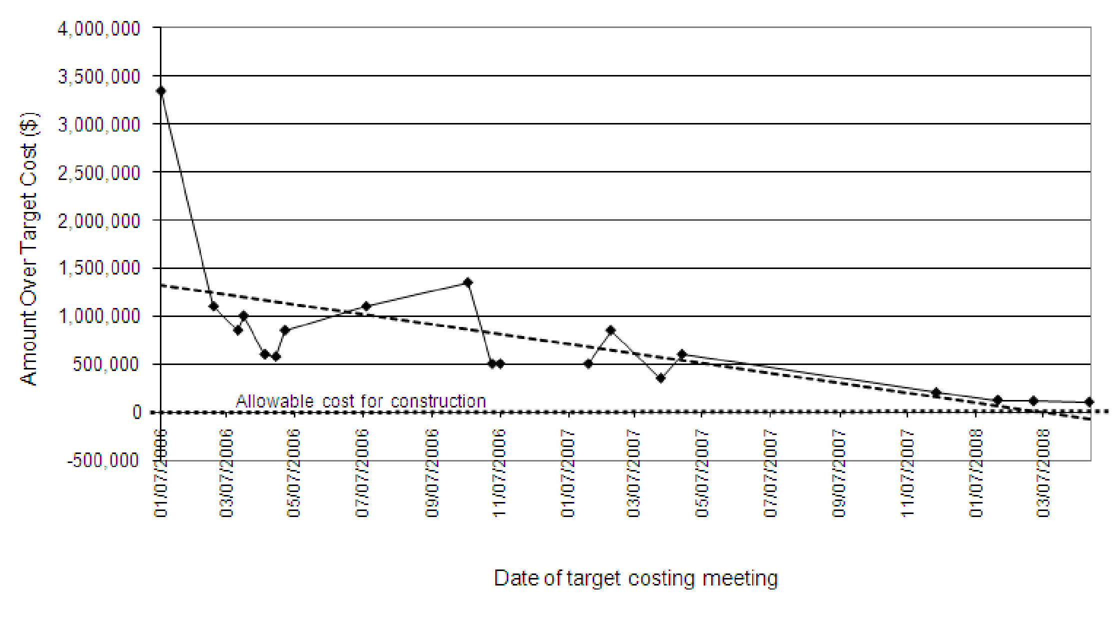


Figure 52. Project estimates, over time, for the Sutter Fairfield project

One of the most exciting aspects of the Sutter Fairfield project is that construction is already complete. In the end, although the project team had set an $18.9 million target (14% below the original $22 million market cost or benchmark estimate), the actual cost came to $17.9 million (19% below the market cost or benchmark estimate). The reduced costs the team had estimated during Target Costing held true during actual construction. The owner declared the project a success.

Development of the Fairfield project was so successful—even from the general contractor's side—that Boldt Construction authored its own in-house case study so that future employees could be trained in Target Costing methods (Toussaint and the Boldt Company 2008). In a report to the Construction Industry Institute and later in a summary paper to the International Group for Lean Construction, Ballard et al. (2007) included Target Costing as one of the key practices recommended when engaging a project team in Lean Construction methodologies. In their description of Target Costing, the authors indicate the need to "align project scope, budget and schedule to deliver customer and stakeholder value."

5.2.3 Case Study 2: Healthcare Facility in San Francisco, CA

5.2.3.1 Project overview

By the end of 2008, Target Costing had been successfully tested on projects costing less than $20 million. In lean construction, it is customary to experiment with ideas using first run studies before scaling up to costlier projects. While Target Costing had been used on such smaller projects, their stories have not all been told in detail. This chapter captures some of the nuanced methodologies used during Target Costing so these methodologies can be replicated and improved during future projects. Past Target Costing projects have also not included the level of rich complexity that encompasses the more comprehensive version of Target Costing—TVD.

5.2.3.2 Role of researcher within larger P2SL effort

This chapter describes and analyzes a TVD exercise that was a collective brainchild of Dr. Glenn Ballard, co-founder of the Project Production System Laboratory (P2SL) of UC Berkeley, and industry supporters of P2SL itself. It explores TVD of the Cathedral Hill Hospital (CHH) project, a 555-bed, 912,000 BGSF acute care women’s and children’s facility. This case study segment describes some of the key methods used by the project team to implement TVD, as well as the preliminary results of the TVD as of the time of this writing.

The CHH project is the subject of simultaneous analysis by several doctoral students, and so has been studied relatively well. For example, Hung Nguyen examined the project’s use of *Building Information Modeling (BIM*) and its role in Integrated Design Delivery (Nguyen et al. 2009), Farook Hamzeh documented the subtleties of *Last Planner Scheduling* (Hamzeh 2009), and Kristen Parrish addressed the intricacies of *set-based design* experimentation (Parrish 2009). Each researcher focused on a different facet of a metaphorical chiseled "diamond" called CHH. While it is not useful to duplicate the work of my colleagues, I am referencing their work so that anyone who wishes to more fully understand the nuances and complexities of the CHH project will be able to do so.

As mentioned in **Section 2.4**, my observation of Target Costing and TVD began with the Sutter Fairfield project, a 69,000 SF, three-story medical office building in Fairfield, CA. For approximately six months in 2006, I joined the project team for their biweekly—and later weekly—Target Costing meetings at the project's Fairfield headquarters. Because, prior to this time, Target Costing was a relatively untested design strategy within the lean construction community, the sometimes lengthy meetings represented early efforts to define the very meaning of Target Costing in construction.

Several key concepts emerged from these Fairfield meetings. One of the most fascinating was the development of the Target Costing diagram, as illustrated by Boldt project manager Mike Tesmer—referred to as the Tesmer diagram and discussed more fully in **Section 5.2.2.2**.

By the time the CHH TVD exercises began in 2007, the Target Costing process had matured considerably and the client, Sutter Health, was more experienced and confident in the process. The concern described in **Section 5.2.2.2** that had threatened the Target Costing process in the Sutter Fairfield project was no longer an issue by the time the CHH Project came around.

Instead of following the project as a longitudinal observational study as I did with Sutter Fairfield, I visited the CHH project periodically to speak to the project estimator Paul Klemish, to attend “Big Room” meetings, to observe building envelope cluster group meetings, to informally interview several members of the CHH project team, to photograph details of posted graphics of the facility, to monitor the group’s communal website, and to engage in discussions with two of the project’s full time observers, Farook Hamzeh and Hung Nguyen, about their observations regarding the TVD process.

5.2.3.3 Inclusion of Evidence-Based Design interventions in project

Some Evidence-Based Design interventions demand a higher first cost. Therefore the purpose of this chapter on TVD is to make the higher value offered by Evidence-Based Design recommendations financially feasible.

The California Pacifica Medical Center (CPMC)—an affiliate of Sutter Health—were the owners of the healthcare facility selected for this case study. Decision-makers for the CPMC project, called Cathedral Hill Hospital (CHH), aspired to the values espoused by Evidence-Based Design proponents. In fact, the patient-centered care mission of the project was posted prominently on a wall of the CHH project team office and has been reproduced in **Figure 53**. While not all EBD interventions necessarily cost more than a facility designed without them some—such as private patient rooms—most likely do. Therefore, the need to be able to meet a heightened first cost is very real.

California Pacific Medical Center
Cathedral Hill Hospital

California Pacific Medical Center is committed to a vision of healthcare for our community that will encompass a new state of the art facility and programs that will fulfill our mission of Clinical Excellence, Education, and Research.

The patient and family experience comes first:

- Patient-focused care
- Private patient rooms
- Accessibility and ease of way-finding
- Comfortable and varied environments
- Healing environments with natural light
- Visitor hospitality lounges on each floor
- Private medical consulting rooms
- Pleasant dining areas
- Awareness of diversity of cultures
- Parking convenience
- Efficient intercampus transfer and mobility
- One stop registration for all OP [operations]
- Easy access to emergency services
- A design that focuses on the patient
- Physician and staff friendly
- Sustainable
- Cost efficient and constructible

Figure 53. Contents of sign posted in CHH project office

It was assumed that the cost saving successes experienced during prior Target Costing exercises could and would be repeated with CHH—a much larger project. Unlike the Sutter Fairfield project, which used the term “Target Costing” to describe their delivery process, the CHH team used the term “Target Value Design” or “TVD”.

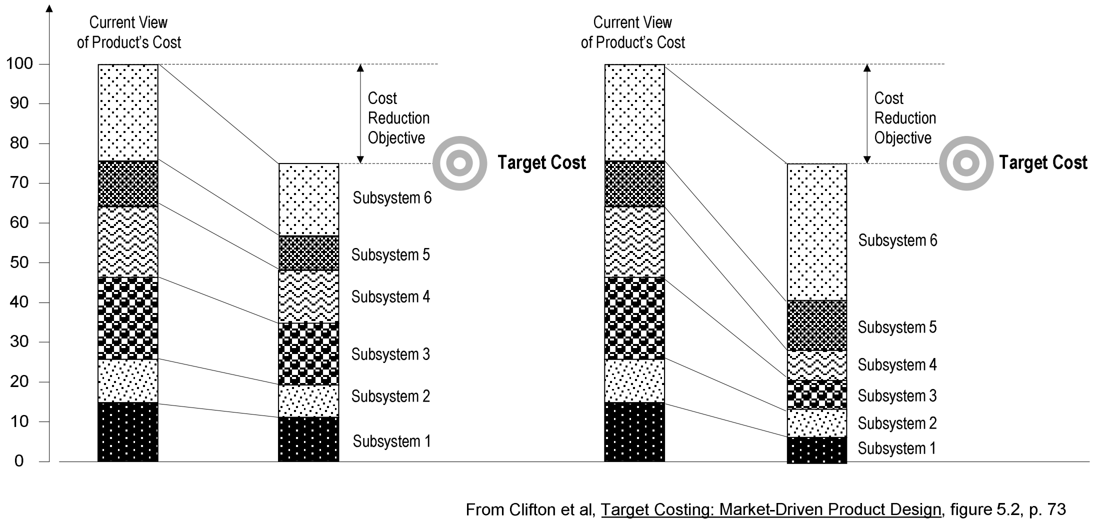
5.2.3.4 Role of Action Research

Because the practice of construction Target Costing is still developing and because implementation requires participation and exploration by all members of the project team (Greenwood et al. 1993), it was decided that action research was the most appropriate methodology to use for research of this nature. Action research can document a single project, but differs from more familiar case study research in that “the researcher is not an independent observer, but becomes a participant, and the process of change becomes the subject of research” (Benbasat et al. 1987; Westbrook 1995). Although my role was one of a case study observer, the project itself can be thought of as an action research experiment because new ideas were continually being tested as they emerged throughout its duration.

5.2.3.5 Role of Integrated Form of Agreement

Construction contracts that subordinate the interests of one party to another or distribute risk unevenly are common in the construction industry and have been blamed for high levels of distrust and litigation. Conversely, when a contract supports risk sharing, as does a relational contract, individual parties identify their own interests with that of the project (Koskela et al. 2006; Lichtig 2006). The CHH project team members were legally bound by a relational contract specific to Lean Construction called an *Integrated Form of Agreement* (IFOA).

One example of how the IFOA is written to favor the good of the whole over the parts is the way in which the contract allows budget allocations to flow across organizational boundaries in search of the optimal life cycle cost investment. For example, in the left diagram of **Figure 54** all subsystems share in cost-savings equally to arrive at the final total target cost. By contrast, the diagram at right demonstrates that, although Subsystem 6 turned out to require additional funds the remaining five subsystems adjusted accordingly to ensure that the overall project cost remains the same.



From Clifton et al, Target Costing: Market-Driven Product Design, figure 5.2, p. 73

Figure 54. Fluidity of funds across subsystems

Cost savings may be equal (left) or unequal (right) between groups.
Adapted from Clifton et al. (2004)

Specific values from the CHH project and its graphical representation are included in **Figure 55**.

		Amount over (under) budget ($)
Table1	Structural	(6,927,449)
2	Plumbing	(5,126,330)
3	Project Requirements & Escalation	(3,762,486)
4	General Requirements	(3,677,507)
5	Electrical	(1,238,442)
6	Fire protection	(290,644)
7	Building Sitework	(46,015)
8	Conveying Systems	160,934
9	Mechanical HVAC	1,711,316
10	Exterior Enclosure	4,419,058
11	Interiors	10,952,179
Total	**Construction Cost**	**(3,825,386)**

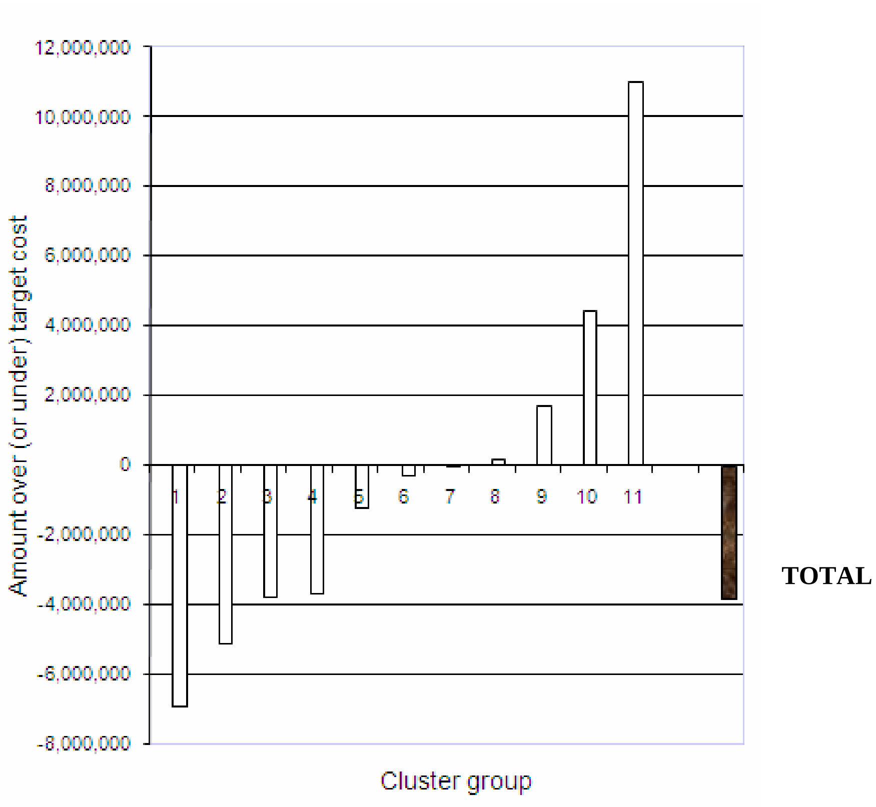


Figure 55. Example of fluidity of budget across cluster groups with CHH

The IFOA also reflected the equalitarian spirit of lean. Trade contractors were referred to as “*trade partners*” to more accurately reflect their role as integral contributors during the preconstruction and construction phases of Target Costing exercises. All existing team members and trade partners were permitted to interview new members under consideration and were permitted an equal voice during the hiring process.

The IFOA contract was utilized throughout the CHH project.

5.2.3.6 Role of Co-location

To maximize collaboration, team members physically *co-located* to the same office floor (**Figure 56**) during design of the CHH project. The co-located team included the contractor, as well as representatives from the mechanical, plumbing and electrical (5 days/week), curtain wall, architectural metal panels, shoring, elevator, drywall, structural steel and concrete trade partners (2-3 days per week). To enhance communication, members from a single company sat in multiple groups; for example, architectural representatives sat in the sustainability, planning, exterior enclosure, interiors, administration and technical architect groups (Klemish 2008).

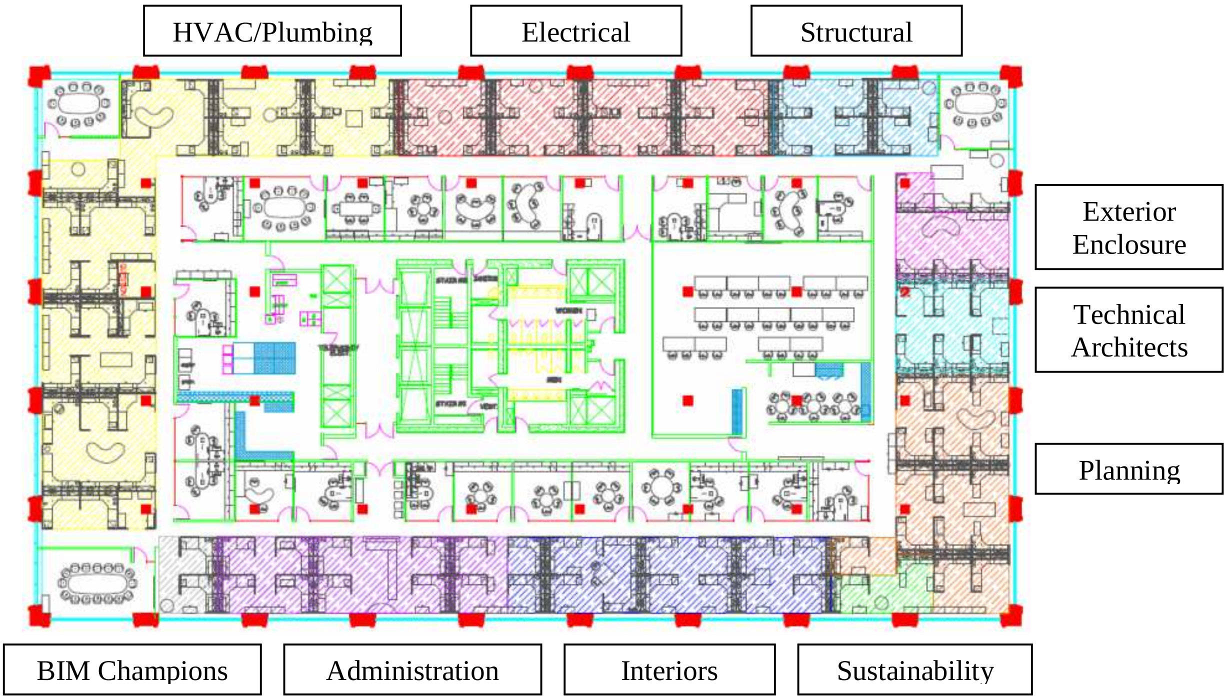


Figure 56. Cluster groups physically co-located on the same floor

Although the advantages of co-location may seem intuitively obvious, the amount of time that can be saved by situating team members within walking distance of other members' desks can be surprising. For example, in the swimlane diagram shown in **Figure 57**, information that travels from party to party via e-mail or fax may sit in a member's inbox or in-tray for hours or even days before being processed by the receiving party—time which can be classified as "waste". This time lag is minimized when members are co-located or rapidly conversing in a "Big Room" as represented by **Figure 58**.

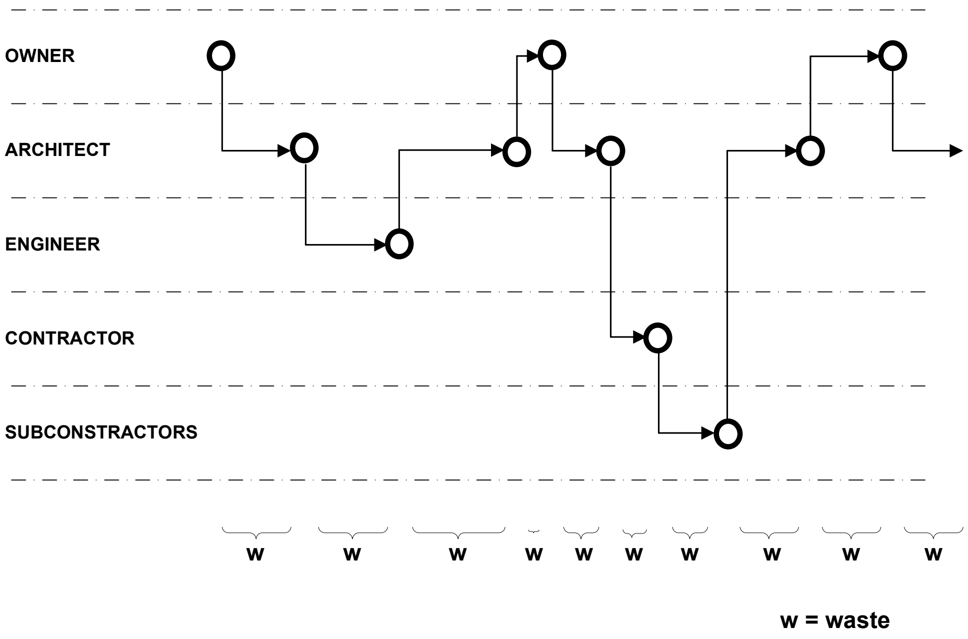


Figure 57. Communication without co-location

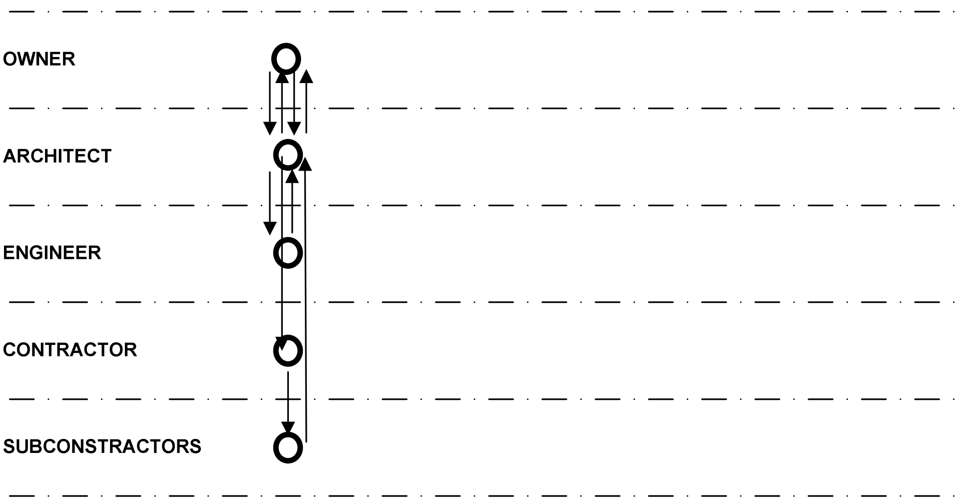


Figure 58. Communication between team members when co-located

5.2.3.7 Structure of CHH project delivery process

TVD is the practice of setting and designing to targets and providing feedback on achievement. Last Planner is a management system for coordinating action toward achieving project goals. Set Based Design is a strategy for designing and structuring design work, in terms of sets of design, their evaluation and selection.

As has been mentioned previously, the CHH TVD process took place within the culture of lean construction. In other words, while TVD was underway, coordination using Last Planner was taking place concurrently. The team designed to client value using Set-Based

Design, as well as its accompanying tools, within a culture of continuous improvement, while acknowledging and responding to price and schedule constraints. The TVD process enabled the team to respond to price constraints and the Last Planner system to schedule constraints. The delivery process was enveloped by the supportive legal framework called the Integrated Form of Agreement (IFOA)—a type of relational contract specific to Lean Construction (Integrated Project Delivery Team 2007), as described in **Sections 5.2.3.5** and **5.2.3.8.2**.

The structure of these inter-relationships is diagramed in **Figures 59-60**. I have used terms specific to Lean Construction in **Figure 59**. For clarity, the terms are replaced with functional descriptors in **Figure 60**. The term "pull"—which describes a methodology used during lean construction to describe a process that begins at a goal and works backward—is described extensively in **Sections 9.1.5.1** and **9.1.5.2**.

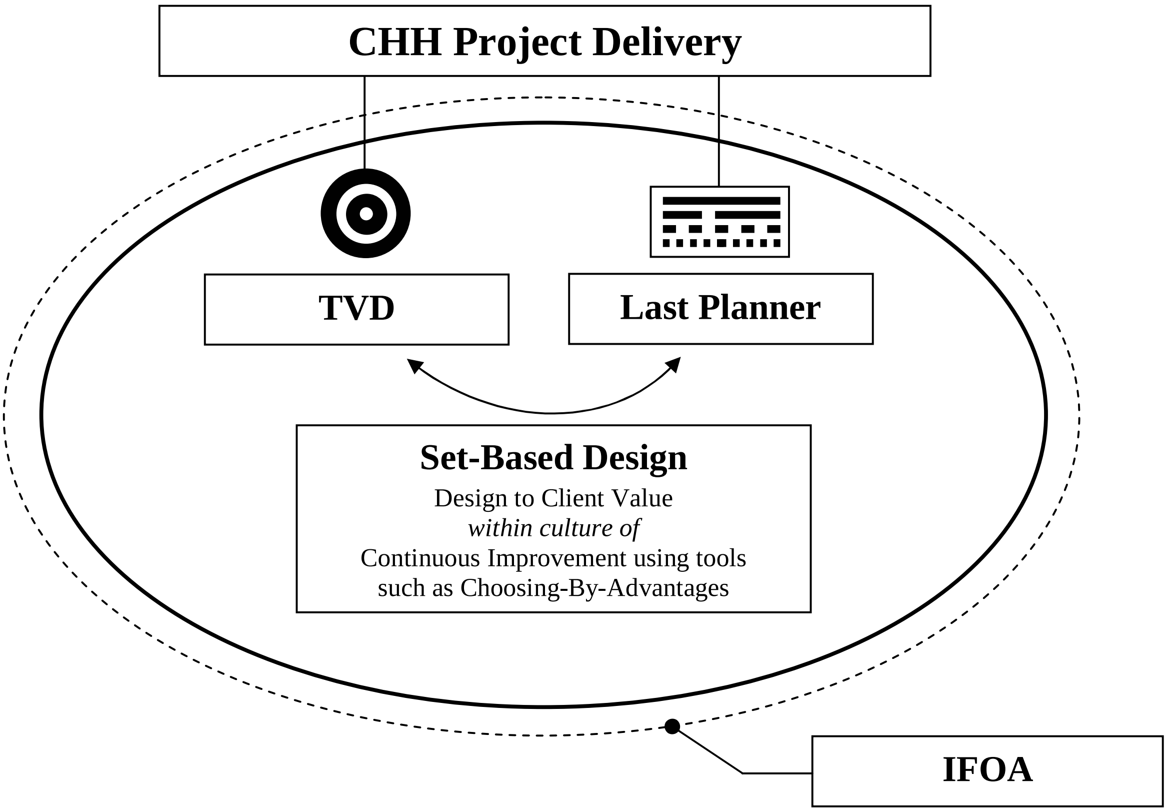


Figure 59. Structural overview of the CHH project delivery using Lean Construction Terminology

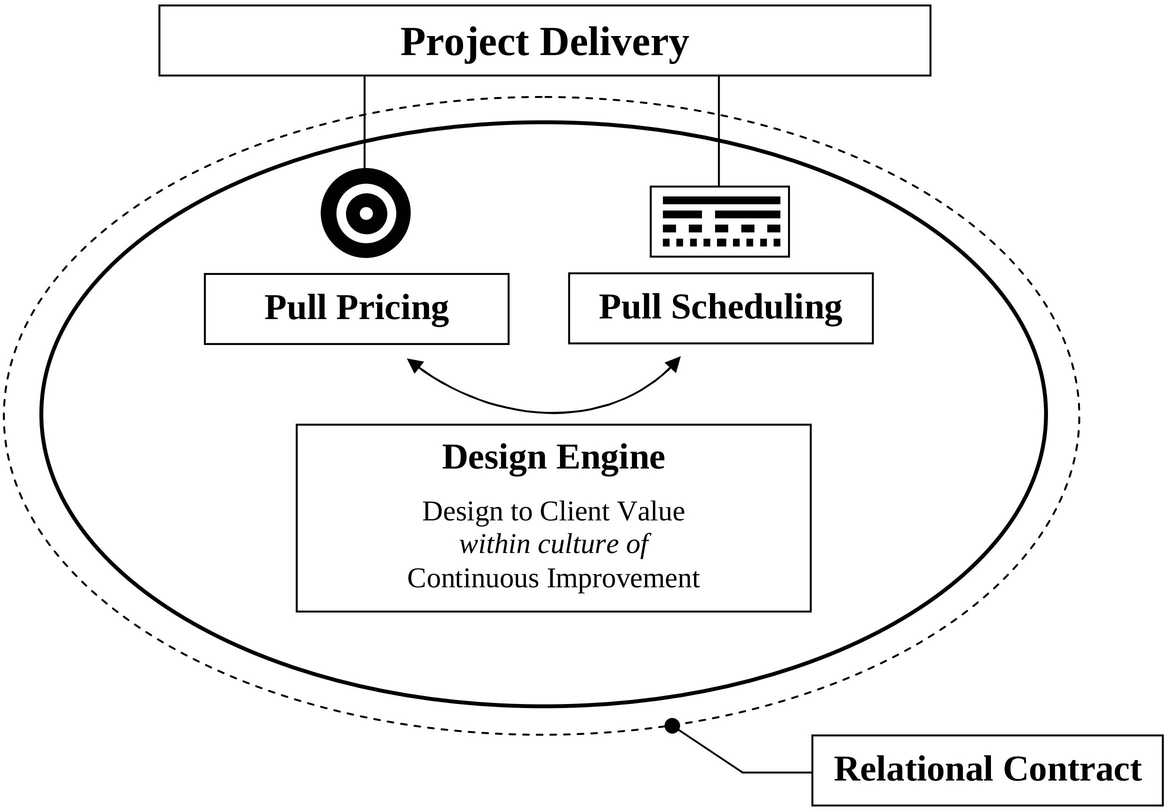


Figure 60. Structural overview of TVD using Functional Descriptors
(as practiced by the CHH project team)

TVD, as practiced by the Cathedral Hill Hospital project, consisted of a metaphorical Design Engine answerable to two key constraints: Price and Completion Date. To help the design teams respond to these two constraints, the team met regularly in full team TVD and Last Planner meetings.

Ultimate price constraints and scheduling constraints were determined during Plan Validation. Once these constraints were established, it was the role of the project team to brainstorm ways to collectively meet client value within the boundaries of these two constraints. The project team members generated ideas individually, during informal meetings at the project office site, within cluster group and committee meetings. They posted alternative (set-based design) ideas on the walls of the project office and discussed the financial and scheduling implication of those ideas. They used a decision-making tool, Choosing-by-Advantages (Parrish 2009; Suhr 1999) when deciding between critical alternatives, and used Building Information Modeling (BIM) to estimate constructability alternatives (Nguyen et al. 2009). An environment of Lean was cultivated. As soon as new team members joined, they were initiated into the lean way of thinking through group discussion of the Toyota Way. Ideas were continually discussed and improved; this reflected the lean ideal of continual improvement.

Responding to the two key constraint alignment processes: Pull Pricing and Pull Scheduling, took place once per week, each, in two “Big Room” meetings. The term “Big Room” has too meanings in lean thinking. It refers to the practice of co-locating teams and to bringing together team members in large group meetings. Pull Pricing used *Target Costing* strategies (Cooper and Slagmulder 1997); Pull Scheduling used the *Last Planner System of Production Control* method (Ballard 2000a). Engaging pull systems ensured the project team would be able to meet both the allowable cost and the final delivery date. Because they require different skill sets, the two types of “Big Room” meetings were facilitated by different individuals on the CHH project. The project estimator, Paul Klemish, facilitated TVD meetings and Andy Sparapani, Virtual Design and Construction Specialist, facilitated the Last Planner meetings. The temporal relationship of the “Big

Room" constraint alignment meetings (i.e., TVD and Last Planner) to Design Engine (Cluster Group) meetings is illustrated in **Figure 61.**

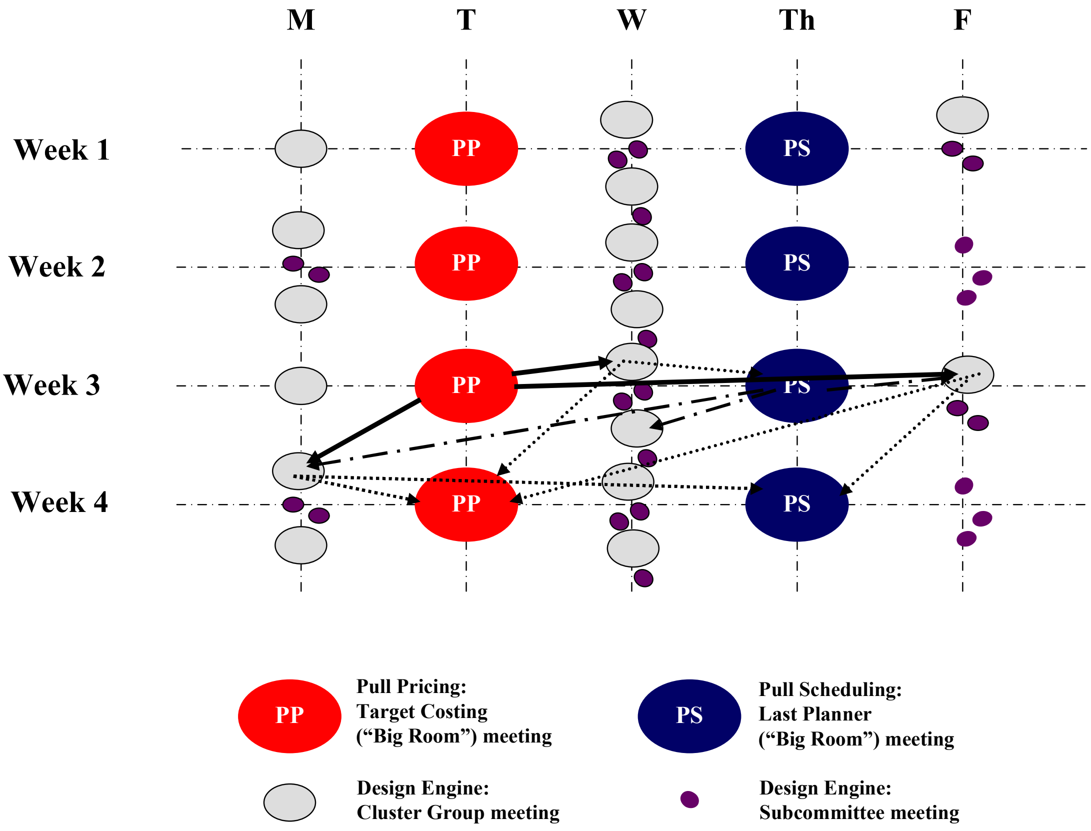


Figure 61. Structure of TVD exercise

Arrows indicate information flows iteratively from cluster group to big room meetings and back again

5.2.3.7.1 Role of multi-sized meetings

The Target Costing process is meeting intensive, as may be apparent from **Figure 61**. The project team met in a *big room* for approximately two hours each meeting, two times per week—once for a Target Costing exercise and once for a Last Planner exercise (Ballard 2000b; Hamzeh et al. 2008).

Planning and preplanning of individual parts of the project were generally accomplished during *cluster group* and subcommittee meetings. Each cluster group was assigned its own target cost to meet. Value engineering changes recommended by one group were circulated to all others to determine the cost implications on the entire project. Cluster Groups for this project included structural, MEP (mechanical, electrical and plumbing), exterior skin (architectural enclosure), interiors, project requirements, site work, and conveying systems. In addition to meeting with the entire project team twice weekly as previously described, Cluster Groups individually met 2-3 hours per week; these meetings were scheduled *not* to overlap, so that team members could attend other Cluster Group meetings, as needed. Representatives from a single company were members of multiple Cluster Groups. Additionally, a *Core Group* met weekly, and included executive representation from the owner, architect, contractor and concrete trade partner.

To benchmark the team's progress toward its target cost goal, the estimating manager weekly presented a current estimate plot so the entire team could monitor its current position vis-à-vis the target cost, as shown in **Section 5.2.2.3**. Material escalations were updated every 6 months and labor escalations every 12 months. Target Costing goals were established for each building subsystem to motivate each Cluster Group to develop innovative and unique cost saving opportunities.

Each group was permitted to use its own methods to update estimates. For example, although the structural engineering group used building information modeling (BIM) to regularly update its estimates, the architecture group used 2D electronic estimating methods.

Cluster Groups updated their estimates every 3 weeks. Paul Klemish, the Project Estimator, updated the project estimate weekly to reflect the total Cluster Group inputs.

5.2.3.7.2 The Design Engine: Set-Based Design & Continuous Improvement

Set-based design is a process in which design alternatives are defined and communicated between all disciplines, and choosing a single alternative is done at the last responsible moment. This occurs at each level of design development; from concept to detailed design (Parrish et al. 2008a; b). The process reduces the waste that accompanies negative iteration—iteration that does not add value to the design. Cluster groups used A-3 sized sheets of paper to document and post—for all to see and evaluate—design alternatives they recommended the owner adopt.

Although the project maintained a central intranet site with current drawings, updated drawing sets were regularly printed and posted on designated walls at the project office to reduce the waste and confusion that sometimes occurs when individual team members print their own sets.

Photographs of set-based design alternatives posted on the CHH project office walls, as well as images capturing the intensely graphic nature of Lean Construction are included in **Appendix 9.2**.

As explained in **Section 9.1.6.1**, a *plus/delta* exercise was used following meetings to ensure a spirit of continual improvement.

While this section presented an overview of the TVD process, the following sections will explore many of these processes in greater detail.

5.2.3.8 Structure of TVD processes

5.2.3.8.1 Role of plan validation & setting the target price

An earlier attempt to design the Cathedral Hill Hospital to budget failed. The cost reduction headway made on the earlier Sutter Fairfield project made Sutter corporate more willing to repeat its Target Costing experiments with the CHH affiliate. In fact, David Long, Senior Program Manager and Lean Coordinator, represented Sutter Health for both the Fairfield and CHH projects.

As he had done with the Fairfield project, Glenn Ballard, Adjunct Associate Professor at UC Berkeley and Research Director of P2SL, initiated the Target Costing exercises of CHH. However, instead of being called Target Costing, the exercises were now christened as Target Value Design or TVD—a term the group felt was more representative of the comprehensive nature of the exercises. Learning from initial pricing errors experienced during the Sutter Fairfield project (the initial price had been generated from rough estimates rather than through systematic analysis), Ballard urged the group to engage in an early pricing process known as *Plan Validation*. Although similar to preparation of a business plan, plan validation is much more participant-inclusive than a traditional business planning process. Like the rest of TVD processes, plan validation is an extension of Integrated Project Delivery (IPD); accuracy of estimating is improved by virtue of the fact that so many knowledgeable individuals—architect, engineer, contractor and critical trade partners—are included in partnership with the owner during price planning (Klemish 2009). Nevertheless, although the plan validation process used on the CHH project was helpful and more rigorous than processes previously implemented on P2SL projects, it still lacked the rigor of derivation from an operations cost model. Noting that the rigor of plan validation needs to be enhanced is one example of how construction processes benefit from a lean philosophy that is always in search of opportunities for continuous improvement.

To recall how plan validation sits within the TVD process, it may be helpful to refer back to the flow chart depicted in **Figure 50**. A flow chart depicting the Plan Validation process alone was developed by Ballard (2006) and is presented in **Figure 62**. For the Project Definition phase of the CHH project, the target cost was established during an extensive *business planning* and was followed by a four month *business plan validation*.

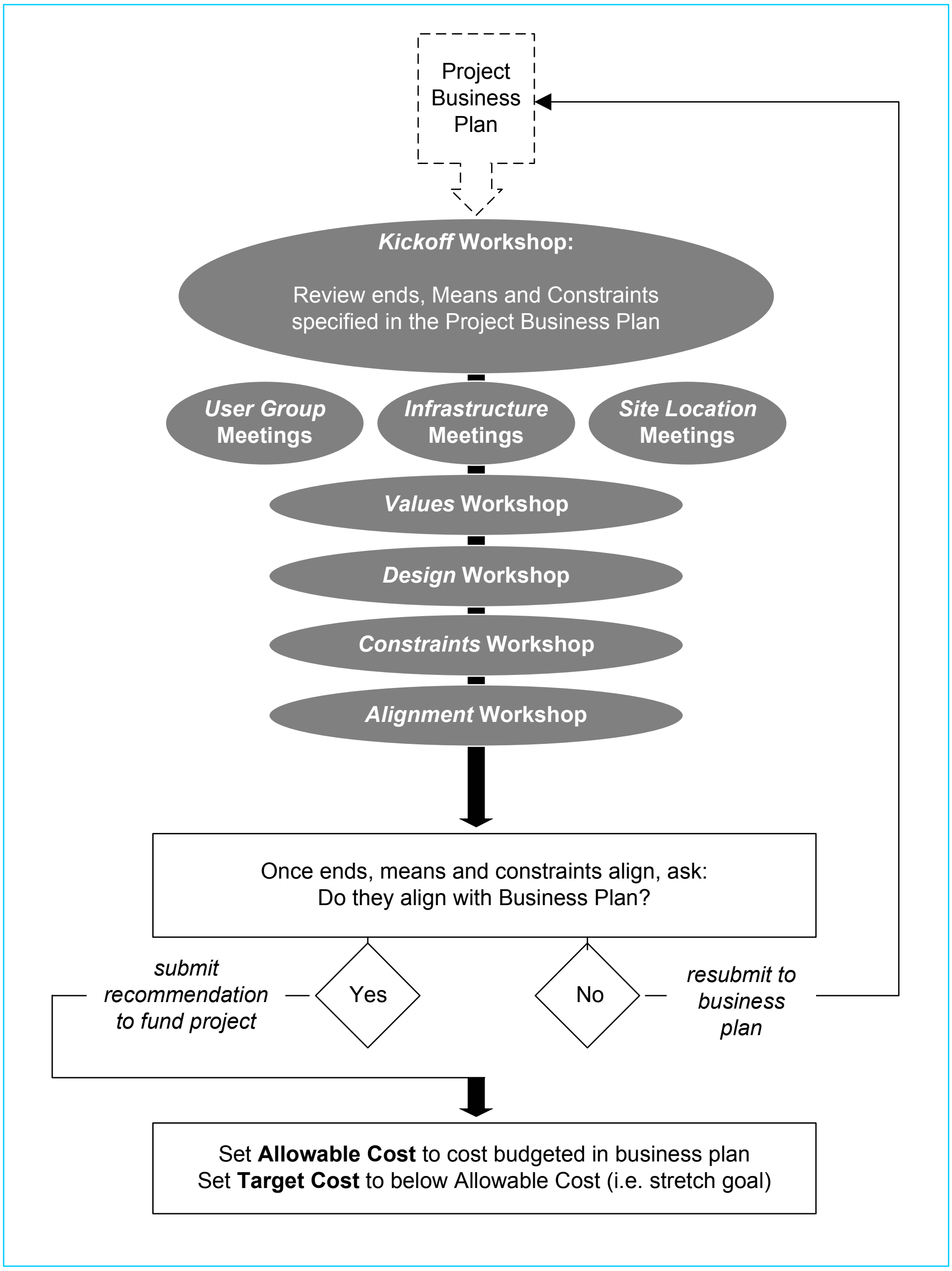


Figure 62. The project validation process.

Adapted from (Ballard 2006)

According to recollections of the project estimator Paul Klemish, the project's functionalities and capacities were inherited from an earlier unsuccessful design attempt: a 1.4 million SF hospital co-designed by architects SOM, the Smith Group and SMW. The first design attempt failed and the original design team was disassembled; a budget of approximately $911,000,000 was then established by the owner after the project had been resurrected. The owner then hired a new project architect; it was the Smith Group, as before, but this time, the Smith Group only. The owner required that 90% of the previous program fit into an area that was now 858,000 SF—approximately 60% of what it had previously been. After the cost of the parking garage ($40,000,000) was subtracted from the $911,000,000, a total of $871,000,000 remained. The new cost per square foot was therefore $871,000,000 / 858,000 SF or $1015/SF, with escalation. In other words, the client required the new project team to develop a fresh design for the same total allowable cost but that was more dense (i.e., more walls/SF, more doors/SF, etc.) than the previous hospital.

In order to determine how the $1,015/SF price compared to other projects built in the San Francisco Bay area, project estimator, Paul Klemish, obtained prices from peer estimators of other hospitals in Northern California. Klemish escalated these other hospital prices to current costs (2nd quarter of 2009), and applied cost adjusted factors, such as a high-rise factor, or a geographic adjustment, so that peninsula, Sacramento-based, or North Bay projects could be converted to San Francisco-based costs, to create a market cost benchmark. Klemish also removed the cost of owner-provided items that had been rolled into the $1015/SF cost of the CHH Project (e.g., Medical equipment, cabling, pneumatic tube systems, sitework or parking). Once these items were excluded, a cost of $719/SF remained and a reasonable apples-to-apples comparison could be made (Klemish 2009).

Deleting high and low outliers, Klemish obtained an adjusted average market cost of $753/SF for similar projects. He then plotted the original estimate value of $719/SF against the average adjusted market cost. After project validation, an allowable cost target of $654/SF emerged. These values are represented in **Figure 63**.

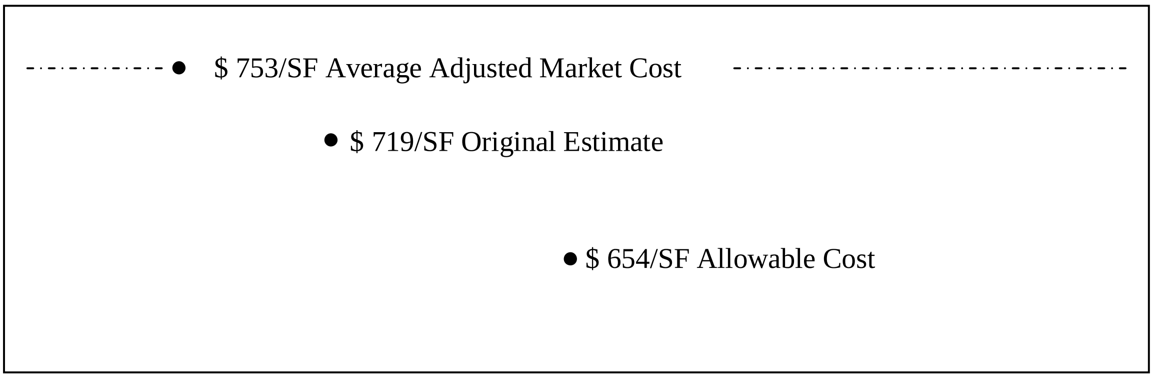


Figure 63. Setting the Allowable Cost
The original estimate was already below the Average Adjusted Cost, and the Allowable Cost was set below the Original Estimate (Klemish 2009)

The allowable cost target turned out to be 13% below market cost/SF and 10% below the original estimate, and it gave the team a goal to meet or even beat. This allowable cost target was based on the owner’s ability to finance the project, coupled with a desire to extend below market cost/SF. A target cost—or stretch goal—was later established to surpass the allowable cost target. It is worth reflecting again on the Tesmer Diagram shown in **Figure 51**. It is not only unusual for a project’s costs to drop during the design process, the normal expectation of an owner and project team is that costs will increase over time. Therefore it only made sense to set an allowable cost target after it had been shown to be reasonably achievable (i.e., reinforcing the need for plan validation).

The relationship between these values and the Target Costing process will become more apparent in **Section 5.2.3.9** that presents the final results.

5.2.3.8.2 Motivating team to undertake Target Costing: the IFOA

As was introduced in **Section 5.2.3.5**, the TVD processes of CHH were protected by a relational contract, called an *Integrated Form of Agreement*, a collaborative contract drafted by attorney and shareholder with McDonough Holland & Allen, Will Lichtig. The contract is structured to motivate sharing of risk and rewards between parties. There were two separate incentive plans; the first was structured to motivate team members to reach allowable cost, the second was structured to motivate team members to push for additional savings beyond allowable cost.

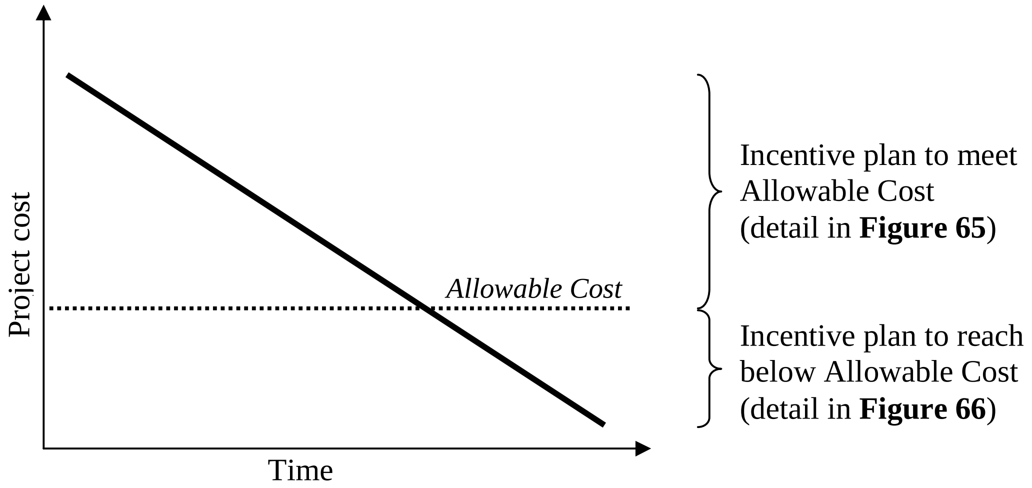


Figure 64. Two different incentive plans were used to motivate team members to design to save on cost

Ninety percent of the parties elected to participate in the incentive plan (Klemish 2009; Nguyen et al. 2009). For those that did, the contract motivated team members to meet the allowable cost as follows:

Meeting the allowable cost was a critical goal of the TVD exercise. To motivate parties to achieve this, each trade partner was given the option of signing onto an incentive plan that put at risk a specified percentage of their preconstruction fixed fee (Integrated Project Delivery Team 2007). This amount was deposited into an At-Risk Pool, as shown in **Figure 65**.

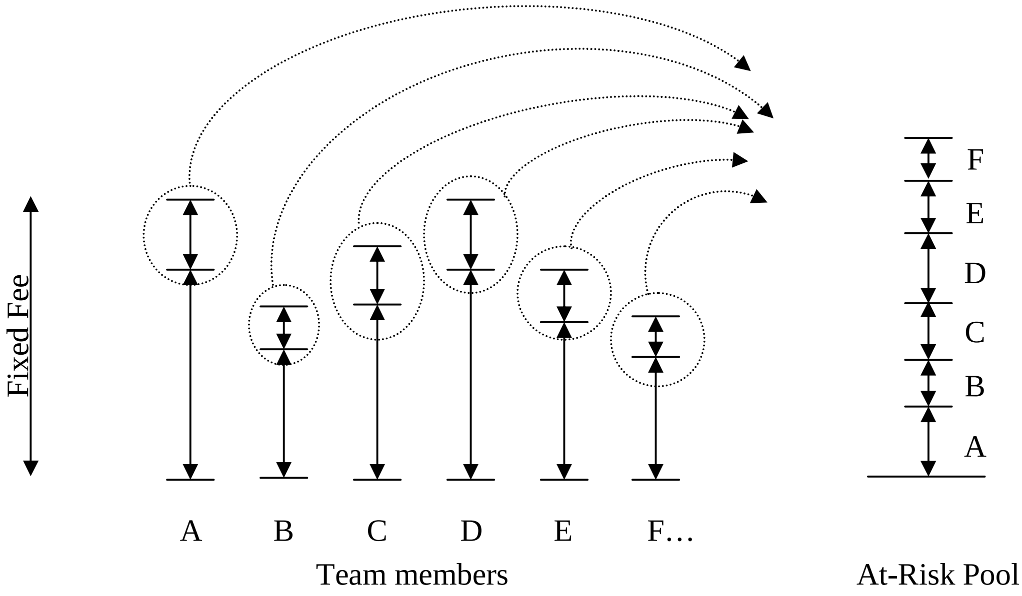


Figure 65. Remunerative fee structure

Incentive plan designed to motivate team members to reach Allowable Cost.

The plan stipulated that, if the allowable cost were met, all parties would receive the amount that was deposited. If it were not met, the at-risk pool would be used to repay the owner. However, in order to help the team to truly collaborate and collectively focus on benefits to the project rather than on optimizing their individual roles, team members would not be held liable for damages and claims in excess of the amount deposited in the at-risk pool (Nguyen et al. 2009).

Interestingly, the client wished to achieve additional savings of $70,000,000 even after the allowable cost was attained. The difficulty was that most trade partners were compensated as percentage (between 5-10%, varying by trade) of the project direct cost. Because of this, any further savings the team gleaned for the client would lower each trade partner's profit (Klemish 2009). Recognizing the conflict of interest this presented to the trade partners, the client froze profits as soon as the allowable cost of $911,000,000 was reached. Freezing profits has become a standard feature of Target Costing projects because if profits are not frozen, the incentive is for trade partners to increase rather than decrease costs. By contrast, when profits are frozen, every additional drop in project cost increases each trade partner's percent profit—offering them the opportunity to report higher profit margins to share holders. The contract also presented a further profit incentive: for every additional specified increment the team lowered the cost, the savings would be shared between the owner and the project team, as shown in **Figure 66**. While the actual amounts are considered confidential, for the purpose of illustration I have set this specified increment at $10 million. For example, for the first $10 million drop in project cost, 95% of the profit went to the owner and 5% to the team, to be split proportionally among them. Additional savings in $10 million increments brought additional profit to each trade partner; the net effect was that each team could increase its profit (Klemish 2009).

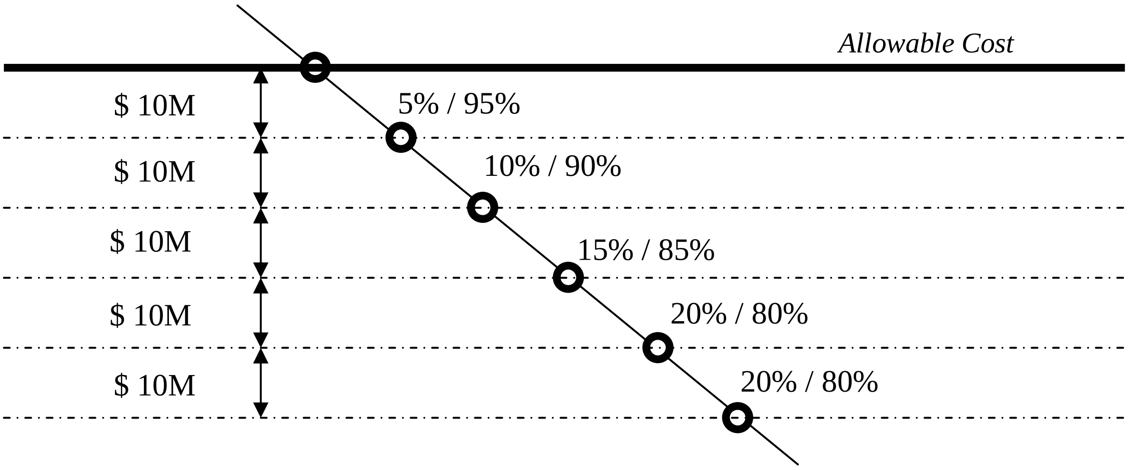


Figure 66. Remunerative structure beyond Allowable Cost

Incentive plan designed to motivate members to dip *below* Allowable Cost. Sample incentive plan based on the concepts at CHH; actual commercial terms are withheld for reasons of confidentiality.

One of the keys to TVD is to re-estimate the cost of the project every week as the design is modified and increases in detail. Early in the project, re-estimation was almost the sole task of CHH project estimator, Paul Klemish. However, as designs increased in detail, almost all estimate revisions were performed by the trade partners themselves and supplied to Klemish for compilation (Klemish 2009). With the CHH project, a declining-cost-over-time chart was projected at each Tuesday's TVD meeting.

5.2.3.8.3 Adjusting the Allowable Cost to accommodate scope changes

With the Cathedral Hill Hospital project, the cost did not always decrease. This is because the owner added scope to the project on several occasions. For example, an additional 45,000 SF was added to the building's program. To ensure that the TVD exercise fairly reflected this value, the allowable cost value was increased to reflect the same amount as the cost of the scope increase.

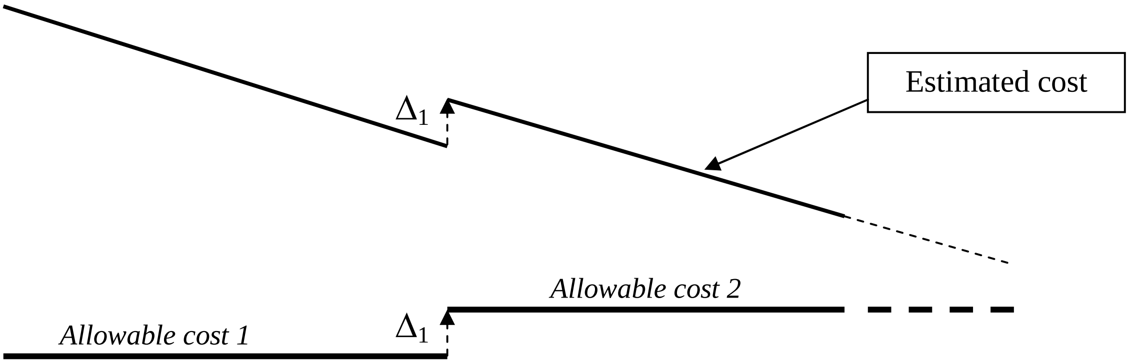


Figure 67. Adjusting to change in scope

At moments of scope increase, the Allowable Cost was modified in an amount equal to the change in scope

The actual documents prepared by the cost estimator are attached in **Appendix 9.3**.

5.2.3.8.4 Maintaining value while reducing cost

When value engineering is applied to a project only near the end of design, as is sometimes done, some of the best aspects of a project may be eliminated in an effort to save on first cost. Although TVD actually involves value engineering, it is performed as value engineering was originally intended; cost adjustments are applied continually and systematically by a fully integrated project delivery team. Unlike the former case, proper value engineering enables design team members to respond to one another’s design recommendations according to the lean ideal—i.e., waste is eliminated and value enhanced. For example, to emphasize the importance of Integrated Project Delivery

(IPD), Barnett (2004) describes the exchange that takes place when low-e glass is proposed by the architect. During traditional design-bid build systems, specifying the more expensive glazing system would likely lead to enhanced first cost. However, if the project team is involved early on, as it is during IPD, the mechanical engineer would likely note the reduced cooling load resulting from the heat insulating glass. The reduced cooling load offers the possibility of downsizing chillers and reducing the size of duct work. Smaller duct work, in turn, enables the structural engineer to minimize the building’s floor-to-floor height. These types of exchanges, occurring often and from the beginning of design, enable the quality of building to either improve or remain constant while overall cost decreases.

On CHH, project estimator Paul Klemish recalls two times, in particular, when this type of trade-off enhancement occurred. In one instance, the architects felt that a 5’X5’ window was not large enough to offer the level of natural light and views they desired for the individual patient rooms. Had they simply increased the window size without consulting the rest of the design team, the mechanical engineers would have been required to increase the size of the air handling units and cooling tower, substantially increasing the project cost. However, thanks to the IPD process, the designers did increase the window size, but did so while specifying higher performing glass. It was therefore unnecessary to modify the air handling unit or cooling tower size (Klemish 2009).

In another instance on the CHH project, the architects wanted to reduce the curtain wall stack joint from 5/8” to 3/8” for aesthetic reasons. While feasible, the thinner mullion would unacceptably deflect at the midspan of the bay, requiring the addition of $400,000 to the structural steel of the building. The IPD team questioned the overall aesthetic difference 1/4 inch would really make: Can most people really tell the difference between a 5/8” and 3/8” inch joint from 200 feet away? Looking at the two options, the team voted against the thinner joint and saved $400,000 in the process (Klemish 2009).

5.2.3.8.5 Satisfaction of the project team

Section 9.1.1.1 described some of the failings of the traditional design-bid-build delivery method, as expressed in research surveys. These failings reflected considerable dissatisfaction with the delivery process. To test the satisfaction of team members with the CHH process, project trainer Stephanie Rice administered a survey she called a Pulse Report in December 2009 (see **Appendix 9.4**). The survey questions had been created by the integrated project delivery team who would also respond to them. Of the 125 individuals offered the opportunity to respond to the survey, 62% completed it. Completion of the survey was via the internet and anonymous. The overall level of satisfaction, as reflected on the survey is high. When asked how the satisfaction values might compare to other hospital projects, Paul Klemish noted that team members who were simultaneously working on other hospital projects unanimously expressed that the CHH delivery method was much better than their involvement on other projects or agreed that “this is a good project (Klemish 2009). Klemish stated that there is normally a lot of pressure to build it right because if there is a problem, team members fear being blamed.

By contrast, the team structure minimizes individual blame in favor of collective responsibility so that the enormous stress that often accompanies traditional design-bid-build delivery is minimized. However, Rice (2009) felt the survey results also reflected a frustration about the large number of meetings team members were being asked to attend; the frustration was soon resolved by requiring all meeting facilitators to adhere to a start and finish time as well as to distribute a pre-determined agenda to invited attendees.

5.2.3.9 Results of estimated cost saving due to Target Costing

The purpose of this chapter has been as much to describe the TVD process as it has been to report on a final result. For this reason, photographs that help capture the spirit of Lean Construction and the TVD office are included in **Appendix 9.2**. Also included are actual cost estimation sheets prepared by estimator Paul Klemish. These sheets present in greater detail the specifics of TVD. However, for clarity and to help compare the CHH project results with that obtained for Sutter Fairfield (**Figure 52**), a summary of Klemish’s TVD sheet is presented in **Figure 68**.

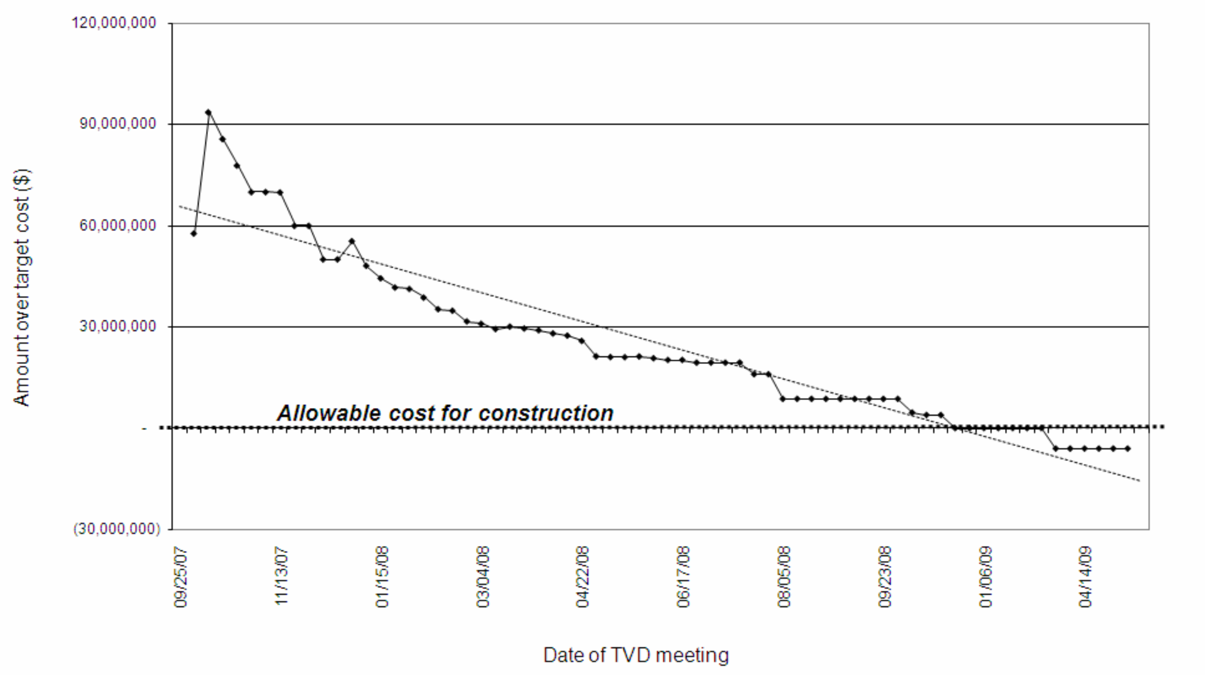


Figure 68. Estimated project costs over course of TVD meetings.
Adapted from graphs by Paul Klemish (see **Appendix 9.3**)

5.3 Discussion

Chapter X of this dissertation discusses the striving of the scientific community to increasingly enhance the quality of available research evidence. However, quantifying the financial impact of TVD on a project is not easy in the construction industry where case study research is the norm. It is certainly hard to deny that—at least from a statistical perspective—a case study can never represent more than N=1. How can we know the results are not a fluke or outlier if the process is performed on a singularly unique project? Or, as with the TVD case studies, how can we be certain that the drop in cost is due to the TVD process itself if there is no control? Skeptics may argue that the drop in price may simply be due to employees realizing that they are being studied, as was suggested by the famous Hawthorne Effect (Roethlisberger and Dickson 1939).

However, it *is* realistic to conduct randomized controlled trials in Lean Construction and TVD, albeit on a smaller scale. In lean consultancy games, such as the Airplane Game described in **Section 9.1.5.1**, subjects form assembly lines and are asked to “manufacture” a Lego airplane in two different ways: the traditional “push” way using large batch sizes and the lean “pull” way using a batch size of one. The results indicate that lean principles do work at a physical level—suggesting the results obtained from lean construction practices on a larger scale are not only dependent on characteristics of the persons involved.

Also, the results obtained on Action Research projects in TVD have thus far been repeated. Because allowable cost targets are established after benchmark or market cost is determined from square foot average costs on similar projects, it is likely that the cost savings are real. Experience form the first case study project, Sutter Fairfield, demonstrates that actual total construction costs not only can meet total estimated costs, they can better them. Another strong indication of the effectiveness of TVD is the eagerness of owners to re-engage in the process again after it has once been tried.

While attending EBD conferences during the past three years, I have been struck by the nervousness of clients who worry they can never afford the heightened first cost sometimes associated with EBD. From the perspective of a healthcare facility owner aiming to apply Evidence-Based Design, results of first cost savings from the TVD action research experiments are exciting. If owners can save 15-20% on the first cost of project, EBD interventions suggested by patient-centered care start to become feasible. The observation that quality is not only not sacrificed but *enhanced* during the process of achieving these savings makes TVD a viable option for the EBD community.

Chapter 6

This chapter summarizes key discoveries presented in Chapters 4 and 5, discusses original contributions made, suggests limitations of the study and explores opportunities for future research.

6.0 Conclusion

6.1 Summary of key discoveries

6.1.1 Long-term savings from EBD

A tacit motivator behind EBD research is an underlying hope that a well-designed facility improves outcomes sufficiently to both enhance revenue streams and reduce operating costs throughout the life cycle of the facility. Though a plausible assumption, the already intensive capital requirements of healthcare facilities force choices between competing items on a wish list. The EBD field must work toward answering key investment questions, such as: How great a health impact does the built environment actually have? If I only have X dollars, will it be better to construct private rooms or install sinks in every room? These questions concern both therapeutic impacts of the designed environment and business outcomes not mediated by therapeutic impacts; e.g., increased patient satisfaction from reduced waiting times; increases in nursing productivity from reduced travel time.

The repetitive nature of annual expenses and receipts over the life of a 20+ year facility makes the prospect of EBD enhancements attractive. Owners weigh returns from alternative investments. Additionally, possible increases in capital costs induce owners and financial stakeholders to request quantification of benefits that would enable estimation of potential payback periods.

Although the need to quantify the impact of EBD interventions had long been acknowledged, one difficulty inherent in EBD research is that it relies on experimental observations that are not always randomized and controlled, or rigorously modeled. This is partly due to the nature of medical experimentation in which deprivation of healthful conditions may be considered unethical, and partly due to the reality of confounding factors within an environmental surround. This is perhaps why the oft-cited 1984 Ulrich study was so long in coming. The circumstances of the study—that all patients, both experimental and control, had been subjected to nearly identical surgical procedures and were placed in nearly identical rooms, save the view from their window—are difficult to come by. Nevertheless, since then, a number of indicators have been collected from Pebble Projects (an initiative of the Center for Health Design) and other collaborative healthcare facilities.

Thanks to the willingness of industry participants to share their collected before-and-after-EBD-interventions data, several researchers and hospital CEOs made an attempt to quantify the costs and benefits associated with EBD adaptations in a paper entitled, “A Business Case for Better Buildings” (Berry et al. 2004). At the heart of the Berry et al. piece is the Fable Hospital, a fictional facility that represents a composite of healthcare facilities with facets of EBD. Among its features, the hospital includes oversized rooms with dedicated space for families, acuity-adaptable rooms, double-door access, decentralized nursing stations, alcohol-rub hand hygiene dispensers in every room, HEPA filters in ventilation units to improve air quality, noise reducing measures, and art work displays and gardens. The article then itemizes incremental costs associated with each of these additions and compares them to the financial impact of the design decisions. At the time of the article’s publication, the authors presented an itemized incremental cost of over $12 million. However, based on data obtained from a number of hospitals, they estimate the additional cost could be offset by $11.5 million in savings garnered from reductions in patient falls, patient transfers, nosocomial infections, drug costs, and nursing turnover, as well as increases in market share and philanthropy (Berry et al. 2004). In other words, they believe the increased incremental capital cost would be offset by significant annual savings, and would enjoy a payback period of just a little over one year.

Although the Berry et al. paper is admirable as an early effort to quantify some of the costs and benefits associated with the implementation of EBD interventions, a rigorous research framework within the EBD community needs to be developed, so that financial savings promised by EBD interventions can be trusted.

However, the task of building an EBD decision-making framework with financial databank is not easy, as I discovered in preparing this dissertation. Publications featuring experiments relating the environment and human health do exist, but they are of varying quality and reliability. This research established that populating a Root Cause Analysis framework based on EBD literature reviews—especially cumulative meta-analyses—may be possible in Evidence-Based Medicine. However, it is extremely difficult to do this in EBD because confounding variables riddle the vast majority of EBD research. Additionally, assembling a useful database of articles that have been prescreened for their level of evidence and that can be related to a root cause analysis decision tree will require an army of well trained and like-minded researchers. To do this, the EBD community might consider developing a data base modeled on the Evidence-Based Medicine community known as the Cochrane Collaboration. Beyond this, the dissertation calls for collaborating with Departments of Research Psychology to undertake proper, well-designed experimentation in EBD.

6.1.2 Overcoming the hurdle of first cost associated with EBD

Ulrich et al. (2004) write: “Many of the improvements suggested by EBD are only slightly more expensive than traditional solutions, if they are more expensive at all.” While this may, at first, seem to reflect wishful thinking, it is worth considering an analogous dilemma owners face when designing and constructing LEED-certified buildings. Estimators at Davis Langdon, an international cost management consulting firm, accumulated costing data per square foot from almost 600 building projects in nearly 19 states. They observed that the costing of LEED-certified buildings was scattered throughout and then subjected the data to statistical t-tests. They found no statistically significant difference between cost-per-square-foot of LEED-certified and non-LEED-certified buildings (Matthiessen and Morris 2004; Morris and Matthiessen 2007). Skeptics may wonder: How can this be, especially since there are certainly additional incremental costs associated with many of the individual parts? The authors, anticipating this response, wrote: “The projects that were the most successful in remaining within their original budgets were those which had clear goals established from the start, and which integrated the sustainable elements into the project at an early stage. Projects that viewed the elements as added scope, tended to experience the greater budget difficulties."

In another example, the authors from the Rocky Mountain Institute (Barnett 2004; Hawken et al. 2000) speak to the importance of integrating design decision-making early in the decision-making process. Systems thinking enables stakeholders in the design and construction industry to work together to offset first costs with reductions elsewhere in the system.

In other words, the savings experienced by sustainability projects likely came not from introducing lesser quality parts (some of these parts are, in fact, more expensive) but from upfront savings in design and planning productivity. This issue falls squarely within the realm of project management.

Interestingly, TVD and Lean Construction share similar, integrated project management methodologies as those used by many in the sustainable design community. Early, repeatable results from P2SL action research experiments suggest that those who wish to incorporate Evidence-Based Design interventions into their healthcare facilities can realistically do so by achieving 15-20% savings on the construction costs of their project.

In other words, those who fear the hurdle of first cost sometimes associated with EBD might do well to look to TVD and Lean Construction processes for assistance.

6.2 Original contributions

All additions to knowledge build on the work of others and this is certainly true of a dissertation. That being said, this research makes contributions to the field of Evidence-Based Design in a myriad of minor ways, but most significantly in two critical ways:

1) Prior to this dissertation, there had been numerous efforts to better understand how the built environment affects patient recovery outcomes in healthcare facility settings. However, to my knowledge, there had as yet been no serious attempts to respond to the Joint Commission's appeal to situate EBD within the larger rubric of Root Cause Analysis. This dissertation appears to be the first attempt to help fill that gap.

2) Prior to this dissertation, there was an urgent need to determine how the increased capital costs which accompany implementation of some EBD interventions could be met. This dissertation shortens that gap by linking Lean Construction and TVD to the Evidence-Based Design community.

6.3 Limitations of study

It is almost a given that any research that requires investigating companies' financial strategies will be difficult because of concerns of confidentiality. This research was no exception. In the earliest phases of this work, I attempted to establish a benchmark for capital budgeting methodologies through structured interviews with appropriate individuals in healthcare facilities. Although several individuals clearly tried to be helpful, they were bound by their positions to not reveal much beyond generalities. Very little of any substance could be gleaned from early these conversations and, after a year of nearly fruitless efforts, I decided to steer the work away from capital budgeting in practice as it actually *is*, to capital budgeting as it potentially *could* be.

Naturally, it would still be helpful to understand better how capital budgeting is currently performed by healthcare facility owners. Therefore, in the absence of this information, I am obligated to acknowledge that not having it available is a limitation in this research.

Other limitations include:

The Cochrane Collaboration calls for hand-searching for articles found outside internet databases, searching for non-English language articles, and blinding reviewers to the article authors. However, the solitary nature of dissertation research made these recommendations difficult to fill. To compensate, I decided to focus on locating systematic reviews prepared by teams who had more substantial resources than my own.

In TVD I felt my intermittent presence as an observer was both a weakness and a strength. Certainly, those who participate in the day-to-day operation of project development will be exposed to a greater level of detail than someone who comes only once per week or who relies on the interview responses of those who are continually present. However, that being said, I would also like to suggest that my more distant role as researcher-observer was helpful as well. For example, shifts in strategy between the Fairfield and Cathedral

Hill projects became more apparent to me in part precisely because my role was that of someone more removed.

However, I felt the limitations mentioned above were comparatively minor and did not significantly compromise the contributions made in the dissertation.

6.4 Opportunities for future research

The potential for growth in this field is enormous. There is a great need to conduct randomized controlled trials to quantify links between environmental cues and the physiological responses they trigger. As was repeatedly mentioned in this dissertation, RCTs are needed to offer owners the predictive level of confidence they seek. Much good work can be done on EBD by collaborating with Departments of Psychology that focus on human behavior research. These departments have access to large numbers of student subjects and can undertake proper randomized controlled trials with these subjects. For example, it is possible to identify stresses in the built environment by asking subjects to move through a space while monitoring physiological metrics for stress, such as blood pressure and cortisol levels and heart rates. This work can be extended by monitoring a subject’s physiological reactions to specifically designed virtual built environments and comparing their results against a control.

This is an exciting moment for EBD researchers. Almost any work in this area promises to significantly shape the field.

7.0 Glossary

BCA	Benefit-Cost Analysis: "A basic premise of the...(method) is that future as well as present benefits and costs arising from a decision are important to that decision, and, if measurable in dollars, should be included in calculating the (Benefit-to-Cost Ratio)…"; To perform a BCA, calculate "benefits (or savings) divided by costs, where all dollar amounts are discounted to present or annual values." (ASTM April 2006a)
Bias	Introduction of a systematic error in a procedure that leads to a wrong estimate of a phenomenon. In a meta-analysis there are several potential biases that need to be controlled. The most important is 'publication bias.'" (Leandro 2005)
Capital budget	The budget used to forecast, and in some cases justify, the expenditures (and in some cases the sources of financing) for noncurrent assets. (Cleverley and Cameron 2002)
Capital financing	Financing used expressly for the purchase of noncurrent assets. (Cleverley and Cameron 2002)
Design-Bid-Build	"Traditional contracting method where the architect and contractor secure separate contracts with the owner to provide specified services." (Construction Management Association of America 2009)
Design-Build	"An architect or contractor that provides design and construction services under as single responsibility contract to an owner." (Construction Management Association of America 2009)
Environmental Docility Hypothesis	" 'Asserts that the less competent the individual, the greater the impact of environmental factors on that individual.' Thus, frail and more impaired individuals, in comparison to more vigorous and less impaired individuals, are expected to be more vulnerable to the effects of environmental demands." (Connell 1997)
Environmental Press Model	"Describes the relationship between an individual's 'competence' or capabilities in the conduct of activities and the 'environmental press' or demands place on the individual by task-related components of the physical environment and their implications for affect and behavior." (Connell 1997)

Environmental Psychology	“An area of psychology whose focus of investigation is the interrelationship between the physical environment and human behavior and experience.” (Holahan 1982)
Evidence-Based Design (EBD)	“the conscientious and judicious use of current best evidence, and its critical interpretation, to make significant design decisions for each unique project. These design decisions should be based on sound hypotheses related to measurable outcomes.” (Hamilton 2006)
Evidence-Based Medicine (EBM)	“Approach to clinical problems aimed at the integration of individual clinical expertise with the best clinical evidence available from a systematic review. In other words, EBM is the use of both evidence and experience in clinical practice.” (Leandro 2005)
Fomite	Any inanimate object that can transfer infectious agents from one person to another such as a tie, towel, or pen.
Healthcare	Field concerned with the maintenance or restoration of the health of the body or mind. (Berger 2002)—p. 3
Incremental	Cash flows that occur solely as a result of a particular action, such as undertaking a project. (Zelman et al. 2003)
Just-in-Time (JIT)	A strategy where components are delivered from the provider to the customer of a supply chain immediately before needed. JIT reduces in-process inventory.
Kanban	A signaling system used in lean production to trigger action. The signal may be done using various methods, such a signboard, card, or empty trolley.
Last Planner	“The person or group that makes assignments to direct workers. ‘Squad boss’ and ‘discipline lead’ are common names for last planners in design processes. ‘Superintendent’ (if a job is small) or ‘foreman’ are common names for last planners in construction processes.” Last Planner™ is also the name for the Lean Construction Institute’s system of production control. (Lean Construction Institute 2009)
Last Responsible Moment	In considering alternatives, the last responsible moment for one alternative is the time at which, if that alternative is not selected and pursued, that alternative is no longer viable. (Tommelein 2009).
Lean	“Extend(s) to the construction industry the Lean production

Construction	revolution started in manufacturing. This approach maximizes value delivered to the customer while minimizing waste.” (Lean Construction Institute 2009)
Life Cycle Cost Analysis (LCCA)	“The basic premise of the (LCCA) method is that to an investor or decision maker all costs arising from an investment decision are potentially important tot that decision, including future as well as present costs. Applied to buildings or building systems, the LCC encompasses all relevant costs over a designated study period, including the costs of designing, purchasing/leasing, constructing/installing, operating, maintaining, repairing, replacing, and disposing of a particular building design or system.” (ASTM April 2006b)
Load Leveling	A procedure where demand is rearranged so it is distributed evenly during a specified time period.
Maintenance Costs	The cost of keeping a building in good repair and working condition. (RICS 1986)
Meta-analysis	“Method that aims to reach the comprehensive synthesis of data issued from a systematic research and to analyze congruent and divergent findings from reports in literature.” (Leandro 2005)
Operating costs	The costs associated with operating the building itself. (RICS 1986)
PMPM	Per member per month. “The most common method in which providers receive captivated payments.” (Cleverley and Cameron 2002)
Preferred Provider Organization (PPO)	“An independent provider or provider network preselected by the payer to provide a specific service or range of services at predetermined (usually discounted) rates to the payer’s covered members.” (Cleverley and Cameron 2002)
Randomized Controlled Trial (RCT)	“An experiment in which two or more interventions, possibly including a control intervention or no intervention, are compared by being randomly allocated to participants. In most trials one intervention is assigned to each individual but sometimes assignment is to defined groups of individuals (for example, in a household) or interventions are assigned within individuals (for example, in different orders or to different parts of the body).” (Cochrane Collaboration May 2005)
Reverse Phase Scheduling	A strategy used in lean construction to develop the schedule of a project by first anchoring the desired delivery date of a project and then scheduling activities backward toward the start of the project.

Running costs	The sum of maintenance and operating costs. (Al-Hajj and Horner 1998)
Systematic review	“Review performed by an expert in the field based not only on the knowledge of the single investigator but also on data issued from systematic research.” (Leandro 2005)
Takt time	In a manufacturing assembly line, the maximum time allowed per unit to meet demand; it sets the pace of the assembly line.

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9.0 Appendix

9.1 Lean Construction: a response to the troubled nature of the construction industry

9.1.1 Overview

A brainchild of the lean construction community, Target Value Design (TVD) has emerged as a tool to resolve long-standing problems that have plagued the construction industry. Because TVD is inseparable from lean construction methodologies, an introduction to the methodology as it operates within lean construction principles will be presented here.

In a traditional design-bid-build delivery system, a client hires an architect and engineer to design according to client requirements. The architect and engineer prepare drawings in alignment with the client’s needs and put these documents out to bid. Contractors wishing to bid on the documents estimate the cost to build the project and add a profit markup. The resulting sum represents their offer to build the project for a specified price. Once the contractor has been selected, the process of refining the drawings and constructing the actual project begins.

The design-bid-build process described above is typically linear—the contractor is not brought on board until after key features of the project have already been defined (Barrie and Paulson 1992). The practice of excluding key players, such as the general contractor until after the bid has been placed, has been shown to introduce a number of problems, as will be discussed in the following sections.

9.1.1.1 Indications of industry failure

In order to better understand problems plaguing the construction industry, construction management research has focused on identifying sources of failure.

For example, Josephson and Hammarlund (1999) observed seven building projects during a six month period, analyzed nearly 3000 defects and then identified the root causes of the defects. Perhaps surprisingly, the researchers discovered that the greatest number of defects were not induced by stress or risk, but instead by a lack of motivation and knowledge among four participant categories surveyed: designers, site managers, workers and subcontractors. Researchers found a strong alignment of ranking among the top two causes within each of the four categories (**Table 15**).

Table 15. Causes of defects

Adapted from Josephson and Hammarlund (1999)
Category titles are authors' own.

	Cause of defect (% of defect cost per category)			
	Workmanship	*Site Management*	*Subcontractors*	*Design*
Motivation	69	50	47	35
Knowledge	12	31	27	44
Information	2	8	13	18
Stress	1	6	3	2
Risk	16	5	10	1

Other researchers have focused less on defects, and more on the adversarial nature of the construction industry. For example, Black, Akintoye, and Fitzgerald (2000) surveyed over 78 consultants, contractors and clients. They found that respondents perceived traditional design-bid-build systems as failing in a number of ways, including: exploitation is common, specifications are rigid, decisions are made with limited knowledge, and focus is placed on short-term (rather than long-term) success.

Such failings appear to be pervasive and common to the design-bid-build delivery method—regardless of geography or nationality. For example, Iyers et Jha (2005) identified 23 critical failure attributes plaguing construction projects in India. Distributed surveys were returned from 112 owners and contractors; the authors then ranked the attributes by their importance to each of the two groups, as shown in **Table 16**. Interestingly, while there are some ranking differences between expressed priorities of the Owners and Contractors, there is considerable agreement. Adjectives such as conflict, negativity and hostility are common to failed projects.

Table 16. Critical failure attributes of projects in India

(By rank according to survey; the authors' indices have been deleted for clarity)

Adapted from Iyers et Jha (2005).

Project Attributes	**All response**	**Owner**	**Contractor**
Poor human resource management and labor strike	1	2	1
Negative attitude of PM and project participants	2	3	3
Inadequate project formation in the beginning	3	4	4
Vested interest of client representative in not getting the project completed on time	4	5	1
Conflicts between PM and top management	5	2	8
Mismatch in capabilities of client and architect	6	6	7
Conflicts between PM and other outside agency such as owner, sub-contractor or other contractors	7	8	5
Reluctance in timely decision by PM	8	9	6
Lack of understanding of operating procedure by the PM	9	7	13
Conflicts among team members	10	10	11
Ignorance of appropriate planning tools and techniques by PM	11	11	12
Holding key decisions in abeyance	12	13	10
Reluctance in timely decision by top management	13	14	9
Harsh climactic condition at the site	14	12	16
Hostile political and economic environment	15	16	14
Tendency to pass on the blame to others	16	16	15
Hostile social environment	17	15	18
Project completion date specified but not yet planned by the owner	18	18	17
Uniqueness of the project activities requiring high technical know-how	19	20	19
Urgency emphasized by the owner while issuing tender	20	19	20
Size and value of the project being large	21	21	22
Aggressive competition at tender stage	22	23	21
Presence of crisis management skill of PM	23	22	23

Prevalence of dispute claims can also signal a troubled industry. A database search through the directories of Martindale Hubbell, a company which catalogs and connect lawyers around the world indicates that there are currently 16,931 professionals who list themselves as construction law specialists in the US; this can be compared to 14,035 who list themselves as bankruptcy law specialists (Martindale Hubbell 2009).

The litigious nature of the profession is not limited to the US. In 1997, Kumaraswamy searched for root and proximate causes of dispute claims on projects in Hong Kong. The author generated weighted average indices to determine how three project team members (contractors, clients and consultants) ranked, by importance, the root causes of claims. Adjectives such as “unfair,” “unclear,” unrealistic,” “inappropriate,” and “inadequate,” pepper the suggested list of causes. The top ten causes identified by Kumaraswamy are shown in **Table 17**. In **Figure 69**, the author separates root and proximate causes of claims, but the sheer number of claim categories is striking.

Table 17. Root causes and proximate causes of dispute claims in Hong Kong

Weighted indices to account for different numbers in the three groups (8 from contractors, 21 from clients, 17 from consultants; indices are irrelevant to this discussion and have been deleted here for clarity).

Adapted from Kumaraswamy (1997).

Cause	**Overall**	**Contractors**	**Clients**	**Consultants**
		(rank)		
Inaccurate design information	1	1	4	1
Inadequate design information	2	4	2	5
Inadequate site investigations	3	5	5	4
Slow client response (decisions)	4	3	11	6
Poor communications	5	10	12	2
Unrealistic time targets	6	2	7	12
Inadequate contract administration	7	15	3	3
Uncontrollable external events	8	12	1	10
Incomplete tender information	9	6	13	8
Unclear risk allocation	10	7	6	11

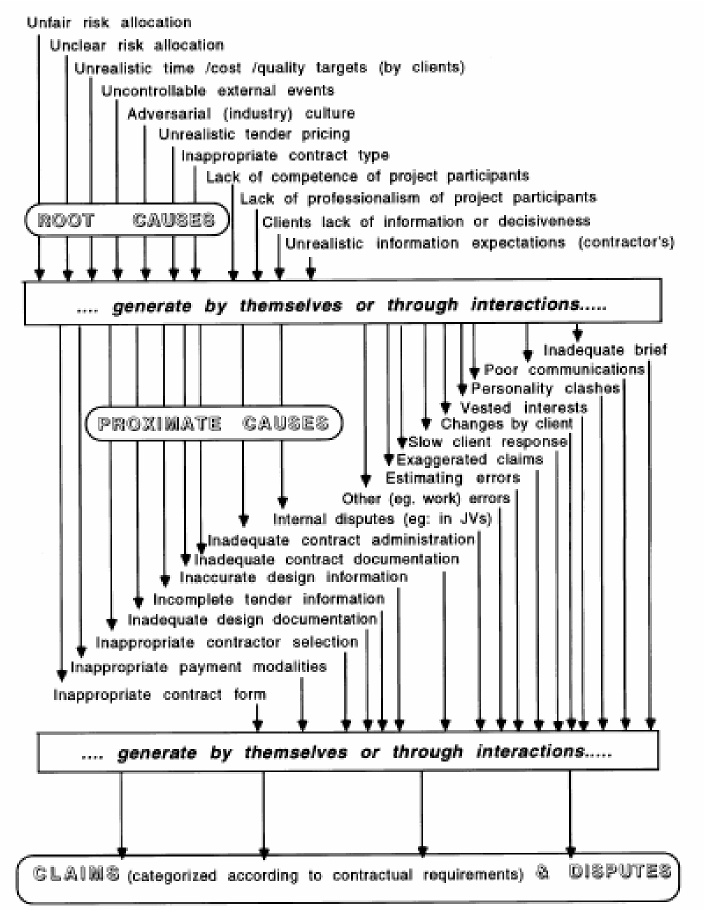

Figure 69. Root and proximate causes of claims in construction

(Kumaraswamy 1997)

From Kumaraswamy, M. M. (1997). "Conflicts, claims and disputes in construction." *Engineering Construction and Architectural Management*, 4(2), 95-111.
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While prevalence of claims and disputes is certainly an indication of a troubled industry, so is the frequency and extent to which lawyers must be engaged. For example, Owers and al. (2007) found that nearly every participant engages the services of lawyers for many, if not most, of ten types of activities, as is shown in **Table 18**.

Table 18. Function of lawyers depending on type of issue versus industry participant

Adapted from Owers et al. (2007)

Type of issue	General Contractor	Subcontractor	Designer	Supplier	Manufacturer	Owner	Labor force
General business	x	x	x	x	x	x	
Transactions	x	x	x	x	x	x	
Bid protests	x					x	
Lien laws	x	x		x	x	x	x
Intellectual property	x	x	x	x	x		
Tort liability	x	x	x	x	x	x	
Product liability	x	x	x	x	x		
Professional liability	x	x	x				
Litigation	x	x	x	x	x	x	x
Dispute resolution	x	x	x	x	x	x	x

9.1.1.2 Attributes of successful projects

Despite these challenges, the industry has also celebrated success. To increase the likelihood of success, researchers have looked for attributes that successful projects share.

For example, from their survey of owners and contractors, Iyer and Jha (2005) listed 30 critical success attributes of project managers and ranked them according to the importance each category of participant placed on the attribute. What is even more remarkable than the differences, perhaps, is the consistency with which certain attributes appear in the top 10-15 slots (**Table 19**).

Table 19. Attributes of successful projects

Adapted from Iyer and Jha (2005). The authors' indices have been deleted for clarity.

Project Attributes	All response	Owner	Contractor
Effective monitoring and feedback by PM	1	3	4
Coordinating ability and rapport of PM with top management	2	1	7
Effective monitoring and feedback by the project team members	3	2	8
Positive attitude of PM, and project participants	4	6	3
Project manager's technical capability	5	11	1
Understanding operational difficulties by the owner engineer Thereby taking appropriate decisions	6	10	4
Timely decision by the owner or his engineer (reluctance or otherwise)	7	4	23
Selection of PM with proven track record at an early stage by top management	8	7	19
Authority to take day to day decisions by the PM's team at site	9	11	10
Scope and nature of work well defined in the tender	10	11	12
Monitoring and feedback by top management	11	5	26
Understanding the responsibilities by various project participants	12	8	16
Leadership quality of PM	13	16	9
Top management's enthusiastic support to the project manager (PM) and project team at site	14	15	13
Coordinating ability and rapport of PM with his team members and sub-contractor	15	14	16
Project manager's authority to take financial decision, selecting team members, etc.	16	26	2
Commitment of all parties to the project	17	20	11
Coordinating ability and rapport of PM with owner representative	18	17	16
Coordinating ability and rapport of PM with other contractors on site	19	27	6
Top management's backing up the plans and identify critical activities	20	17	20
Regular budget update	21	22	13
Delegating authority to project manager by top management	22	24	13
Training the human resources in the skill demanded by the project	23	23	22
Ability to delegate authority to various members of his team by PM	24	25	24
Construction control meetings	25	29	21
Favorable political and economic environment	26	8	30
Favorable climatic condition at the site	27	19	27
Availability of resources (funds, machinery, material, etc.) as planned during the project duration	28	27	25
Monitoring and feedback by client	29	21	29
Developing & maintaining a short and informal line of communication among project team	30	30	28

Similarly, Menches and Hanna (2006) sought to define project success, according to electrical contractors. The researchers found that ten factors contributing to project success emerged, with (a) profitability and (b) customer satisfaction ranking highest among the ten factors, as shown in **Figure 70**.

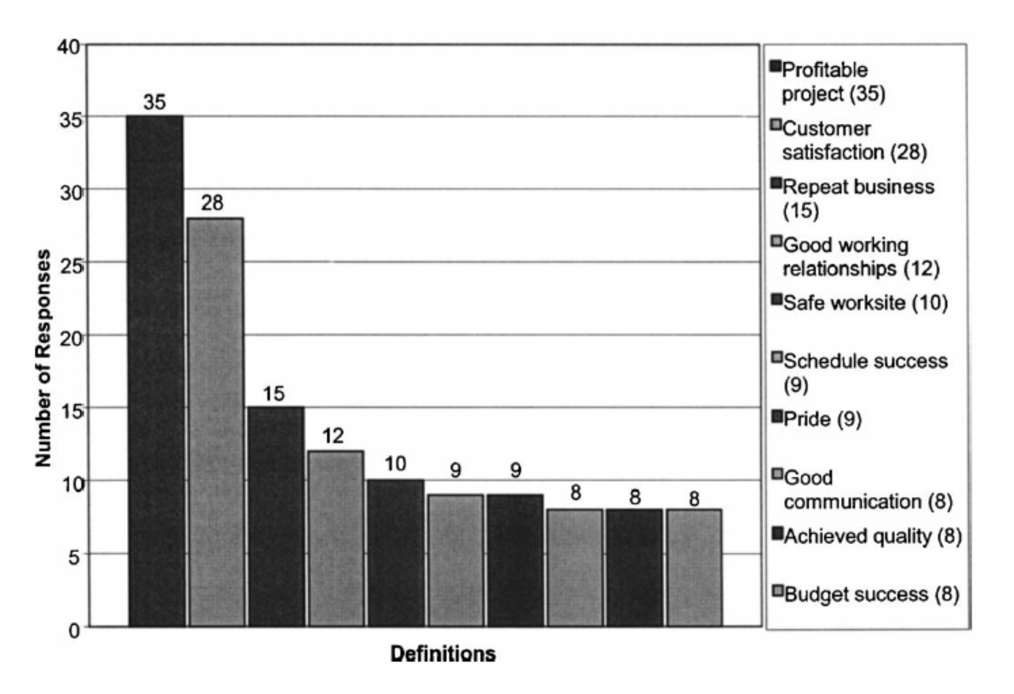


Figure 70. Top ten definitions of successful performance as suggested by electrical contractors

(Menches and Hanna 2006)

Recognizing the failings of traditional design-bid build delivery systems and the benefits associated with successful delivery, researchers have sought to not only characterize the project delivery as it *currently is,* but also to define it as it *can* and *should* be. A number of owners, consultants and contractors have begun to investigate a delivery method known as *partnering*—a delivery method that is intended to foster a collaborative working relationship among team members (Black et al. 2000; Bresnen and Marshall 2000; Cain 2004). To determine if the promise of improvement with partnering was being met, Black et al. (2000) investigated to see if perceptual differences existed between those who had previously tried partnering and those who had not. They found that from a list of factors (**Table 20**) those who had been involved with partnering gave it a higher score than those who had not—suggesting that the benefits promised by the partnering delivery system are real and recognized by those who implement partnering. This is a helpful prelude for this research, since partnering is a close cousin of *integrated project delivery*—a delivery method that sits at the very heart of TVD.

Table 20. Benefits attributable to partnering

(as ranked by those with and without previous involvement in partnering after scores were combined)

Adapted from Black et al. (2000)

	Ranked acknowledgement of benefit
• Less adversarial relationship	*Most*
• Increased customer satisfaction	↑
• Increased understanding of parties	
• Improved time-scales	
• Reduced risk exposure	
• Reduced cost	
• Improved administration	
• Quality improvements	
• Improved design	
• Risk shared	
• Improved return on resources	
• Design cycle reductions	●
• Increased market share	*Least*

9.1.2 The Proposed Solution: Target Costing within a culture of Lean Construction

To ameliorate the problems associated with traditional construction delivery, a new delivery system called Lean Construction emerged. Lean Construction serves as the critical culture in which TVD is practiced. Therefore, any discussion of TVD must be preceded by an introduction to Lean Construction.

9.1.3 Beginnings of lean construction

In the now renowned CIFE Technical Report #72 entitled: *Application of the New Production Philosophy to Construction* (Koskela 1992) Lauri Koskela stood on the principles of a manufacturing movement which he termed “the new production philosophy” and applied its principles to the construction industry. Incorporating Koskela’s concepts, Glenn Ballard and Greg Howell cemented their own observations of the need to enhance reliability of project planning and founded the Lean Construction Institute in August 1997 (Lean Construction Institute 2009).

Lauri Koskela, identified three qualities of lean thinking: transformation, flow, and value (TFV) (Koskela 2000). Although mentioned third in the TFV lineup, the creation of *value*—to design a product or building to customer satisfaction—is arguably the most critical of the three, since it only makes sense to design a building within budget and on time if it serves the function for which it was intended (Ballard 2009a).

The other two elements of TFV triumvirate—transformation and flow—help a design team attain customer value while minimizing waste. *Transformation* is a process through which a metaphorical design engine takes input resources and modifies them into outputs that are of value to the customer. *Flow* is a pull process method used to optimize the whole over the parts.

Ballard's contribution to the creation of flow during project delivery by his development of the Last Planner System of Scheduling is critical to the implementation of Lean in construction and is discussed in greater detail in **Section 9.1.5.2**.

All three elements of TFV are important to TVD. However, while value and transformation may seem somewhat intuitive, the nature of flow is not immediately obvious. It will therefore be presented in greater detail in the following sections.

9.1.4 Goals of lean thinking

In the manufacturing world, the goal of lean is to produce a product that satisfies the customer's requirements—while minimizing waste and maximizing value. At the risk of appearing overly symplistic, it may be useful to draw an analogy between lean construction and a lean animal. A conventional image associated with a word like lean might be suggested by the lithe body of the cheetah which has evolved to build adequate muscle and minimize fat, enabling it to optimize speed while hunting. But an artic seal insulated by a thick layer of blubber also conforms to the lean ideal. The utlimate lean goal is to create a product that is "fit for use" or to customer satisfaction, and to do so while minimizing waste and maximizing value.

In construction, waste is everywhere—and waiting to be eliminated. For example, adversarial relationships, claims and disputes, demotivated workers, defects, etc., as described in **Section 9.1.1.1**, can all be considered sources of waste because these actions do not add value to the final product. One of the benefits of waste reduction is that resources that would have been spent on waste can be reallocated to enhancement of value, as suggested by **Figure 71**.

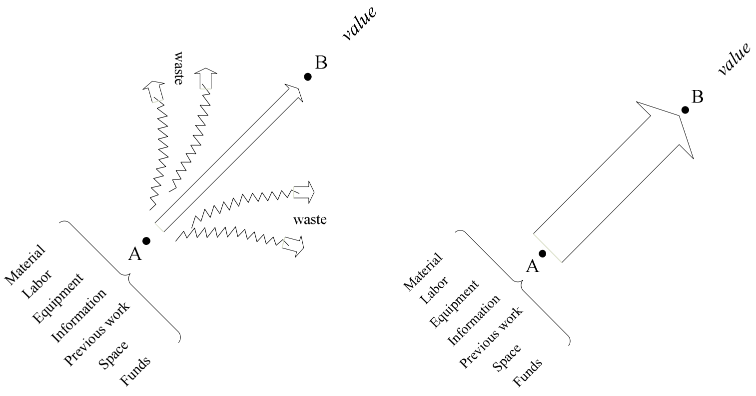


Figure 71. Recapturing waste as value

When a project is made more lean, resources that would otherwise be wasted are captured and can be reallocated to value creation

Resource list from Hamzeh et al. (2008)

9.1.5 The importance of flow

In traditional design-bid-build project delivery, each trade aims to optimize its own processes. Although understandable from the point of view of the individual parts, such thinking can undermine working of the whole. Similar to a public bus that speeds ahead without regard for scheduled arrival and departure times, and in so doing leaves behind riders who rely on that schedule, optimization of individual parts can generate problems for the project itself. For example, a dry wall contractor may believe it is to his personal advantage to install designated walls before the mechanical contractor moves onto site.

However, doing so may create problems for the mechanical contractor who must then employ additional personnel to contort duct fittings around walls that were installed too soon. By contrast, lean thinking aims to optimize the *whole* over the parts. In other words, while the metaphorical bus driver who must wait at a bus stop until scheduled to depart may be personally inconvenienced, the overall transportation system and the majority of its ridership will benefit.

In lean manufacturing, upstream members of a manufacturing line or supply chain assemble parts only at the rate at which they are needed by those downstream. This rate is referred to as *takt time* and is set to the rate of the customer's demand. For example, at Toyota, takt time is the rate at which customers order cars. On a construction project, however, takt time is the rate at which work must be completed to meet the customer's desired completion date. To ensure that each station of an assembly can keep pace with the takt time, assembly processes are broken into pieces of approximately equal size (ideally one piece), streamlining the flow of a product between stations. In the bus analogy, takt time might represent the rate at which subsequent buses would embark on the same designated route, presumably timed to meet rider demand.

9.1.5.1 Making flow with the pull of the kanban

To ensure that no unnecessary inventory (waste) is amassed between manufacturing stations, an upstream station does not assemble and deliver parts until its downstream station (its customer) signals readiness to accept those parts. Signaling for those parts may be done via a kanban—represented in **Figure 72** as an empty cart extended from a downstream station (B) to an upstream station (A)—waiting to be filled with upstream parts. In practice, a kanban may take the form of an overhead sign board. A kanban is one type of pull signal typically used to replenish or withdraw products from a supermarket shelf. Hence the use of a kanban presumes that the consuming workstation can have multiple inputs.

Lean thinking aspires to make batches as small as possible; one-piece flow is ideal.

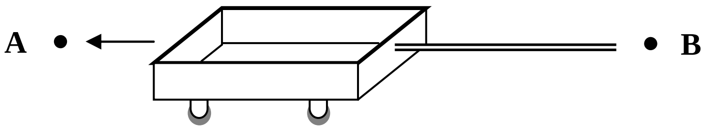


Figure 72. A metaphorical kanban cart

In a lean manufacturing assembly line, each station thrusts out its own kanban cart to the rhythm of takt time. This manufacturing of parts and transfer of resources from one supply chain station to the next only at the moment it is needed by the customer station forms the basis of Just-In-Time delivery or *pull*. The importance of pull is demonstrated during the playing of a lean game—the Airplane Game—used by lean production consultants to demonstrate some of the principles of Lean. Players seated around a table work in supply chain fashion to assemble the parts of a Lego® airplane (**Figure 73**). For comparison, players first assemble their station piece using a traditional *push* system—the method to which they are likely accustomed. After six minutes of play, a facilitator makes note of the total number of planes assembled, the time required to complete the first plane, and the amount of work-in-progress (WIP). Players are then asked to change their assembly strategy to conform to lean principles, using *pull* system between stations. They are also asked to reduce batch sizes transferred between stations, from 5 to 1. The game has been played live and simulated by computer (**Figure 74**). In both instances, the difference in results is dramatic. The pull assembly method outperforms push with reduced WIP. Also, when the batch size is reduced from 5 to 1, “planes completed” is increased and “time elapsed until first plane” is reduced. In other words, pull and one-piece flow lead to generally desireable outcomes when manufacturing a product (**Table 21**) (Rybkowski et al. 2008).

Figure 73. First Four Workstations from the "Airplane Game"

Reprinted with permission from Visionary Products, Inc. (2008), as it appeared in Rybkowski et al. (2008).

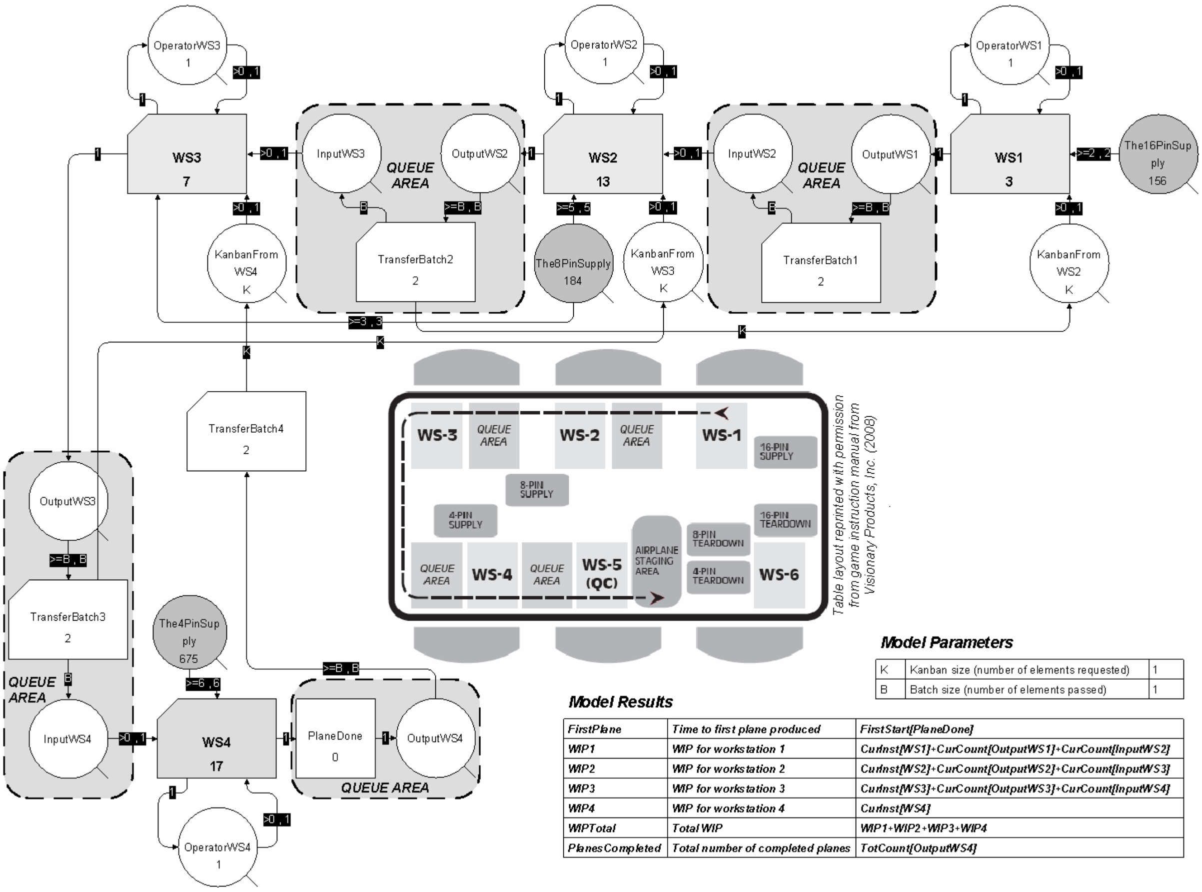


Table layout reprinted with permission from game instruction manual from Visionary Products, Inc. (2008)

Model Parameters

K	Kanban size (number of elements requested)	1
B	Batch size (number of elements passed)	1

Model Results

FirstPlane	*Time to first plane produced*	*FirstStart[PlaneDone]*
WIP1	*WIP for workstation 1*	*CurInst[WS1]+CurCount[OutputWS1]+CurCount[InputWS2]*
WIP2	*WIP for workstation 2*	*CurInst[WS2]+CurCount[OutputWS2]+CurCount[InputWS3]*
WIP3	*WIP for workstation 3*	*CurInst[WS3]+CurCount[OutputWS3]+CurCount[InputWS4]*
WIP4	*WIP for workstation 4*	*CurInst[WS4]*
WIPTotal	*Total WIP*	*WIP1+WIP2+WIP3+WIP4*
PlanesCompleted	*Total number of completed planes*	*TotCount[OutputWS4]*

Figure 74. EZStrobe Computer Simulation of the Airplane Game

Reprinted from Rybkowski et al. (2008)

Table 21. Results from the Airplane Game based on Computer and Live Simulation

Adapted from Rybkowski et al. (2008)

	Transfer type	**Planes completed**	**Time elapsed until first plane**	**WIP from WS1**	**WIP from WS2**	**WIP from WS3**	**WIP from WS4**	**WIP Total**
	(system)	*(# of units)*	*(sec)*	*(# of units)*				
Batch Size 5								
Computer	Push	15	138	54	4	5	0	63
Live	Push	12	150	30	4	7	1	42
Computer	Pull	10	138	5	1	4	0	10
Live	Pull	10	145	5	2	3	0	10
Batch Size 1								
Computer	Push	20	46	55	0	3	0	58
Live	Push	20	43	51	1	5	0	57*
Computer	Pull	12	46	1	0	1	0	2
Live	Pull	12	39	1	1	0	0	2

*WS1 ran out of pieces at 5'20"

It makes intuitive sense that—to achieve one piece flow—manufacturing times at each station would need to be approximately equal. Dividing work into stations that require work of approximately equal time is a process known as *load levelling*. The advantage of most product manufacturing processes is that system optimization through load levelling is possible because the process is performed numerous times, enabling industrial engineers to continually tweak improvements into the system over time. More is said about load levelling and ways to reduce waste associated with it, in **Section 9.1.5.2.4**.

A simple manufacturing process may be perceived as linear. As mentioned previously, in a lean supply chain, each downstream station may use a metaphorical kanban car to signal its respective upstream station that it is ready to receive parts, as suggested by **Figure 75**. However, unlike the linear nature of some factory floor manufacturing, construction processes can be complex; they may require nodes with multiple branches and interdependencies—resembling a chain link fence more than a supply chain, as represented by **Figure 76.**

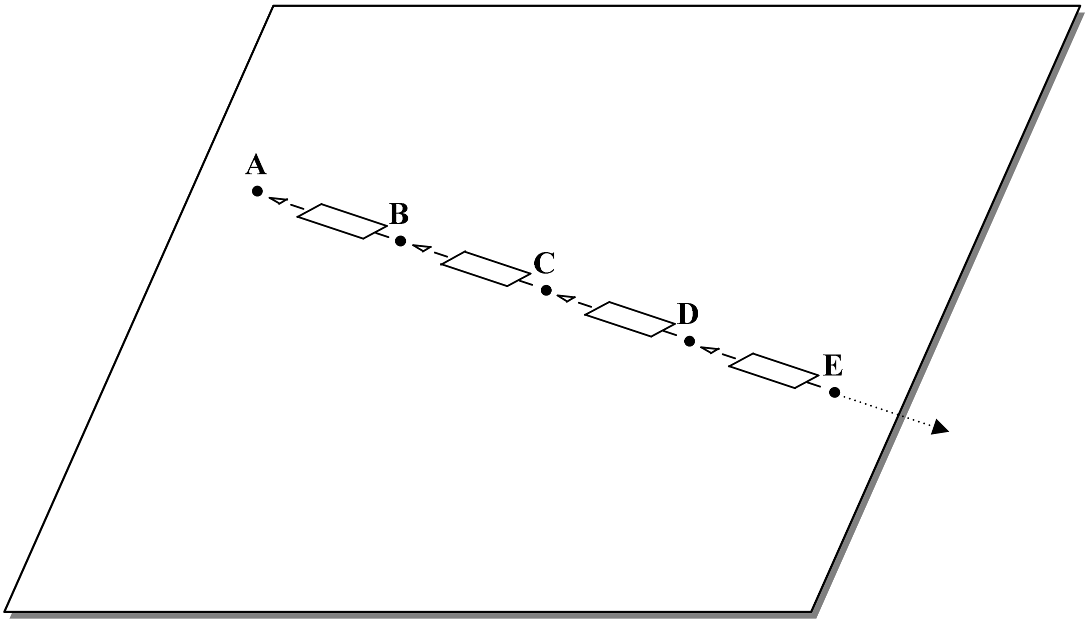


Figure 75. Kanban carts transferring resources between stations along a linear manufacturing chain

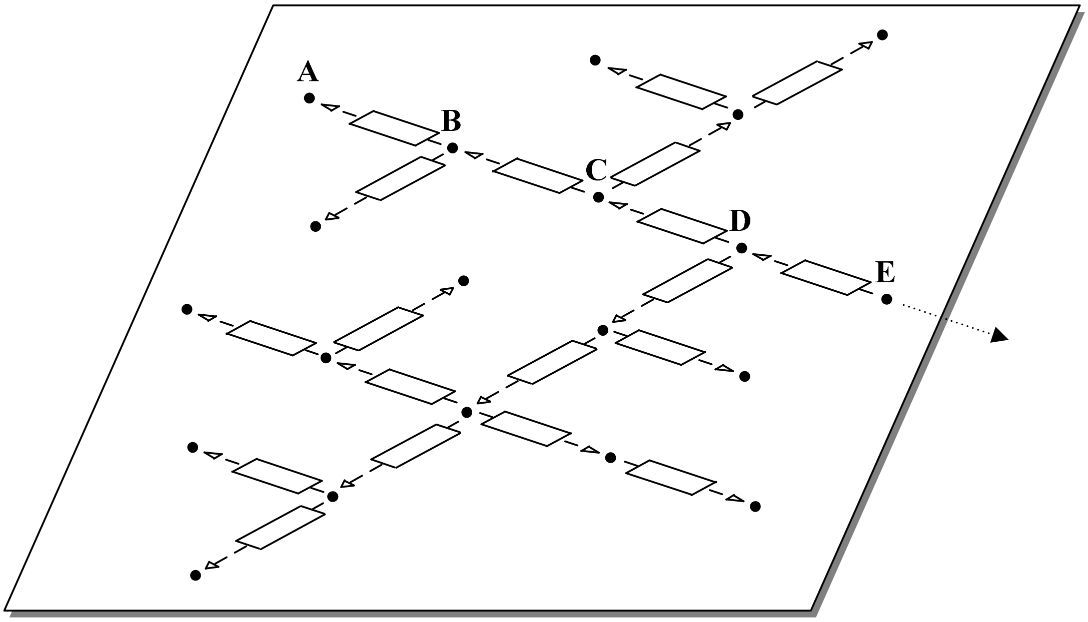


Figure 76. Kanban carts transferring resources between stations with feeder flows, such as on a construction project

For example, a drywall contractor cannot install drywall until *both* electrical and plumbing work have been roughed in. Naturally, this complicates the pull process. Also, unlike product manufacturing, the "one off' nature of many building projects complicates the ability to continually improve since there may be only one time to "get it right". To further complicate the construction cocktail, knowledge is dispersed among numerous participants.

9.1.5.2 Last Planner System as the pull for construction

The lean construction community has responded to these challenges by adopting the *Last Planner System*™—a production planning and control system that is the brainchild of Lean Construction Institute co-founder, Glenn Ballard (Ballard 2000a). The term "Last

Planner" refers to the front line supervisor. Ballard initiated pull in construction by asking construction partners to engage in a process known as *reverse phase scheduling*. Once a client's time constraint has been established, that deadline is fixed to a wall with a self-adhesive notecard. Team members then plan activities collaboratively and collectively, also on the wall using self-adhesive notecards—and backward from the posted deadline. The deadline establishes the basis for a type of "takt time"—the rate at which individual activities need to be accomplished in order to meet the client's required deadline. It must be mentioned here that, unlike a manufactuing assembly line where the final design is known before manufacturing the product, the Last Planner is applied while design of a building is under development. This means precise that the construction times of various phases of the building can not be more than estimates and the term "takt time" must be applied loosely to Last Planner as a general rate at which a project must be pulled in order to meet the required time contraints. Nevertheless, the analogy is helpful to understanding how lean construction principles intersect with those of lean manufacturing.

There are four components of the Last Planner system—Master Scheduling, Phase Scheduling, Lookahead Planning and Commitment/Weekly Work Plan—as graphically depicted in **Figure 77** (Hamzeh 2009). The last two phases, Lookahead Planning and weekly work plan, are of special interest to us here.

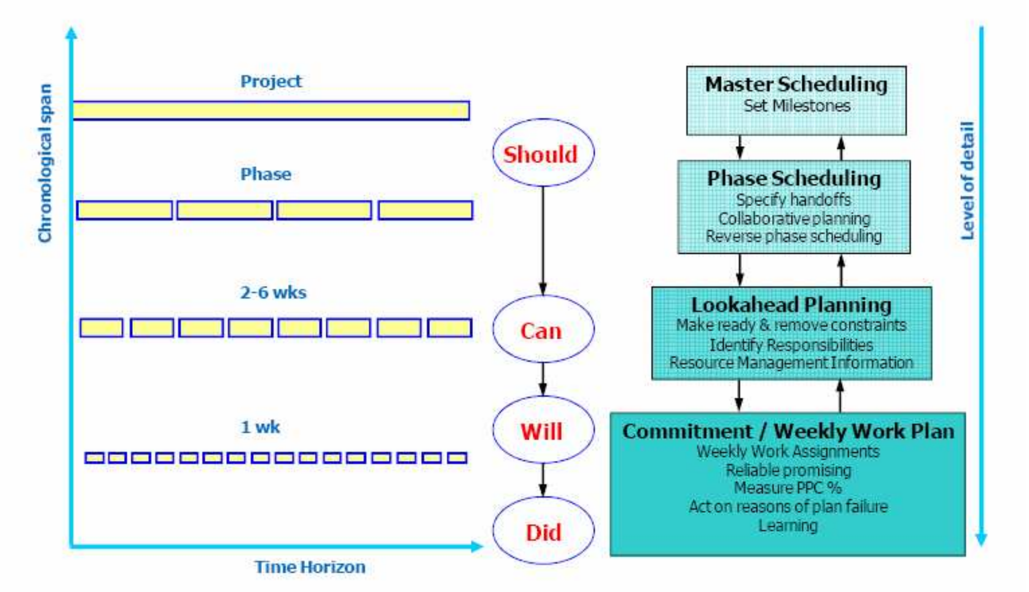


Figure 77. The Last Planner System (Ballard 2000a)

from Hamzeh, F. R. (2009). "Improving Construction Workflow: The Role of Production Planning and Control," Doctoral dissertation, University of California, Berkeley. Reprinted with permission from the author.

It might be argued that a critical purpose of Last Planner is to serve as a series of conceptual kanbans, where metaphorical carts have been replaced by a scheduling directive called the *Weekly Work Plan*. Although Last Planner-as-kanban is an imperfect metaphor, the two processes share some common traits. On the Weekly Work Plan, the “last planner”—the individual responsible for organizing final work assignments for the overall project—divides work into defined (often day-long) batch sizes. The last planner then “fills the kanban carts”—assigning work to each day of the work week. Like the bus driver who must wait at a stop to conform to an overall transit plan and wait at a stop if he arrives ahead of schedule, no member of a team may perform work either before or after his turn has been designated. Team members are, in effect, informed by the last planner facilitator about when to get on the bus—not a moment before and not a moment after the appropriate time. This is the essence of the Just-In-Time system, so integral to lean thinking.

9.1.5.2.1 Facilitating flow: knowledge sharing

One challenge of construction is such that it requires the knowledge of multiple fields. For example, realizing a construction project requires the collaboration of professionals with varied formal educational backgrounds: from those with technical school training or no secondary or tertiary education at all to those with BAs/BSs, MBAs, MSs and PhDs. Even within a university, there may be little overlap of professional education; engineering students seldom, if ever, take courses that are part of an architecture curriculum and architecture students rarely set foot inside an engineering department. On the job site, language and cultural differences create additional friction; the construction industry tends to rely on local professionals for financial and design expertise but immigrant labor for site work. Such a wide spectrum of ways of doing likely contributes to misunderstandings and a litigious “culture of blame” that plagues the construction industry in many parts of the world, as has already been discussed. Moreover, unlike products turned out on a manufacturing assembly line, differing site conditions ensure that every construction project is somehow unique.

In other words, construction is a complex process. The culture of lean acknowledges the need to respond to this complexity and encourages adaptation to each new set of circumstances. Metaphorically, lean principles should not be envisioned as a completed book but rather as a loose-leaf binder. The number of pages documenting ideas for lean will continue to grow, because fundamental to lean construction is the concept of continual improvement; there will always be opportunities for growth.

Unlike traditional construction project management which is often led from the top, the pages of the binder are also informed by those who perform the work. In fact, because critical knowledge is distributed throughout all levels of an organization, knowledge sharing through facilitation has become key to the successful development of lean construction theory and practices. The “cloud of shared knowledge” was first introduced in **Section 9.1.5.2.1** and depicted in **Figure 78**. Without shared knowledge, pull scheduling that sits at the heart of Last Planner kanban would not be possible because the there would be no way to plan what should be accomplished within single day with any reliability.

In lean construction, this cloud of shared knowledge begins as early as possible. In a publication on integrated design delivery, the American Institute of Architects advocated that a full team of professionals should begin to work on a project as early as possible to ensure that the ability to effect change could be maximized (AIA National and AIA California Council 2007; MSA 2004)

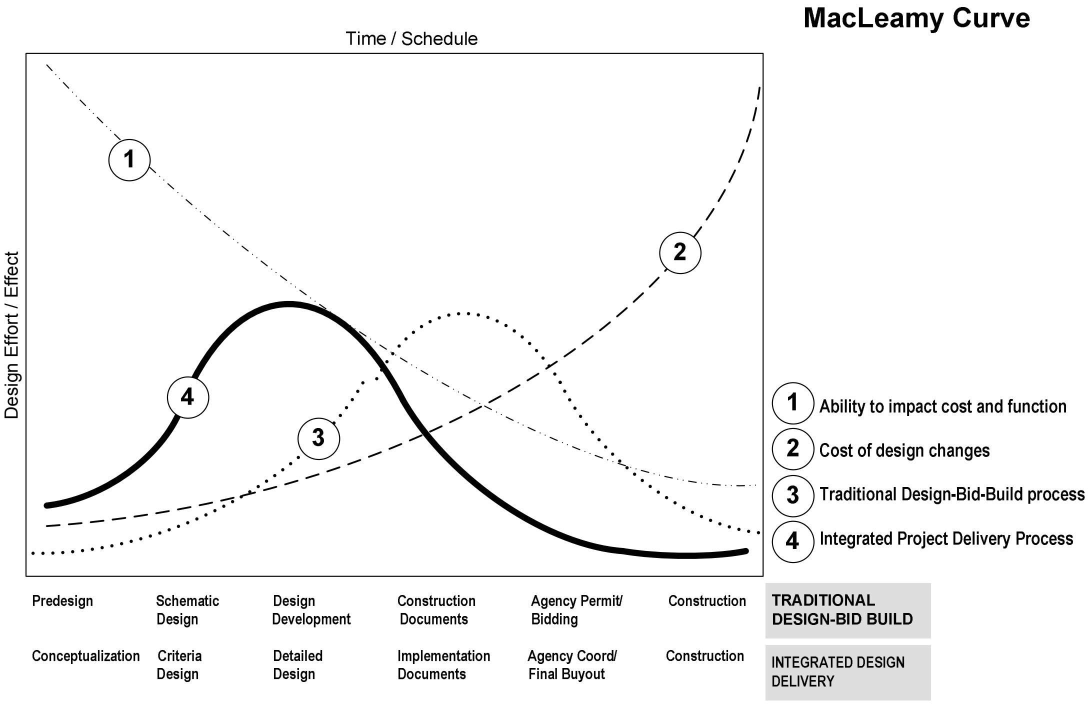


Figure 78. The MacLeamy Curve

In traditional design-bid-build delivery, team members do not participate in the development of the project until the project is already well underway (3). By contrast, Integrated Project Delivery teams participate early (4) ensuring that professionals are informing the development of the project at the time when the ability to impact cost and function is greatest (1) and costs of changing the design are lowest (2).

Adapted from MSA (2004).

Lean construction has been built on this premise as well. The consequences of early knowledge sharing as compared to typical Design-Bid-Build knowledge sharing are perhaps best illustrated by the diagrams shown in **Figure 79**.

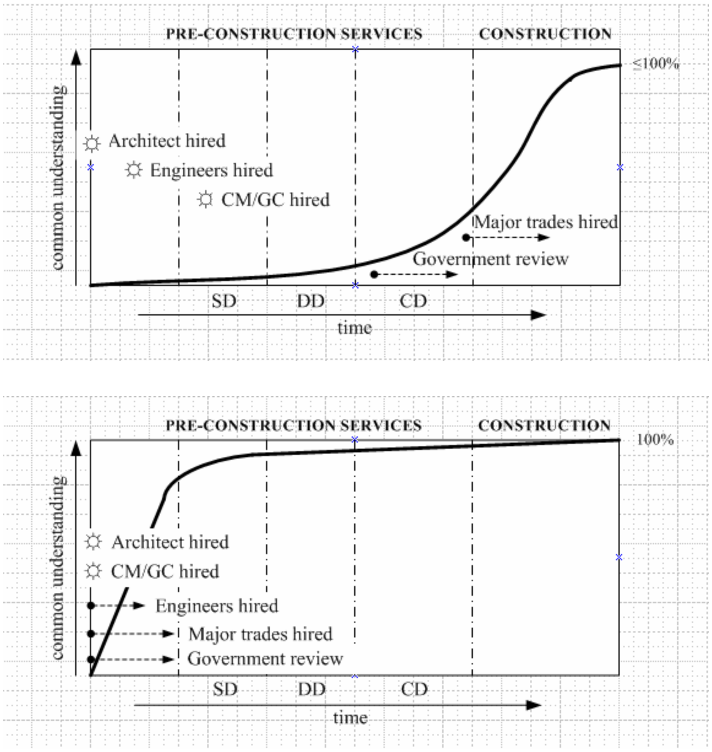


Figure 79. Shared project knowledge

by team members during typical Design-Bid-Build project delivery (top), and during Lean Project delivery (bottom), as speculated by Will Lichtig (2008).

Note that shared project understanding is much greater toward the beginning of a project during Lean Project delivery.

Adapted from Lichtig (2008), as presented in Feng and Tommelein (2009).

The benefits of early knowledge sharing may seem intuitively obvious. But recall that *lack of knowledge* was identified by Josephson and Hammarlund (1999) as one of two of the primary causes of defects, as discussed in **Section 9.1.1.1**—suggesting that the construction industry does not always follow that which seems intuitively obvious.

Most construction projects are unique to their site and function. Because of the one-off nature of most construction projects, no one individual—not even an experienced project manager—can know all that is required to fill the metaphorical kanban carts. Last Planner acknowledges this by engaging the “Big Room” concept of meetings common to lean thinking. The term Big Room refers to the need to bring together all those who are critical to the design of a building so that their knowledge can inform that which needs to be done during a regular specified time period. The day or half-day of a Weekly Work Plan in the Last Planner can be imagined as an empty kanban cart waiting to be filled with resources that will be transformed at designated stations. In **Figure 80**, the collective experience of team members in the big room is symbolized by a cloud of shared knowledge.

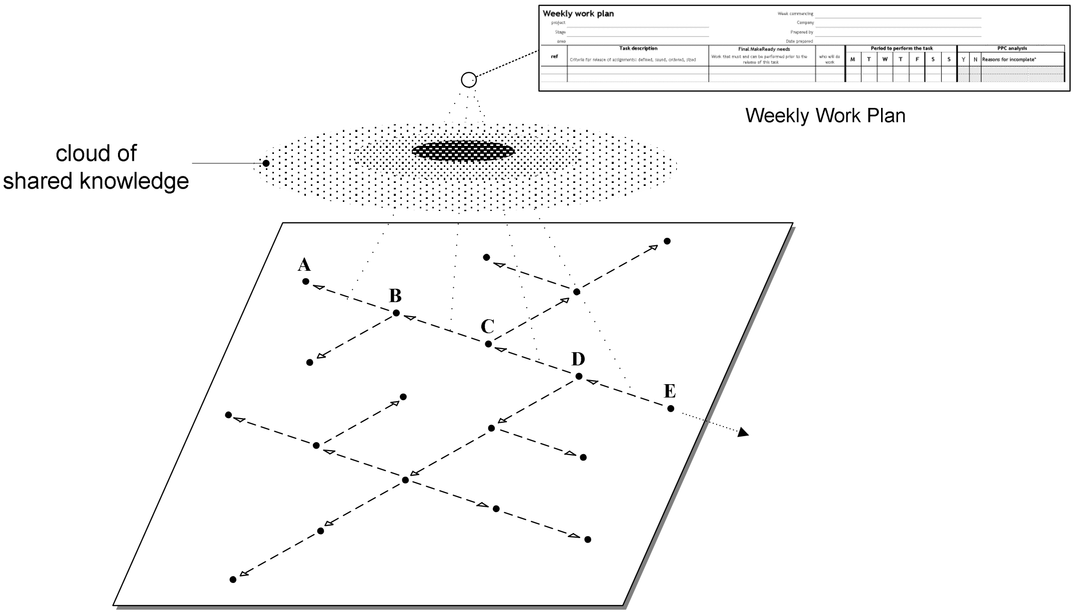
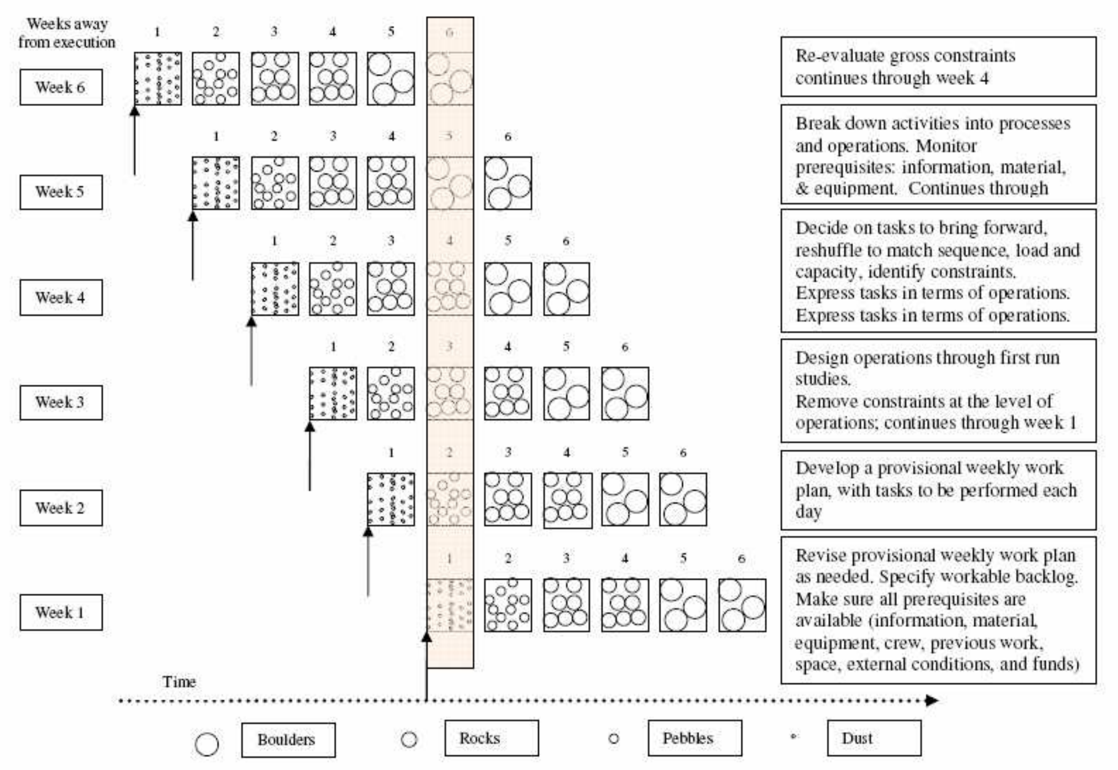


Figure 80. Cloud of shared knowledge: The Last Planner kanban

Naturally, one risk of a Just-In-Time delivery system is that it may place an unfair burden on those who must fill a cart. Anyone who has heard the words “I need it tomorrow” or, worse yet—“give it to me now”—knows how unreasonable such directives can be. Responding to this, lean practitioners frequently use the phrase “last responsible moment” instead of just-in-time. The Lookahead Plan of the Last Planner System focuses on constraints analysis and removal, making JIT possible, as shown in **Figure 81**.



Re-evaluate gross constraints continues through week 4

Break down activities into processes and operations. Monitor prerequisites: information, material, & equipment. Continues through

Decide on tasks to bring forward, reshuffle to match sequence, load and capacity, identify constraints. Express tasks in terms of operations. Express tasks in terms of operations.

Design operations through first run studies. Remove constraints at the level of operations; continues through week 1

Develop a provisional weekly work plan, with tasks to be performed each day

Revise provisional weekly work plan as needed. Specify workable backlog. Make sure all prerequisites are available (information, material, equipment, crew, previous work, space, external conditions, and funds)

Figure 81. Six-week Look-Ahead planning process

from Hamzeh, F. R., Ballard, G., and Tommelein, I. D. (2008). "Improving Construction Work Flow—the Connective Role of Lookahead Planning." *Proceedings for the 16th Annual Conference of the International Group for Lean Construction*, Manchester, UK, 635-646. Reprinted with permission from the author.

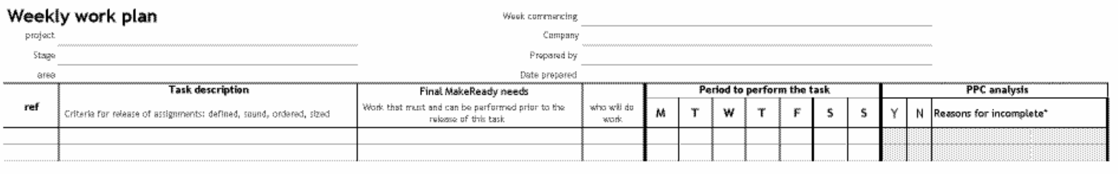
9.1.5.2.2 Facilitating flow: Removing constraints

By the time a task is committed during a Weekly Work Plan meeting, the expectation is that it will be completed as scheduled to maintain a predictable flow of work through the network of specialists. Therefore, anything that might hinder completion of the task needs to be cleared before it is assigned. During Lookahead Planning (2-6 weeks before weekly work plan assignments are made), tasks are *made ready*. In a landmark paper on shielding, Ballard and Howell proposed five *quality criteria* against which a task must be checked before it is allowed into the weekly work plan (Ballard and Howell 1998). These are:

(1) *Definition:* Is the task specific? Will it be clear when it has been finished?
(2) *Soundness:* Are all materials available, including completed prerequisite work, for the task to be performed?
(3) *Sequence:* Is the task being performed in the correct order?
(4) *Size:* Is the task sized to the capacity of the crew?
(5) *Learning:* When assignments are not completed, are they tracked and reasons identified?

The facilitator of the Big Room meeting checks for these conditions in order to ensure that the customer of any task (the trade that immediately follows) is furnished with all that is necessary to complete it successfully. Because all downstream work suffers when a task cannot be completed, it is crucial that the facilitator rigorously honor this checklist. Once a task has been made ready, it can safely be assigned to enter the flow.

The quality criteria “soundness” is satisfied through constraints analysis and removal. In the public transit metaphor, the quality criteria “soundness” is analogous to a parent who wakes up, dresses, feeds a school child, and sends her to the bus stop in time to board the bus at its scheduled arrival time. As in the metaphorical kanban cart, a Weekly Work Plan signals a request for a task to be completed for the customer that follows (**Figure 82**). It includes critical information such as: description of the task, a final check that all prerequisite tasks have been completed and all quality criteria have been met, and an indication as to when the task will be performed that week.



Weekly work plan

project

Stage

area

Week commencing

Company

Prepared by

Date prepared

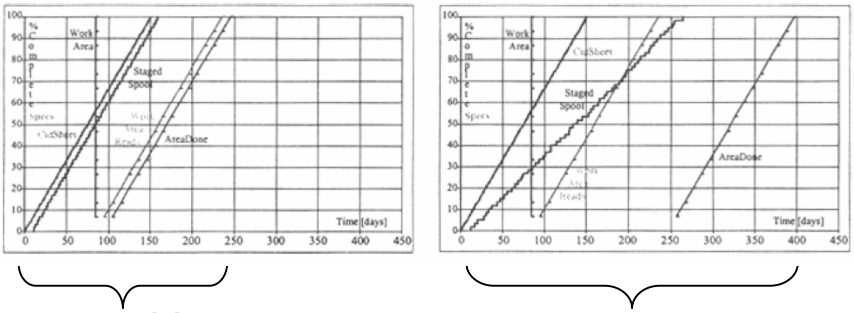
ref	Task description	Final MakeReady needs		Period to perform the task							PPC analysis		
	Criteria for release of assignments: defined, sound, ordered, sized	Work that must and can be performed prior to the release of this task	who will do work	M	T	W	T	F	S	S	Y	N	Reasons for incomplete*

Figure 82. Weekly Work Plan

(Lean Construction Institute 2009)

9.1.5.2.3 Facilitating flow: Percent Planned Complete (PPC)

As has been mentioned previously, variability is undesirable when attempting to achieve flow. To test this principle, Tommelein (Tommelein 1997; 1998; 2000) developed two computer models which simulated manufacturing processes. The researcher compared the total time required to complete a process when individual component tasks were assigned deterministic (coordinated) sequencing versus when they were assigned stochastic (random) completion times. The results, illustrated in **Figure 83**, demonstrate the detrimental impact of variability on flow.



Low variability

High variability

Figure 83. Impact of variability on flow

Variability adversely lengthens overall project schedules

From Tommelein, I. D. (1997). *Discrete-Event Simulation of a Pull-Driven Materials-handling Process that Requires Resource Matching: Example of Pipe-Spool Installation*, Technical Report 97-2, Construction Engineering and Management Program, Civil and Environmental Engineering, U.C. Berkeley. Reprinted with permission from the author.

Section 9.1.5.2.4 discusses ways to fill otherwise unproductive time with workable backlog. However, the impact of variability is important because work cannot be infinitely buffered. The Weekly Work Plan kanban “batch” of one day, for example, is still a defined time limit that should not be exceeded if flow is to be maintained. The assumption is that some work will be accomplished more quickly than planned. However, an alternative scenario is that planned work exceeds its expected completion time. With respect to the public bus analogy, such a scenario may be envisioned as a bus trapped behind an unforeseen traffic accident—making the vehicle arrive at stops later than any reasonable amount of buffering could have accommodated. But buses can also be delayed by unmotivated bus drivers, as well as by unforgiving traffic conditions. For most public transportation networks in the United States, drivers are held accountable to complete a route by a specified time. Accountability is important because it increases reliability and reduces variability.

The critical nature of reliability is also recognized by the Last Planner. For example, a measure of work flow reliability called *Percent Plan Complete (PPC)* is embedded in the Weekly Work Plan process; PPC is used to increase the reliability of planning by reducing variability. The idea is that specific tasks designated to be completed before the next "Big Room" Last Planner meeting are listed. During Last Planner meetings, the list of all items that had been planned to be completed by that time is checked for completeness. Research has demonstrated that when more disciplined screening of potential commitments is used in combination with urgent expectations and peer pressure to make reliable promises, PPC increases—an indication that the reliability of planning increases (Ballard 1999; Ballard and Howell 1998) (**Figures 84 & 85**).

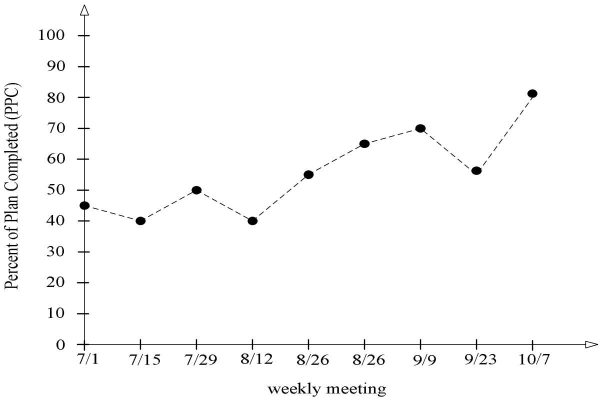


Figure 84. A Percent Plan Complete (PPC) chart

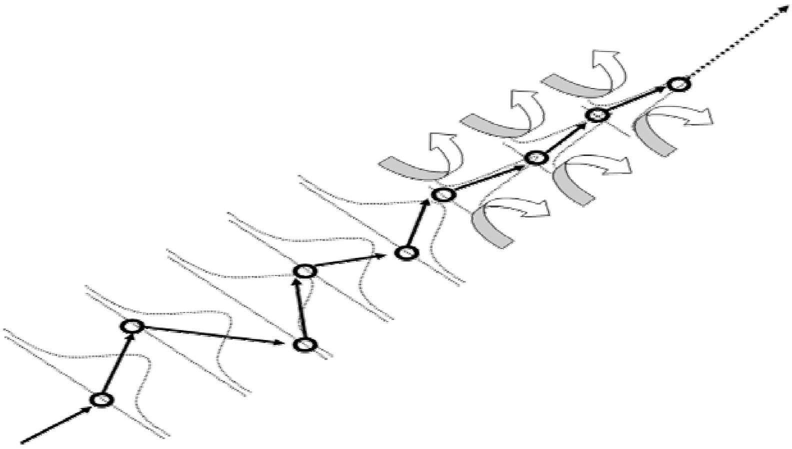


Figure 85. Impact of reduced variability on flow

Because variability negatively affects project schedules, it is advantageous to reduce variability. A PPC chart increases the reliability of deliverables by motivating workers to maximize their PPC ratings.

It is important to mention that PPC should not be mistaken as an indicator of productivity. In fact, if participants took it as such, those who promise to complete an activity might purposely under-promise simply to boost their PPC score. Instead, the role of PPC is to enhance reliability of work promised, making future planning more reliable. In the Last Planner, one critical aspect of the facilitator role is to keep participants accountable to completing the tasks which they themselves promised to fulfill during reverse phase scheduling.

When a task is not completed as planned, the Weekly Work Plan includes a section to indicate the cause for the divergence under “reason for incomplete”, in order incorporate learning into the process should a similar situation arise again. This activity will be discussed in the following section on continuous improvement.

9.1.5.2.4 Buffering capacity loss with workable backlog

Manufacturing in a factory can often be carefully controlled. However, this is not true for construction projects erected on site. The metaphor of the circulating bus as agent of flow is useful because, like a construction project, traffic conditions are often variable, making it difficult to design a perfectly timed bus schedule. To address this uncertainty, many public agencies build buffers into bus schedules—stops at which a driver should stop and wait to realign departure times with those that have been scheduled.

Generally, lean manufacturing discourages the use of buffers and labels buffers as waste because they interfere with the objective to achieve one-piece flow.

In the controlled conditions of a typical factory, one piece flow without buffers is potentially achievable. However, the variability of conditions of a construction site make the elimination of all buffers more difficult, if not impossible. The Last Planner System acknowledges the reality of construction site variability by permitting the inclusion of some buffers. However, because unused buffer times are antithetical to the lean ideal of waste elimination, Last Planner designates certain non-critical path tasks as *workable backlog*. In the bus route analogy, this might entail asking the driver to use the waiting time to collect ridership statistics, for example, or to personally refresh himself with a needed coffee break. On a construction site, Ballard has remarked that it would be better for the project if workers stood with their hands in their pockets waiting for the next task rather than overproduce or perform work that is out of sequence (Ballard 2004). But if buffer time is substantial enough, it would be even better for the project if workers were to produce non-critical path items that have been labeled as *workable backlog,* during that buffer time. Workable backlog renders buffer time productive in the Last Planner kanban system; it is a form of load levelling—and is an opportunity to tranform waste into value (**Figure 86**).

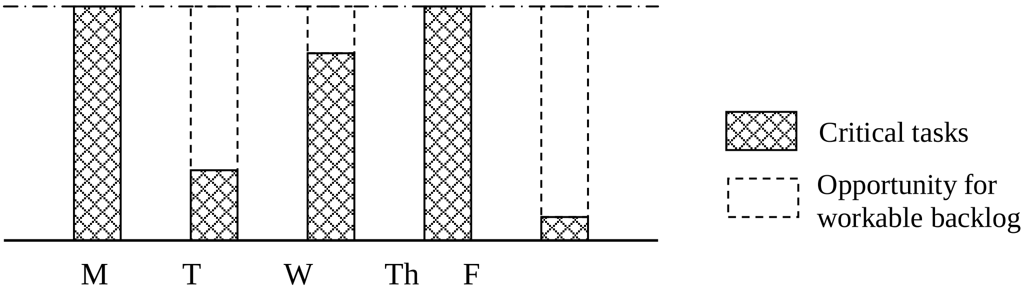


Figure 86. Relationship between critical tasks and workable backlog

Adapted from Ballard (2009a)

9.1.6 The importance of continuous improvement (kaizen)

The design engine of lean construction operates within a culture of continuous improvement, as suggested by **Figure 87**.

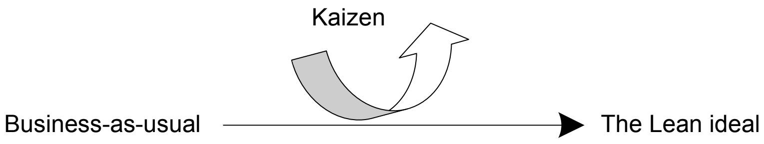


Figure 87. Continuous improvement: kaizen

Lean thinking is like an infinitely large loose leaf binder; it assumes further waste can always be identified and eliminated and additional value can always be created and incorporated. The lean model of continuous improvement is based on Shewhart and Deming's PDCA Circle—an acronym for Plan-Do-Check-Act—as shown in **Figure 88**.

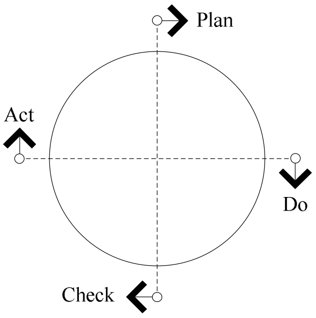


Figure 88. The PDCA or Deming Cycle
Adapted from Shewhart and Deming (1939)

The PDCA circle really represents the scientific process of developing a hunch or hypothesis of how a challenge may be met (plan), testing those hunches through experimentation (do), checking to see if the results of the experiment validate the hypothesis (check), and then modifying the hypothesis to better explain the results obtained (act). Since there is ever more to know, the circle is perceived as continuous and never-ending.

9.1.6.1 Tools to assist continuous improvement

To feed the PDCA cycle and recognition of areas that can be improved, a number of tools have been developed. For example, most lean construction meetings end with a +/Δ debriefing exercise. Although seemingly simple, a +/Δ exercise is really quite effective. During it, a facilitator invites all meeting participants to openly offer what they feel worked effectively during a meeting as well as that which they feel can be improved. Several rules must be obeyed: the facilitator *must* record all comments proffered (i.e., she may paraphrase but not edit). This is important because doing so motivates participants to speak up; some of the best ideas emerge when an environment is perceived as safe and non-confrontational. In the plus (+) column, the facilitator records those items which participants feel worked well and which should be repeated. However, note that the tool is written as +/Δ rather than +/-. The distinction, though seemingly subtle, is actually significant. Delta (Δ) represents opportunity for change whereas minus (-) implies fault-finding. Lean principles are designed to reinforce a culture of collaboration and to focus on continuous improvement—a process which is antithetical to fault-finding.

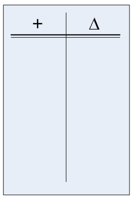


Figure 89. +/Δ chart used to facilitate continuous improvement

Another tool used to inspire continuous improvement includes root cause analysis using the "Five Whys"—a topic which has already been discussed in Chapter 2. Root cause analysis is used after Percent Plan Complete (PPC) exercises to determine the causes of failure when PPC objectives have not been met so that adjustments may be made when encountering a similar situation in the future.

In the subject case study that will be discussed, additional processes, such as *set-based design* and the *Choosing-by-Advantages* decision-making method (Suhr 1999) have provided opportunities for hypothesis creation and testing, using the PDCA cycle. These processes, as applied to the subject case study, have been well described and documented in a doctoral dissertation by Kristen Parrish (Parrish 2009). The interested reader is advised to consult this document for more information about these processes.

9.1.6.2 Lean terminology: a byproduct of continuous improvement

Much has been written on lean construction, including a relatively comprehensive report for the Construction Industry Institute (Ballard et al. 2007). To those first becoming acquainted with lean thinking, the terminology alone may be somewhat baffling

(Bertelsen 2002). Partly because lean construction methodologies have developed incrementally over time by an array of researchers and participants, a number of related concepts have emerged bearing different names. For example, the terms "*just-in-time (JIT)*" and "*last responsible moment*" are nearly synonymous in meaning; the latter simply adds a layer of humane realism. The concept of "pull" is also closely related to JIT, with pull explaining the "how" and JIT indicating "when." As mentioned previously, pull describes a situation where a downstream process signals an upstream process to generate and deliver resources at the moment when they are needed. "Flow" is what is achieved when processes are pulled just-in-time. Because achieving flow is so critical to TVD in construction, the concept of flow is discussed in detail in **Section 9.1.5**.

9.1.7 The importance of the relational contract

As discussed in **Section 9.1.1**, the adversarial nature of most traditional Design-Bid-Build environments encourages litigation. Contracts are therefore structured to avoid risk—a practice which has generated a culture of blame and litigation. Lean construction contracts, by contrast, are designed to motivate collaboration and the sharing of both risk and reward. Drafted by Will Lichtig, an Integrated Form of Agreement (IFOA) bound parties in the subject case study. The American Institute of Architects has drafted its own integrated project delivery forms of contract as of the time of this writing.

9.2 TVD Exercises: Cathedral Hill Hospital

Figure 90. Big Room meetings were used to engage both TVD and Last Planner processes.

(Photo by the author)

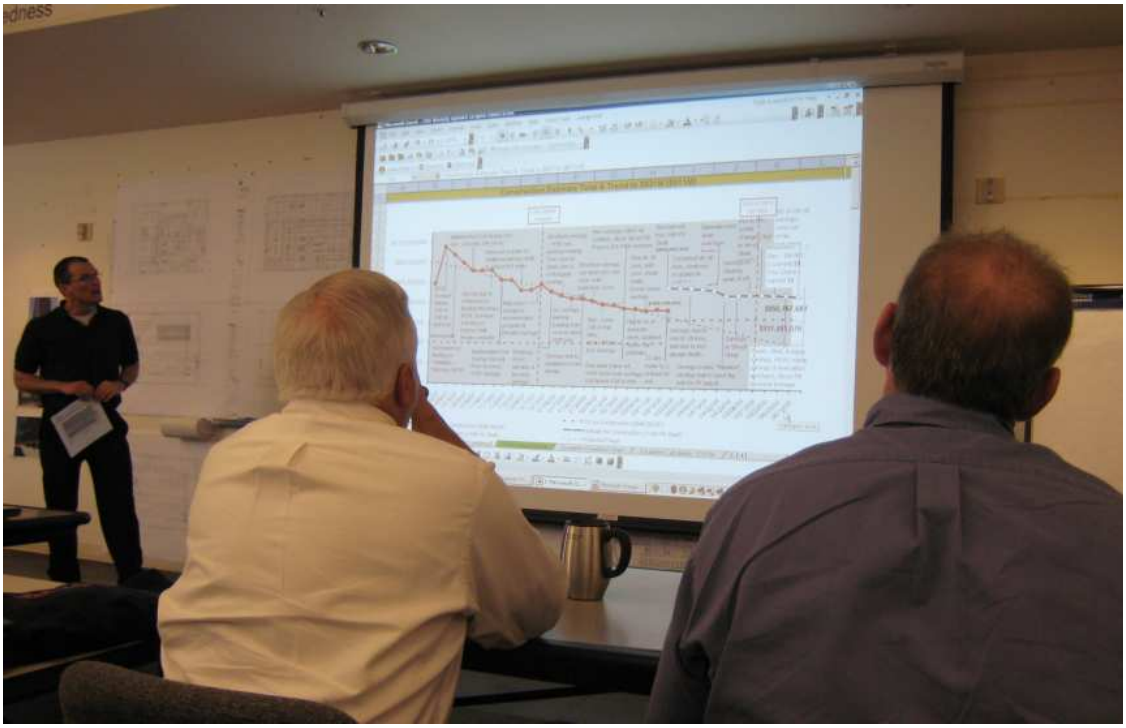


Figure 91. During Big Room meetings the project estimator, Paul Klemish, shared the progress of the team toward meeting target cost.

(Photo by the author)

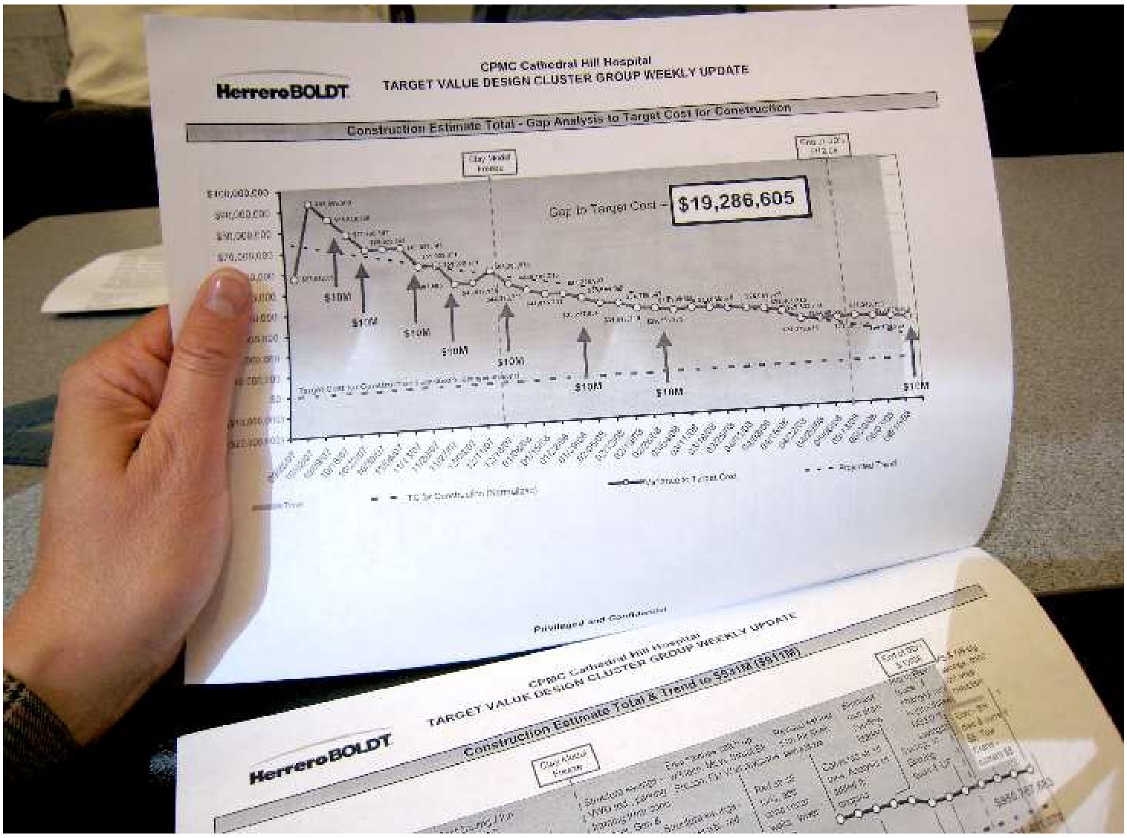


Figure 92. Refreshed TVD charts were distributed to team members during each week's TVD meeting.

(Photo by author)

Figure 93. Team members actively participated during Big Room meetings.
(Photo by the author)

Figure 94. Lean construction emphasizes visual communication. Posting project information on the walls is part of the strategy of lean construction.

(Photo by the author)

Figure 95. Surrounding the project office with visuals assisted the lean agenda. (Photo by the author)

Figure 96. Set-based design solutions were posted on the project office walls to facilitate comment-making.

(Photo by the author)

Figure 97. Meeting rooms were given lean construction names to remind participates of the lean context in which they work.

(Photo by author)

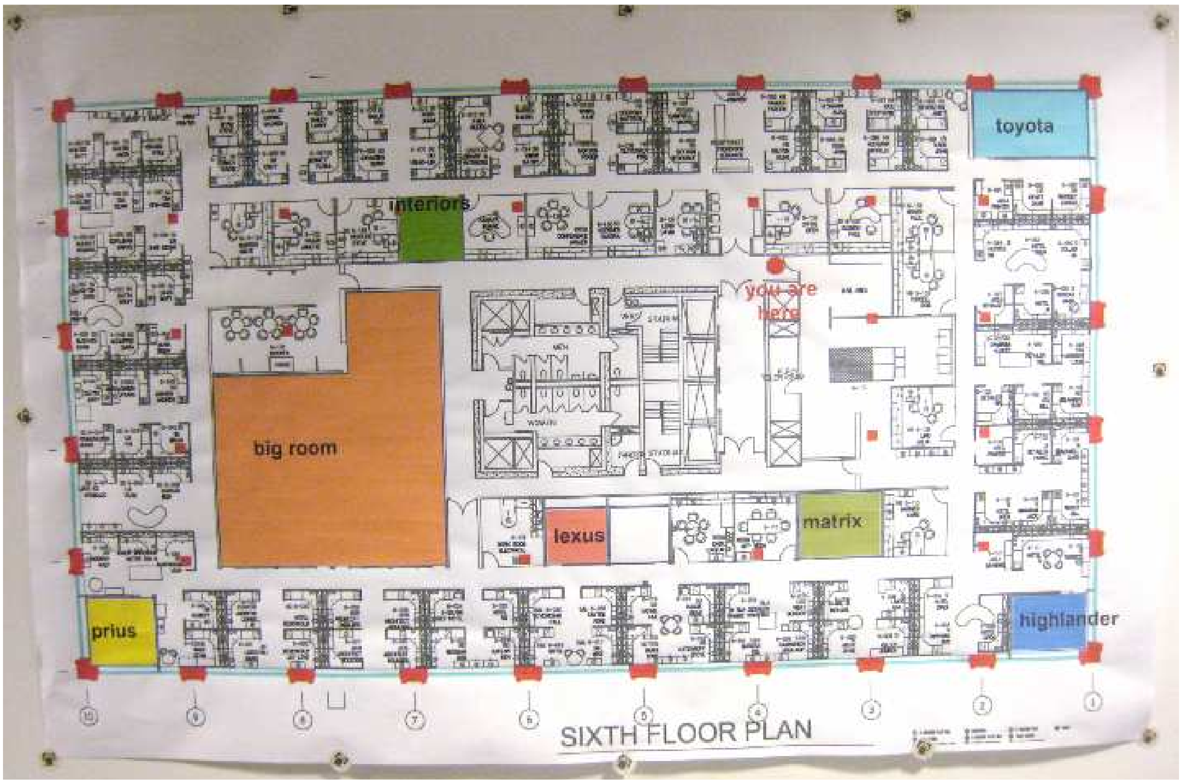
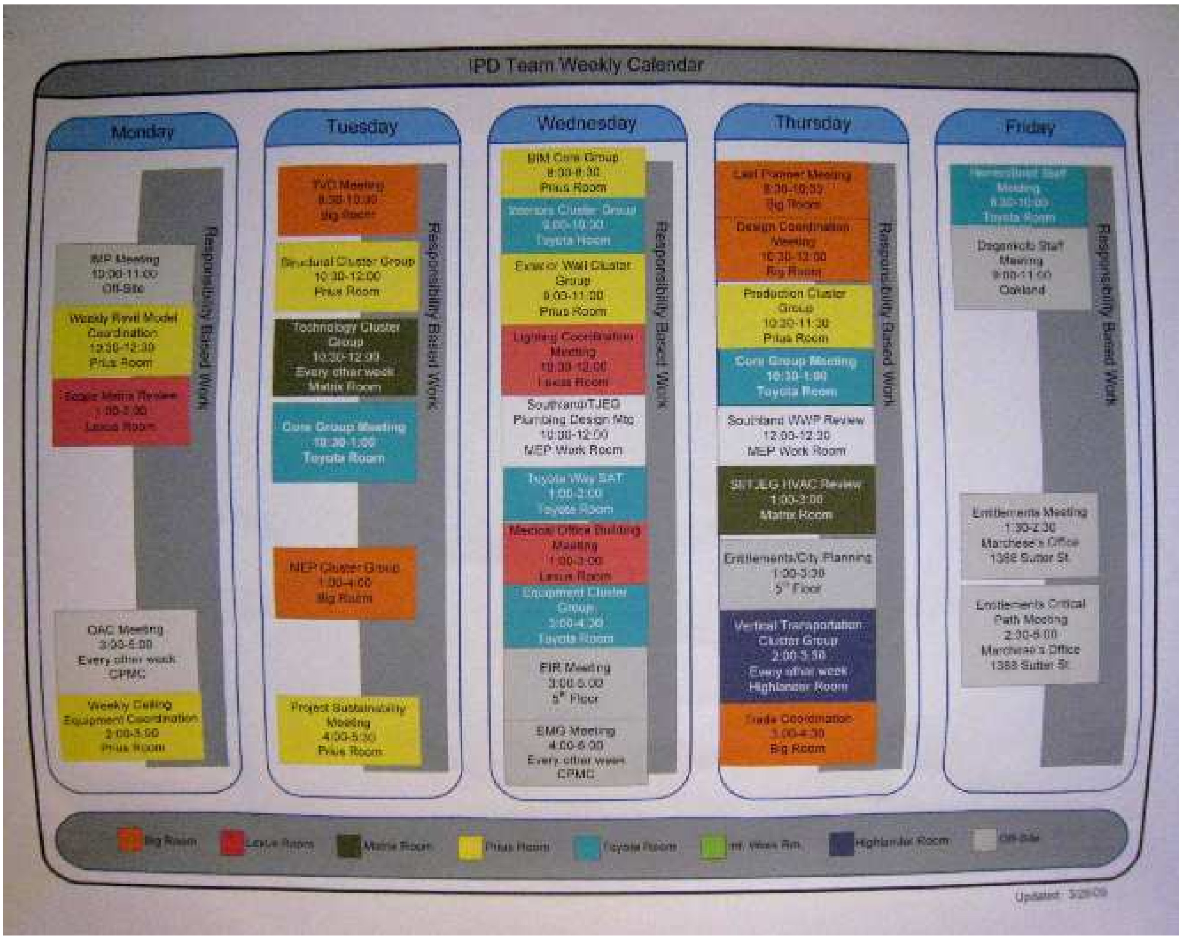


Figure 98. The Cathedral Hill project team office was fitted out with a Big Room and six smaller conference rooms that were labeled with lean names.

(Photo by the author)



IPD Team Weekly Calendar

Monday

IMP Meeting
10:00-11:00
Off-Site

Weekly Revit Model Coordination
11:30-12:30
Prius Room

[illegible] Matrix Review
1:00-2:00
Lexus Room

OAC Meeting
3:00-5:00
Every other week
CPMC

Weekly Ceiling Equipment Coordination
2:00-3:00
Prius Room

Responsibility Based Work

Tuesday

TVD Meeting
8:30-10:30
Big Room

Structural Cluster Group
10:30-12:00
Prius Room

Technology Cluster Group
10:30-12:00
Every other week
Matrix Room

Core Group Meeting
10:30-1:00
Toyota Room

MEP Cluster Group
1:00-4:00
Big Room

Project Sustainability Meeting
4:00-5:30
Prius Room

Responsibility Based Work

Wednesday

BIM Core Group
8:00-9:00
Prius Room

Interiors Cluster Group
9:00-10:30
Toyota Room

Exterior Wall Cluster Group
9:00-11:00
Prius Room

Lighting Coordination Meeting
10:30-12:00
Lexus Room

Southland/TJEG Plumbing Design Mtg
10:00-12:00
MEP Work Room

Toyota Way SAT
1:00-2:00
Toyota Room

Medical Office Building Meeting
1:00-3:00
Lexus Room

Equipment Cluster Group
3:00-4:30
Toyota Room

FIR Meeting
3:00-5:00
5th Floor

EMG Meeting
4:00-6:00
Every other week
CPMC

Responsibility Based Work

Thursday

Last Planner Meeting
8:30-10:30
Big Room

Design Coordination Meeting
10:30-12:00
Big Room

Production Cluster Group
10:30-11:30
Prius Room

Core Group Meeting
10:30-1:00
Toyota Room

Southland WWP Review
12:00-12:30
MEP Work Room

SI/TJEG HVAC Review
1:00-3:00
Matrix Room

Entitlements/City Planning
1:30-3:30
5th Floor

Vertical Transportation Cluster Group
2:00-3:30
Every other week
Highlander Room

Trade Coordination
3:00-4:30
Big Room

Responsibility Based Work

Friday

[illegible] Staff Meeting
8:30-10:00
Toyota Room

Degenkolb Staff Meeting
9:00-11:00
Oakland

Entitlements Meeting
1:30-2:30
Marchese's Office
1388 Sutter St

Entitlements Critical Path Meeting
2:30-5:00
Marchese's Office
1388 Sutter St

Responsibility Based Work

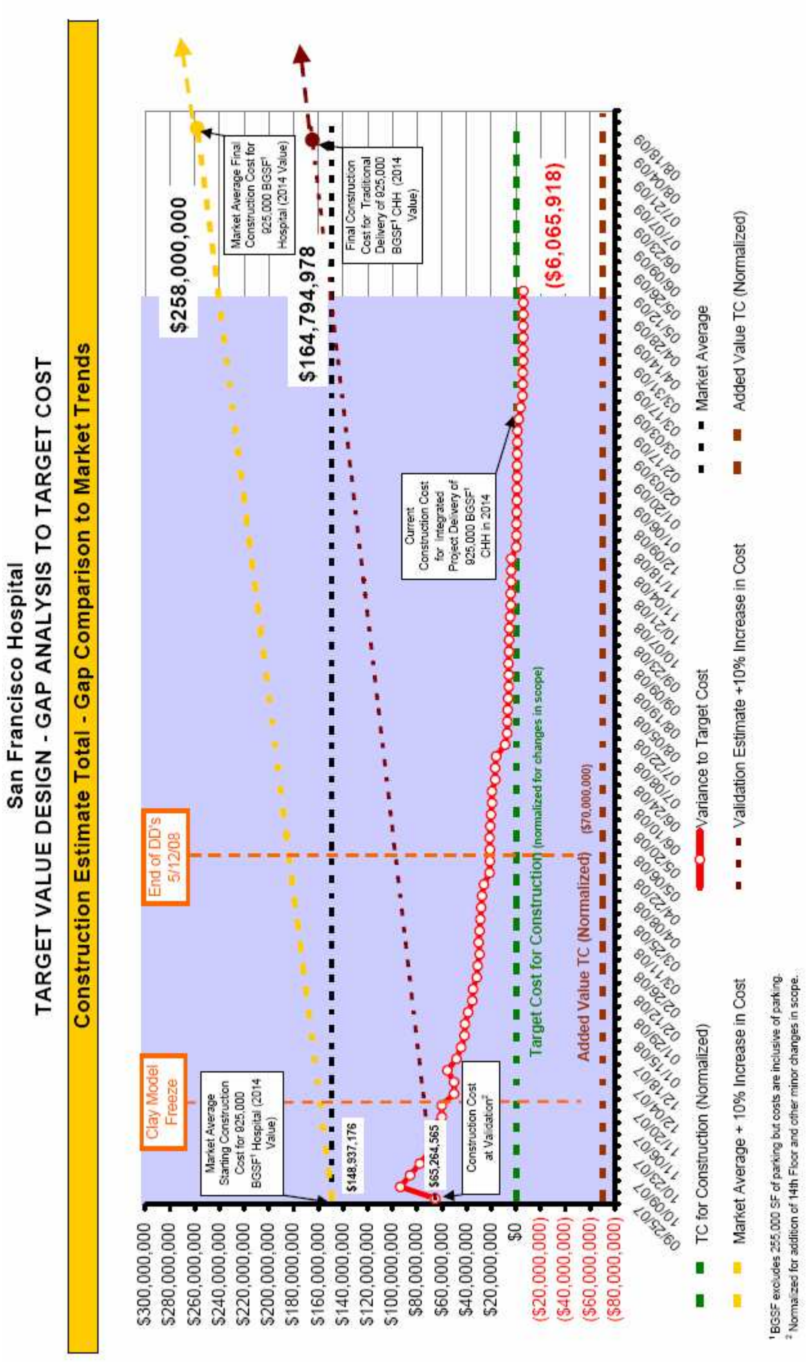
🟧 Big Room 🟥 Lexus Room ■ Matrix Room 🟨 Prius Room 🟦 Toyota Room 🟩 Int. Work Rm ■ Highlander Room ⬜ Off-Site

Updated: 3/26/09

Figure 99. Supporting Integrated Project Delivery: Room meeting schedules for Cluster Group, Committee, Core Group and Big Room meetings (TVD and Last Planner) were posted throughout the project office walls.

(Photo by the author)

9.3 TVD Gap Analysis: Cathedral Hill Hospital



¹ BGSF excludes 255,000 SF of parking but costs are inclusive of parking.
² Normalized for addition of 14th Floor and other minor changes in scope.

Figure 100. TVD Gap Analysis: Cathedral Hill Hospital (1 of 3)

Reprinted with permission from Paul Klemish (2009).

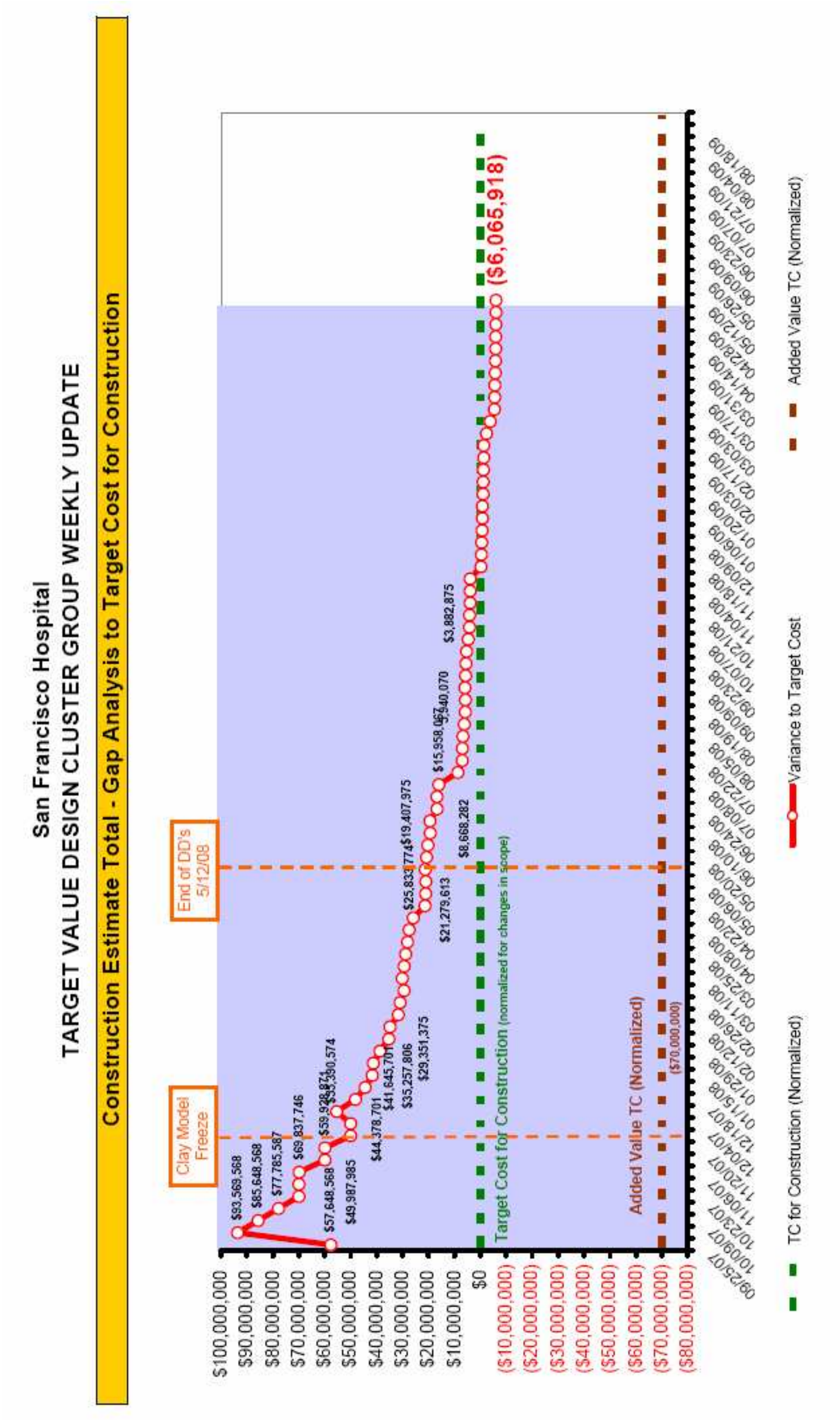


Figure 101. TVD Gap Analysis: Cathedral Hill Hospital (2 of 3)

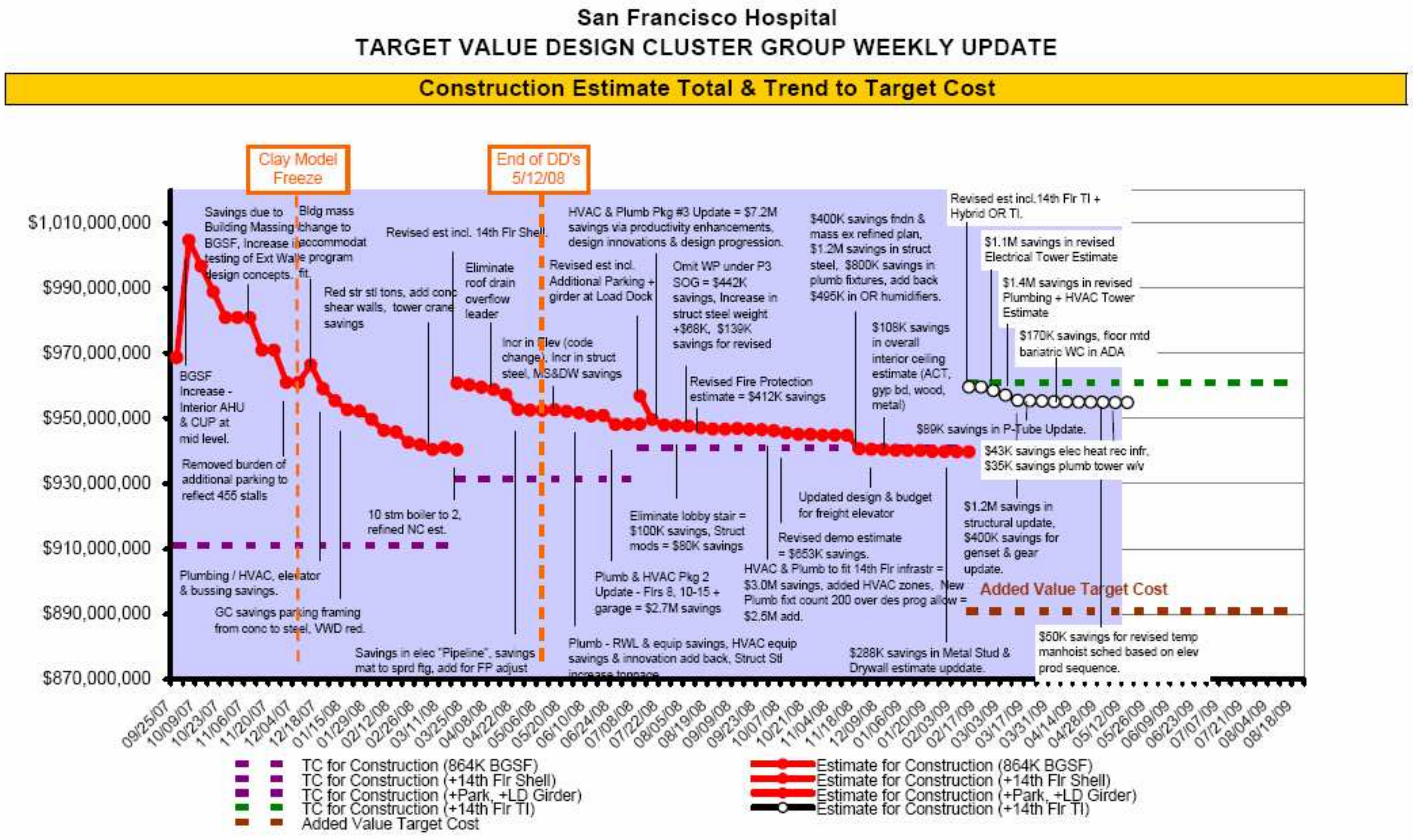
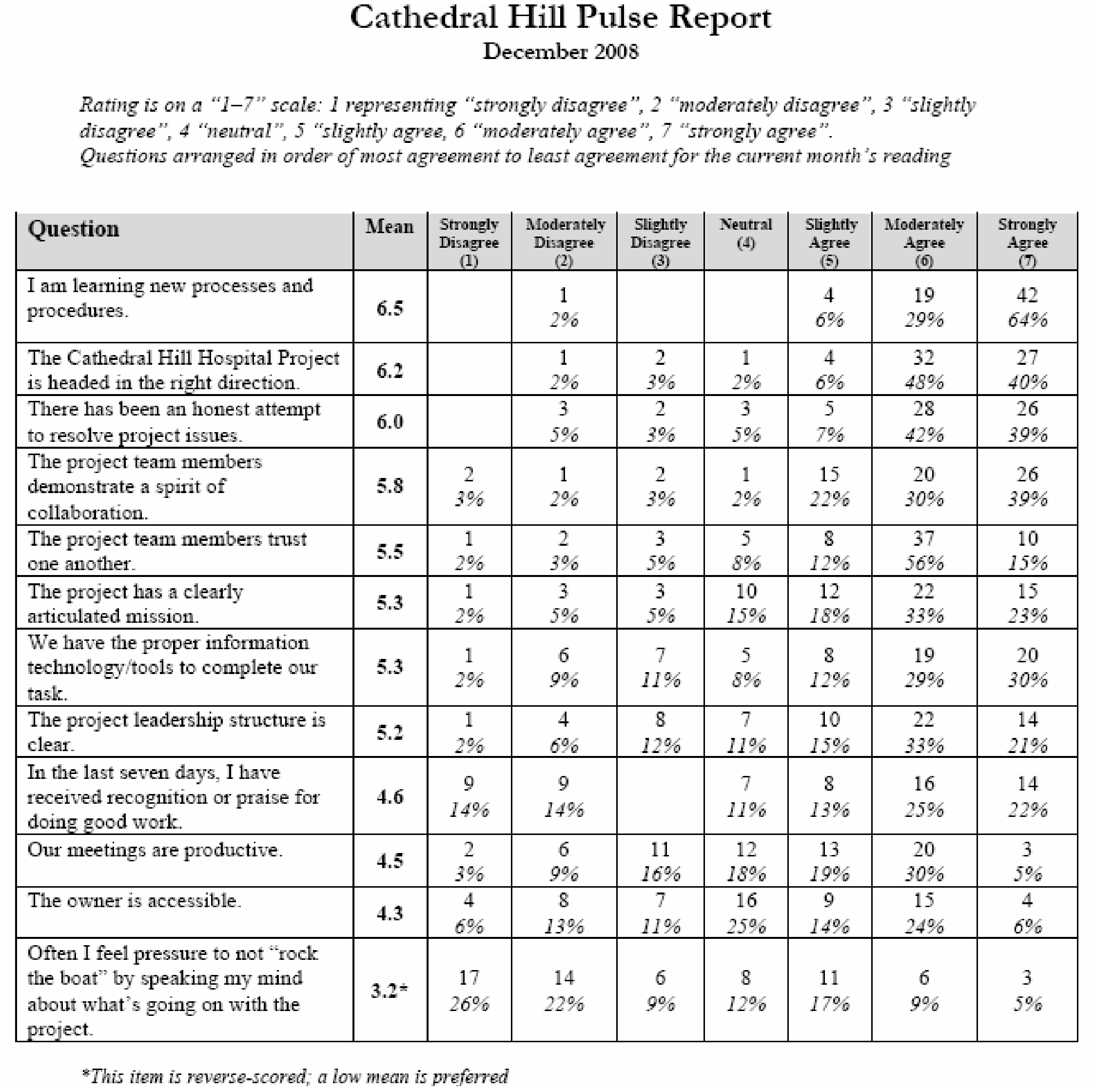


Figure 102. TVD Gap Analysis: Cathedral Hill Hospital (3 of 3)

9.4 TVD Gap Pulse Report: Cathedral Hill Hospital



Cathedral Hill Pulse Report

December 2008

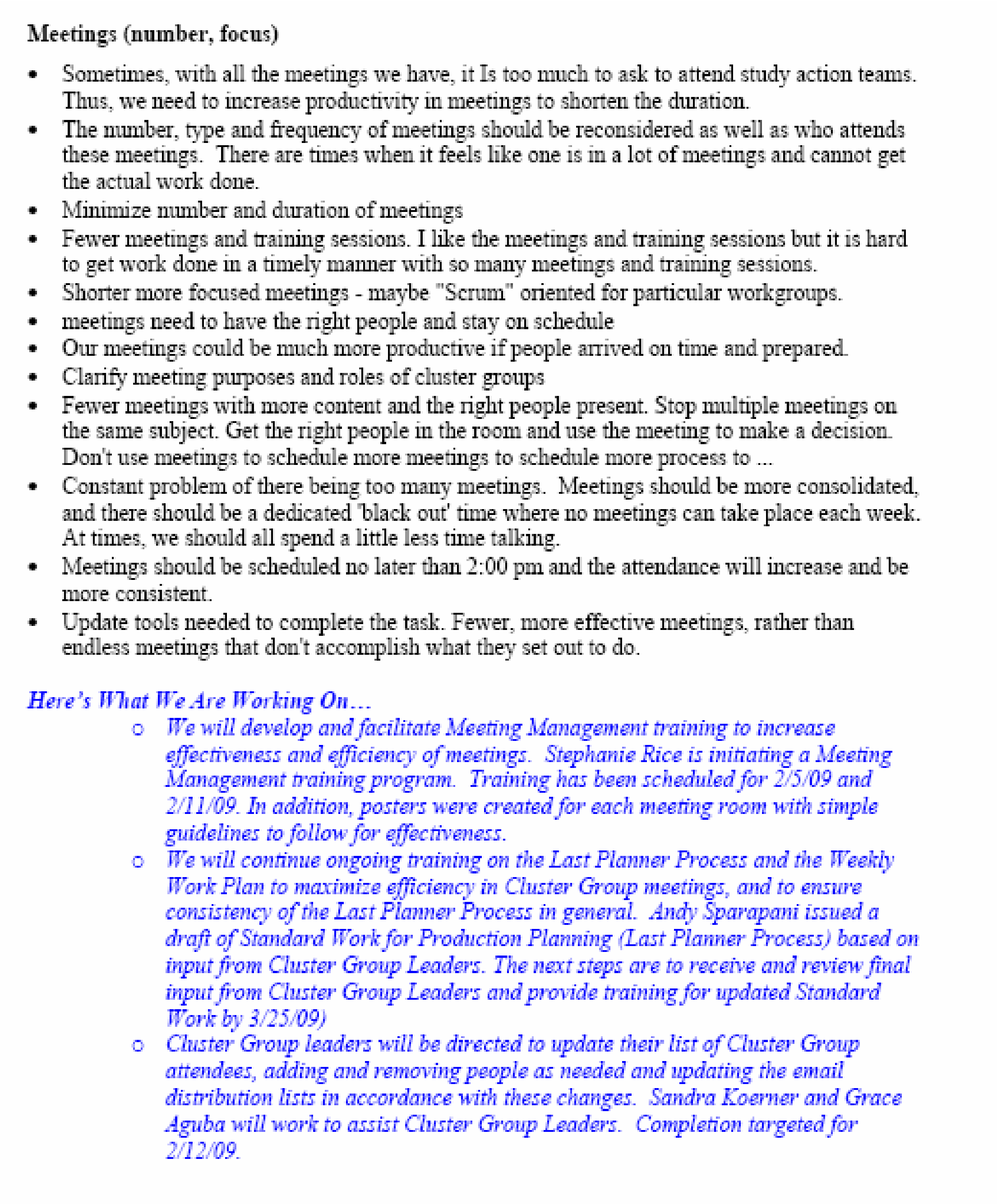
Rating is on a "1–7" scale: 1 representing "strongly disagree", 2 "moderately disagree", 3 "slightly disagree", 4 "neutral", 5 "slightly agree, 6 "moderately agree", 7 "strongly agree".
Questions arranged in order of most agreement to least agreement for the current month's reading

Question	**Mean**	**Strongly Disagree (1)**	**Moderately Disagree (2)**	**Slightly Disagree (3)**	**Neutral (4)**	**Slightly Agree (5)**	**Moderately Agree (6)**	**Strongly Agree (7)**
I am learning new processes and procedures.	**6.5**		1 *2%*			4 *6%*	19 *29%*	42 *64%*
The Cathedral Hill Hospital Project is headed in the right direction.	**6.2**		1 *2%*	2 *3%*	1 *2%*	4 *6%*	32 *48%*	27 *40%*
There has been an honest attempt to resolve project issues.	**6.0**		3 *5%*	2 *3%*	3 *5%*	5 *7%*	28 *42%*	26 *39%*
The project team members demonstrate a spirit of collaboration.	**5.8**	2 *3%*	1 *2%*	2 *3%*	1 *2%*	15 *22%*	20 *30%*	26 *39%*
The project team members trust one another.	**5.5**	1 *2%*	2 *3%*	3 *5%*	5 *8%*	8 *12%*	37 *56%*	10 *15%*
The project has a clearly articulated mission.	**5.3**	1 *2%*	3 *5%*	3 *5%*	10 *15%*	12 *18%*	22 *33%*	15 *23%*
We have the proper information technology/tools to complete our task.	**5.3**	1 *2%*	6 *9%*	7 *11%*	5 *8%*	8 *12%*	19 *29%*	20 *30%*
The project leadership structure is clear.	**5.2**	1 *2%*	4 *6%*	8 *12%*	7 *11%*	10 *15%*	22 *33%*	14 *21%*
In the last seven days, I have received recognition or praise for doing good work.	**4.6**	9 *14%*	9 *14%*		7 *11%*	8 *13%*	16 *25%*	14 *22%*
Our meetings are productive.	**4.5**	2 *3%*	6 *9%*	11 *16%*	12 *18%*	13 *19%*	20 *30%*	3 *5%*
The owner is accessible.	**4.3**	4 *6%*	8 *13%*	7 *11%*	16 *25%*	9 *14%*	15 *24%*	4 *6%*
Often I feel pressure to not "rock the boat" by speaking my mind about what's going on with the project.	**3.2***	17 *26%*	14 *22%*	6 *9%*	8 *12%*	11 *17%*	6 *9%*	3 *5%*

**This item is reverse-scored; a low mean is preferred*

Figure 103. The Cathedral Hill Hospital Pulse Report (1 of 9)

Survey administered to team members
(Cathedral Hill Hospital Integrated Project Delivery Team with Stephanie Rice 2008)
Reprinted with permission from Stephanie Rice.



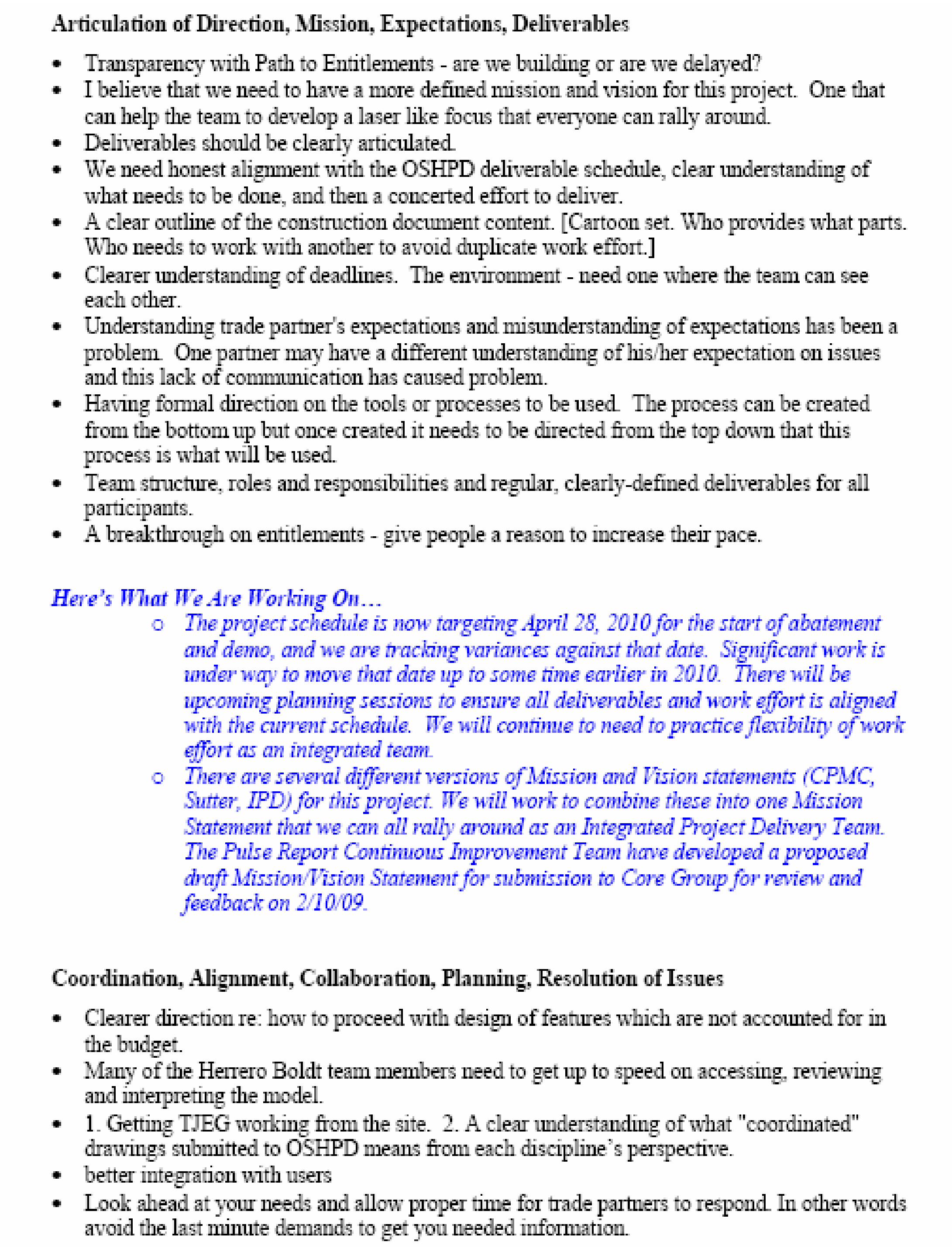
Meetings (number, focus)

- Sometimes, with all the meetings we have, it Is too much to ask to attend study action teams. Thus, we need to increase productivity in meetings to shorten the duration.
- The number, type and frequency of meetings should be reconsidered as well as who attends these meetings. There are times when it feels like one is in a lot of meetings and cannot get the actual work done.
- Minimize number and duration of meetings
- Fewer meetings and training sessions. I like the meetings and training sessions but it is hard to get work done in a timely manner with so many meetings and training sessions.
- Shorter more focused meetings - maybe "Scrum" oriented for particular workgroups.
- meetings need to have the right people and stay on schedule
- Our meetings could be much more productive if people arrived on time and prepared.
- Clarify meeting purposes and roles of cluster groups
- Fewer meetings with more content and the right people present. Stop multiple meetings on the same subject. Get the right people in the room and use the meeting to make a decision. Don't use meetings to schedule more meetings to schedule more process to ...
- Constant problem of there being too many meetings. Meetings should be more consolidated, and there should be a dedicated 'black out' time where no meetings can take place each week. At times, we should all spend a little less time talking.
- Meetings should be scheduled no later than 2:00 pm and the attendance will increase and be more consistent.
- Update tools needed to complete the task. Fewer, more effective meetings, rather than endless meetings that don't accomplish what they set out to do.

Here's What We Are Working On…

- *We will develop and facilitate Meeting Management training to increase effectiveness and efficiency of meetings. Stephanie Rice is initiating a Meeting Management training program. Training has been scheduled for 2/5/09 and 2/11/09. In addition, posters were created for each meeting room with simple guidelines to follow for effectiveness.*
- *We will continue ongoing training on the Last Planner Process and the Weekly Work Plan to maximize efficiency in Cluster Group meetings, and to ensure consistency of the Last Planner Process in general. Andy Sparapani issued a draft of Standard Work for Production Planning (Last Planner Process) based on input from Cluster Group Leaders. The next steps are to receive and review final input from Cluster Group Leaders and provide training for updated Standard Work by 3/25/09)*
- *Cluster Group leaders will be directed to update their list of Cluster Group attendees, adding and removing people as needed and updating the email distribution lists in accordance with these changes. Sandra Koerner and Grace Aguba will work to assist Cluster Group Leaders. Completion targeted for 2/12/09.*

Figure 104. The Cathedral Hill Hospital Pulse Report (2 of 9)



Articulation of Direction, Mission, Expectations, Deliverables

- Transparency with Path to Entitlements - are we building or are we delayed?
- I believe that we need to have a more defined mission and vision for this project. One that can help the team to develop a laser like focus that everyone can rally around.
- Deliverables should be clearly articulated.
- We need honest alignment with the OSHPD deliverable schedule, clear understanding of what needs to be done, and then a concerted effort to deliver.
- A clear outline of the construction document content. [Cartoon set. Who provides what parts. Who needs to work with another to avoid duplicate work effort.]
- Clearer understanding of deadlines. The environment - need one where the team can see each other.
- Understanding trade partner's expectations and misunderstanding of expectations has been a problem. One partner may have a different understanding of his/her expectation on issues and this lack of communication has caused problem.
- Having formal direction on the tools or processes to be used. The process can be created from the bottom up but once created it needs to be directed from the top down that this process is what will be used.
- Team structure, roles and responsibilities and regular, clearly-defined deliverables for all participants.
- A breakthrough on entitlements - give people a reason to increase their pace.

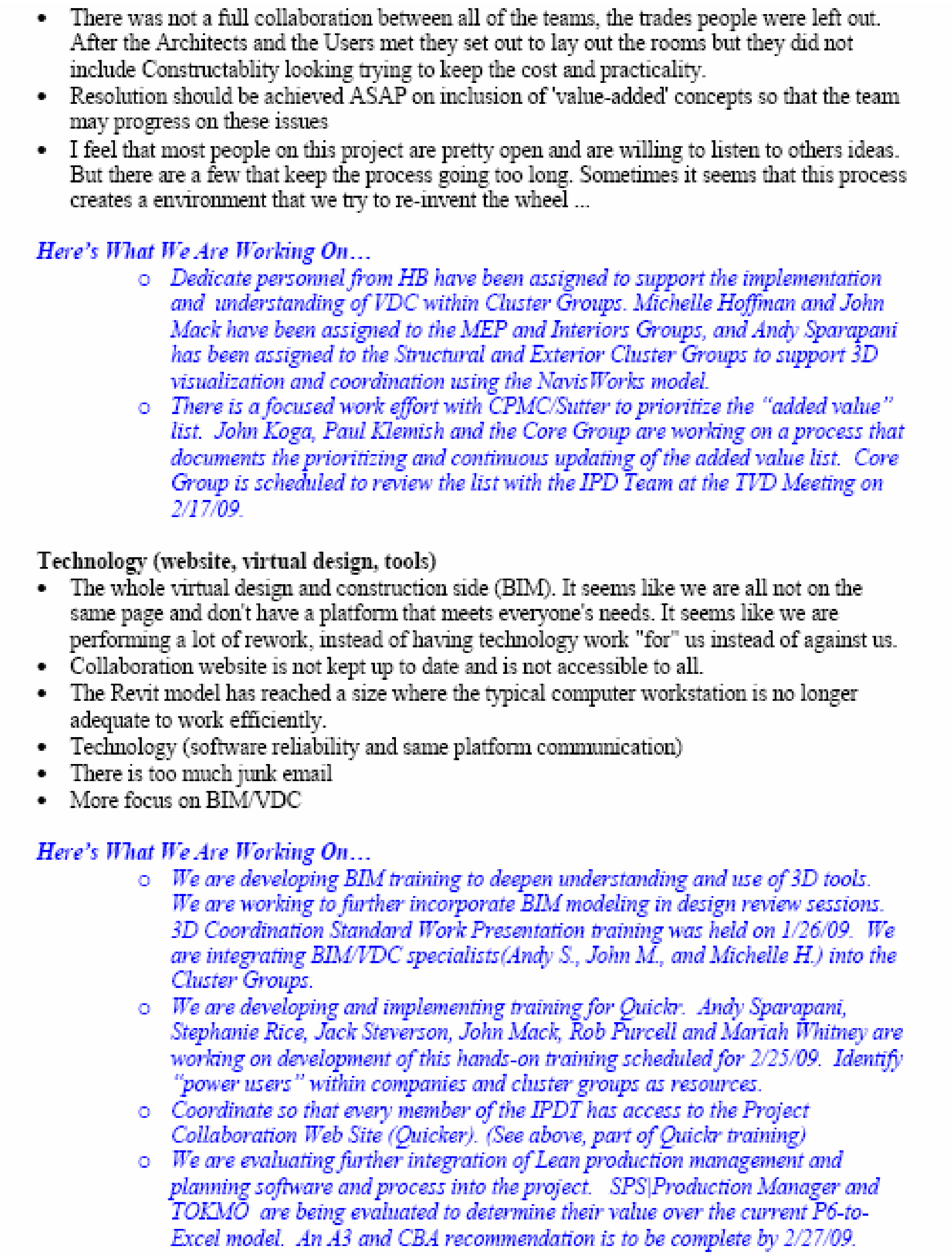
Here's What We Are Working On…

- ○ *The project schedule is now targeting April 28, 2010 for the start of abatement and demo, and we are tracking variances against that date. Significant work is under way to move that date up to some time earlier in 2010. There will be upcoming planning sessions to ensure all deliverables and work effort is aligned with the current schedule. We will continue to need to practice flexibility of work effort as an integrated team.*
- ○ *There are several different versions of Mission and Vision statements (CPMC, Sutter, IPD) for this project. We will work to combine these into one Mission Statement that we can all rally around as an Integrated Project Delivery Team. The Pulse Report Continuous Improvement Team have developed a proposed draft Mission/Vision Statement for submission to Core Group for review and feedback on 2/10/09.*

Coordination, Alignment, Collaboration, Planning, Resolution of Issues

- Clearer direction re: how to proceed with design of features which are not accounted for in the budget.
- Many of the Herrero Boldt team members need to get up to speed on accessing, reviewing and interpreting the model.
- 1. Getting TJEG working from the site. 2. A clear understanding of what "coordinated" drawings submitted to OSHPD means from each discipline's perspective.
- better integration with users
- Look ahead at your needs and allow proper time for trade partners to respond. In other words avoid the last minute demands to get you needed information.

Figure 105. The Cathedral Hill Hospital Pulse Report (3 of 9)



- There was not a full collaboration between all of the teams, the trades people were left out. After the Architects and the Users met they set out to lay out the rooms but they did not include Constructablity looking trying to keep the cost and practicality.
- Resolution should be achieved ASAP on inclusion of 'value-added' concepts so that the team may progress on these issues
- I feel that most people on this project are pretty open and are willing to listen to others ideas. But there are a few that keep the process going too long. Sometimes it seems that this process creates a environment that we try to re-invent the wheel ...

Here's What We Are Working On…

- ○ *Dedicate personnel from HB have been assigned to support the implementation and understanding of VDC within Cluster Groups. Michelle Hoffman and John Mack have been assigned to the MEP and Interiors Groups, and Andy Sparapani has been assigned to the Structural and Exterior Cluster Groups to support 3D visualization and coordination using the NavisWorks model.*
- ○ *There is a focused work effort with CPMC/Sutter to prioritize the "added value" list. John Koga, Paul Klemish and the Core Group are working on a process that documents the prioritizing and continuous updating of the added value list. Core Group is scheduled to review the list with the IPD Team at the TVD Meeting on 2/17/09.*

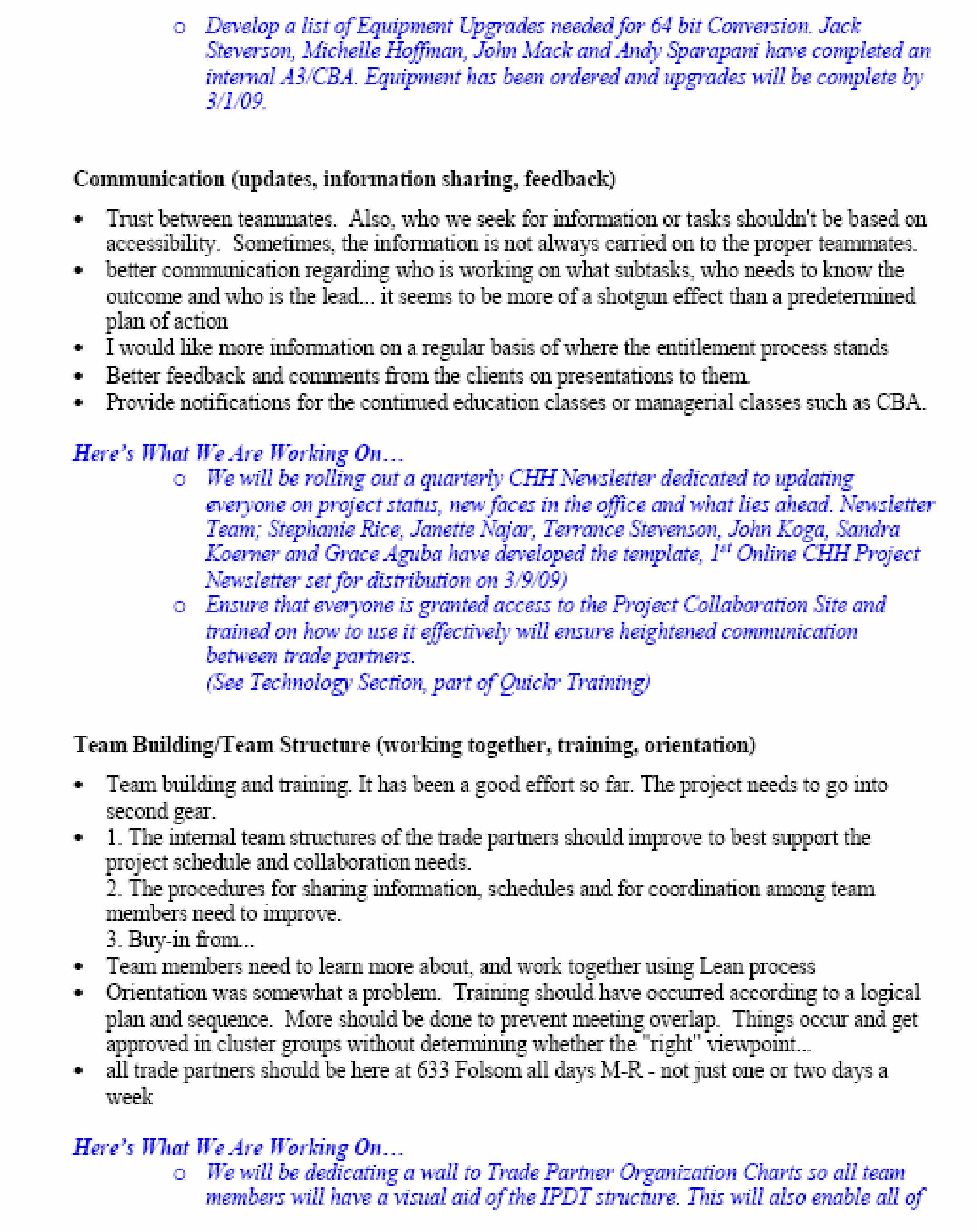
Technology (website, virtual design, tools)

- The whole virtual design and construction side (BIM). It seems like we are all not on the same page and don't have a platform that meets everyone's needs. It seems like we are performing a lot of rework, instead of having technology work "for" us instead of against us.
- Collaboration website is not kept up to date and is not accessible to all.
- The Revit model has reached a size where the typical computer workstation is no longer adequate to work efficiently.
- Technology (software reliability and same platform communication)
- There is too much junk email
- More focus on BIM/VDC

Here's What We Are Working On…

- ○ *We are developing BIM training to deepen understanding and use of 3D tools. We are working to further incorporate BIM modeling in design review sessions. 3D Coordination Standard Work Presentation training was held on 1/26/09. We are integrating BIM/VDC specialists(Andy S., John M., and Michelle H.) into the Cluster Groups.*
- ○ *We are developing and implementing training for Quickr. Andy Sparapani, Stephanie Rice, Jack Steverson, John Mack, Rob Purcell and Mariah Whitney are working on development of this hands-on training scheduled for 2/25/09. Identify "power users" within companies and cluster groups as resources.*
- ○ *Coordinate so that every member of the IPDT has access to the Project Collaboration Web Site (Quicker). (See above, part of Quickr training)*
- ○ *We are evaluating further integration of Lean production management and planning software and process into the project. SPS|Production Manager and TOKMO are being evaluated to determine their value over the current P6-to-Excel model. An A3 and CBA recommendation is to be complete by 2/27/09.*

Figure 106. The Cathedral Hill Hospital Pulse Report (4 of 9)



- *Develop a list of Equipment Upgrades needed for 64 bit Conversion. Jack Steverson, Michelle Hoffman, John Mack and Andy Sparapani have completed an internal A3/CBA. Equipment has been ordered and upgrades will be complete by 3/1/09.*

Communication (updates, information sharing, feedback)

- Trust between teammates. Also, who we seek for information or tasks shouldn't be based on accessibility. Sometimes, the information is not always carried on to the proper teammates.
- better communication regarding who is working on what subtasks, who needs to know the outcome and who is the lead... it seems to be more of a shotgun effect than a predetermined plan of action
- I would like more information on a regular basis of where the entitlement process stands
- Better feedback and comments from the clients on presentations to them.
- Provide notifications for the continued education classes or managerial classes such as CBA.

Here's What We Are Working On…

- *We will be rolling out a quarterly CHH Newsletter dedicated to updating everyone on project status, new faces in the office and what lies ahead. Newsletter Team; Stephanie Rice, Janette Najar, Terrance Stevenson, John Koga, Sandra Koerner and Grace Aguba have developed the template, 1st Online CHH Project Newsletter set for distribution on 3/9/09)*
- *Ensure that everyone is granted access to the Project Collaboration Site and trained on how to use it effectively will ensure heightened communication between trade partners.*
  (See Technology Section, part of Quickr Training)

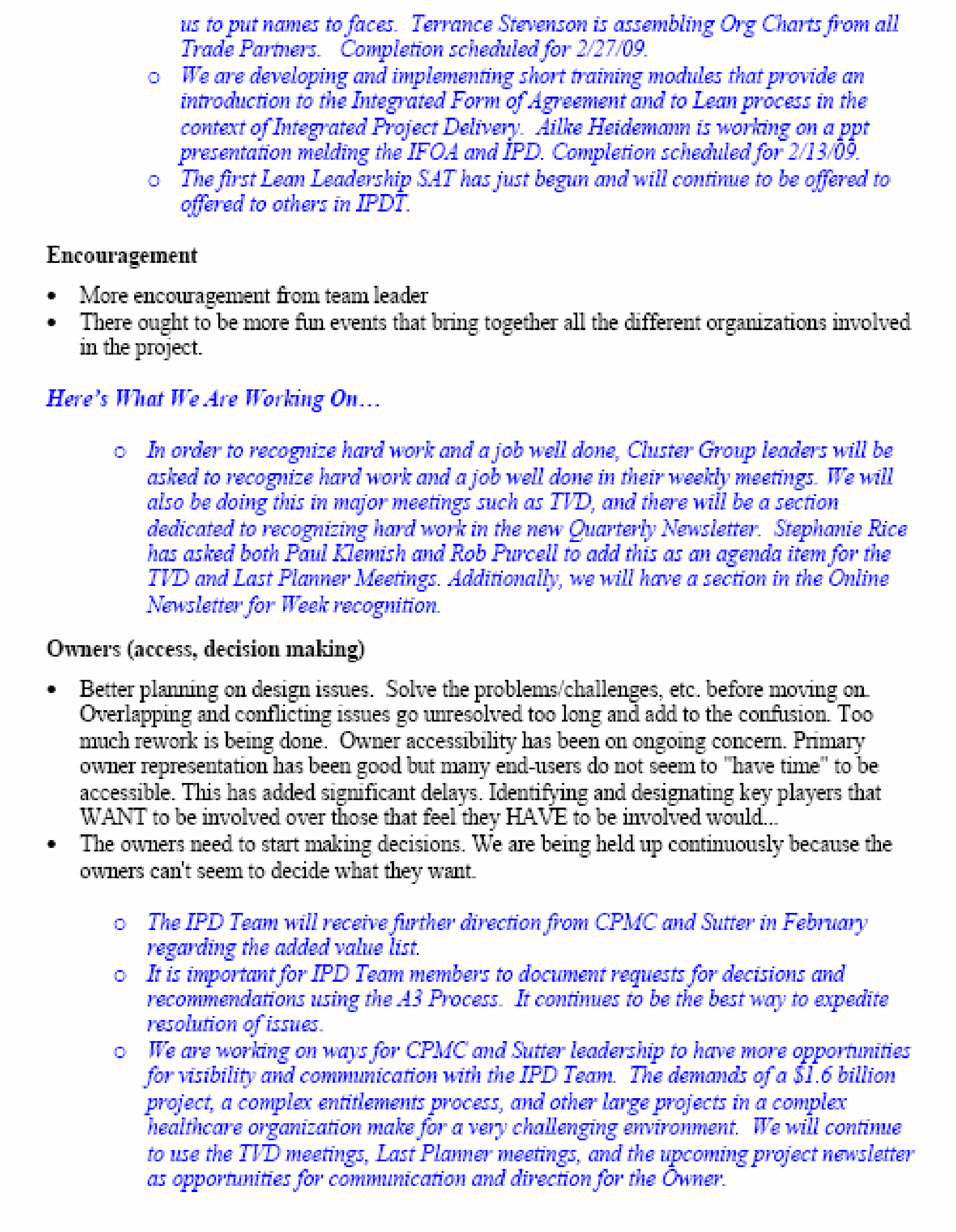
Team Building/Team Structure (working together, training, orientation)

- Team building and training. It has been a good effort so far. The project needs to go into second gear.
- 1. The internal team structures of the trade partners should improve to best support the project schedule and collaboration needs.
  2. The procedures for sharing information, schedules and for coordination among team members need to improve.
  3. Buy-in from...
- Team members need to learn more about, and work together using Lean process
- Orientation was somewhat a problem. Training should have occurred according to a logical plan and sequence. More should be done to prevent meeting overlap. Things occur and get approved in cluster groups without determining whether the "right" viewpoint...
- all trade partners should be here at 633 Folsom all days M-R - not just one or two days a week

Here's What We Are Working On…

- *We will be dedicating a wall to Trade Partner Organization Charts so all team members will have a visual aid of the IPDT structure. This will also enable all of*

Figure 107. The Cathedral Hill Hospital Pulse Report (5 of 9)



us to put names to faces. Terrance Stevenson is assembling Org Charts from all Trade Partners. Completion scheduled for 2/27/09.

- ○ *We are developing and implementing short training modules that provide an introduction to the Integrated Form of Agreement and to Lean process in the context of Integrated Project Delivery. Ailke Heidemann is working on a ppt presentation melding the IFOA and IPD. Completion scheduled for 2/13/09.*
- ○ *The first Lean Leadership SAT has just begun and will continue to be offered to offered to others in IPDT.*

Encouragement

- More encouragement from team leader
- There ought to be more fun events that bring together all the different organizations involved in the project.

Here's What We Are Working On…

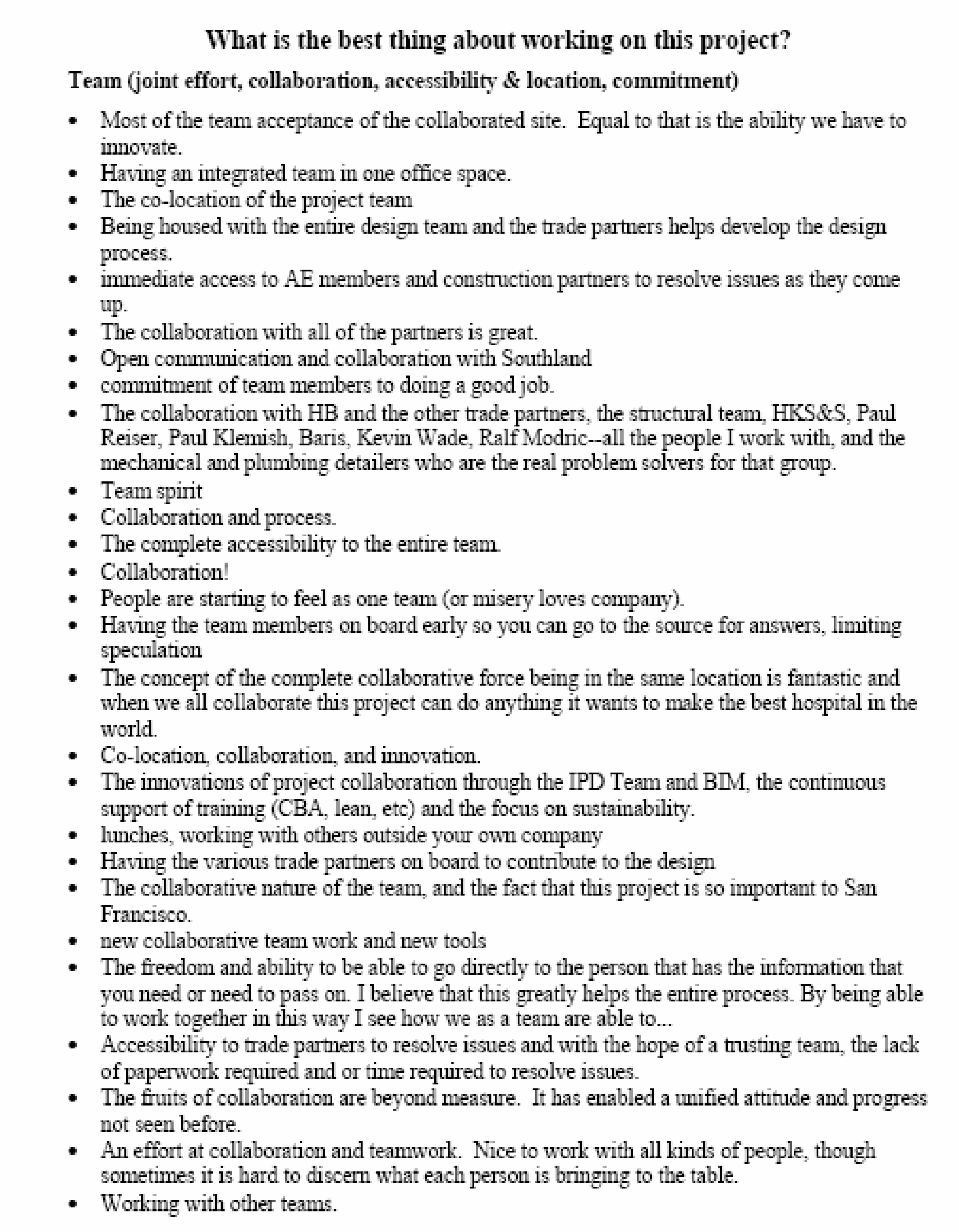
- ○ *In order to recognize hard work and a job well done, Cluster Group leaders will be asked to recognize hard work and a job well done in their weekly meetings. We will also be doing this in major meetings such as TVD, and there will be a section dedicated to recognizing hard work in the new Quarterly Newsletter. Stephanie Rice has asked both Paul Klemish and Rob Purcell to add this as an agenda item for the TVD and Last Planner Meetings. Additionally, we will have a section in the Online Newsletter for Week recognition.*

Owners (access, decision making)

- Better planning on design issues. Solve the problems/challenges, etc. before moving on. Overlapping and conflicting issues go unresolved too long and add to the confusion. Too much rework is being done. Owner accessibility has been on ongoing concern. Primary owner representation has been good but many end-users do not seem to "have time" to be accessible. This has added significant delays. Identifying and designating key players that WANT to be involved over those that feel they HAVE to be involved would...
- The owners need to start making decisions. We are being held up continuously because the owners can't seem to decide what they want.

- ○ *The IPD Team will receive further direction from CPMC and Sutter in February regarding the added value list.*
- ○ *It is important for IPD Team members to document requests for decisions and recommendations using the A3 Process. It continues to be the best way to expedite resolution of issues.*
- ○ *We are working on ways for CPMC and Sutter leadership to have more opportunities for visibility and communication with the IPD Team. The demands of a $1.6 billion project, a complex entitlements process, and other large projects in a complex healthcare organization make for a very challenging environment. We will continue to use the TVD meetings, Last Planner meetings, and the upcoming project newsletter as opportunities for communication and direction for the Owner.*

Figure 108. The Cathedral Hill Hospital Pulse Report (6 of 9)

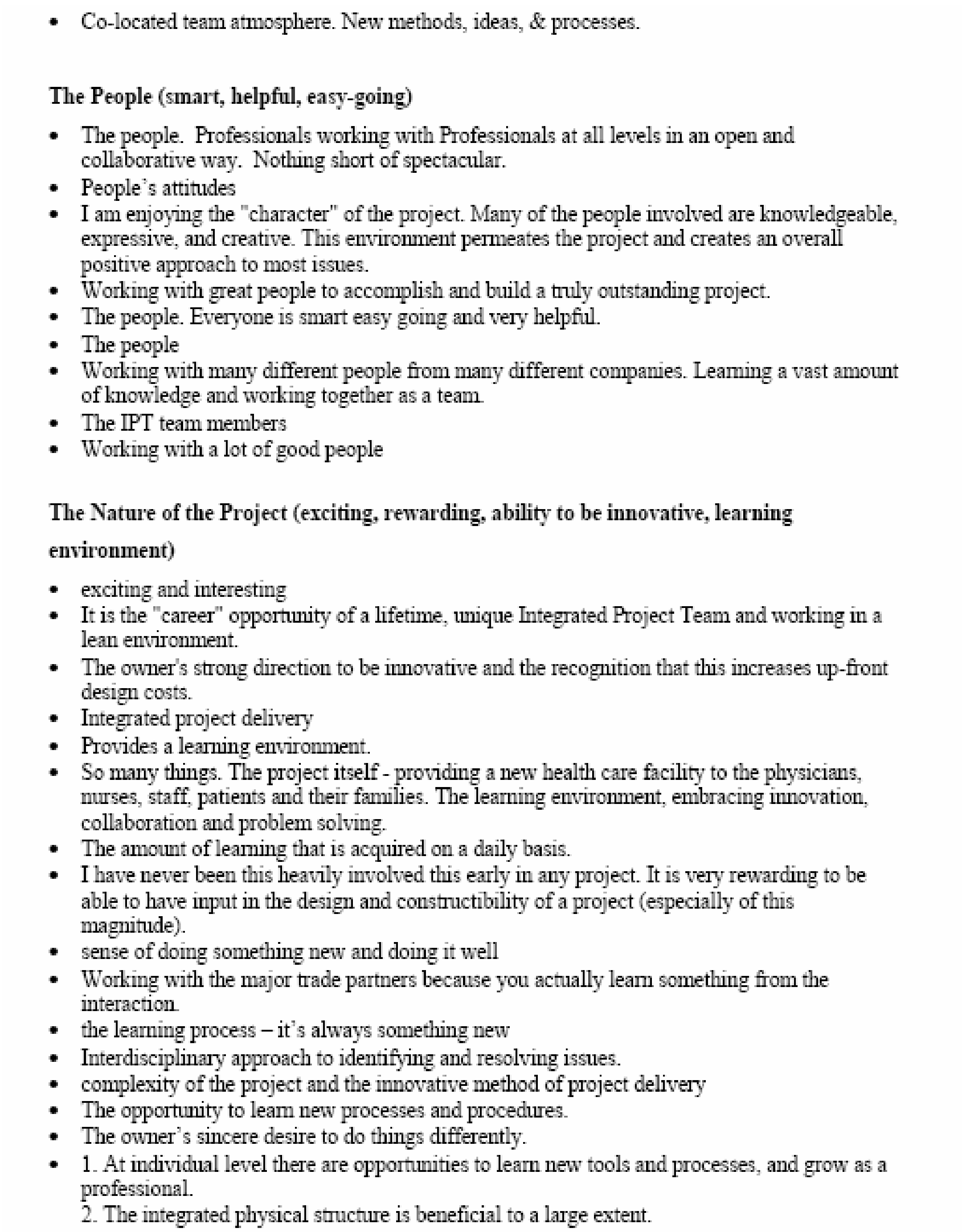


What is the best thing about working on this project?

Team (joint effort, collaboration, accessibility & location, commitment)

- Most of the team acceptance of the collaborated site. Equal to that is the ability we have to innovate.
- Having an integrated team in one office space.
- The co-location of the project team
- Being housed with the entire design team and the trade partners helps develop the design process.
- immediate access to AE members and construction partners to resolve issues as they come up.
- The collaboration with all of the partners is great.
- Open communication and collaboration with Southland
- commitment of team members to doing a good job.
- The collaboration with HB and the other trade partners, the structural team, HKS&S, Paul Reiser, Paul Klemish, Baris, Kevin Wade, Ralf Modric--all the people I work with, and the mechanical and plumbing detailers who are the real problem solvers for that group.
- Team spirit
- Collaboration and process.
- The complete accessibility to the entire team.
- Collaboration!
- People are starting to feel as one team (or misery loves company).
- Having the team members on board early so you can go to the source for answers, limiting speculation
- The concept of the complete collaborative force being in the same location is fantastic and when we all collaborate this project can do anything it wants to make the best hospital in the world.
- Co-location, collaboration, and innovation.
- The innovations of project collaboration through the IPD Team and BIM, the continuous support of training (CBA, lean, etc) and the focus on sustainability.
- lunches, working with others outside your own company
- Having the various trade partners on board to contribute to the design
- The collaborative nature of the team, and the fact that this project is so important to San Francisco.
- new collaborative team work and new tools
- The freedom and ability to be able to go directly to the person that has the information that you need or need to pass on. I believe that this greatly helps the entire process. By being able to work together in this way I see how we as a team are able to...
- Accessibility to trade partners to resolve issues and with the hope of a trusting team, the lack of paperwork required and or time required to resolve issues.
- The fruits of collaboration are beyond measure. It has enabled a unified attitude and progress not seen before.
- An effort at collaboration and teamwork. Nice to work with all kinds of people, though sometimes it is hard to discern what each person is bringing to the table.
- Working with other teams.

Figure 109. The Cathedral Hill Hospital Pulse Report (7 of 9)



- Co-located team atmosphere. New methods, ideas, & processes.

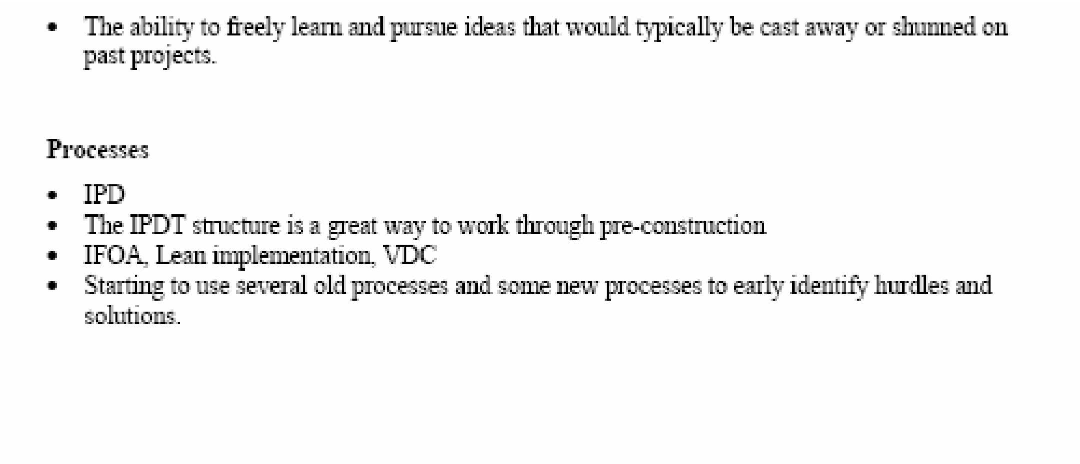
The People (smart, helpful, easy-going)

- The people. Professionals working with Professionals at all levels in an open and collaborative way. Nothing short of spectacular.
- People's attitudes
- I am enjoying the "character" of the project. Many of the people involved are knowledgeable, expressive, and creative. This environment permeates the project and creates an overall positive approach to most issues.
- Working with great people to accomplish and build a truly outstanding project.
- The people. Everyone is smart easy going and very helpful.
- The people
- Working with many different people from many different companies. Learning a vast amount of knowledge and working together as a team.
- The IPT team members
- Working with a lot of good people

The Nature of the Project (exciting, rewarding, ability to be innovative, learning environment)

- exciting and interesting
- It is the "career" opportunity of a lifetime, unique Integrated Project Team and working in a lean environment.
- The owner's strong direction to be innovative and the recognition that this increases up-front design costs.
- Integrated project delivery
- Provides a learning environment.
- So many things. The project itself - providing a new health care facility to the physicians, nurses, staff, patients and their families. The learning environment, embracing innovation, collaboration and problem solving.
- The amount of learning that is acquired on a daily basis.
- I have never been this heavily involved this early in any project. It is very rewarding to be able to have input in the design and constructibility of a project (especially of this magnitude).
- sense of doing something new and doing it well
- Working with the major trade partners because you actually learn something from the interaction.
- the learning process – it's always something new
- Interdisciplinary approach to identifying and resolving issues.
- complexity of the project and the innovative method of project delivery
- The opportunity to learn new processes and procedures.
- The owner's sincere desire to do things differently.
- 1. At individual level there are opportunities to learn new tools and processes, and grow as a professional.
  2. The integrated physical structure is beneficial to a large extent.

Figure 110. The Cathedral Hill Hospital Pulse Report (8 of 9)



- The ability to freely learn and pursue ideas that would typically be cast away or shunned on past projects.

Processes

- IPD
- The IPDT structure is a great way to work through pre-construction
- IFOA, Lean implementation, VDC
- Starting to use several old processes and some new processes to early identify hurdles and solutions.

Figure 111. The Cathedral Hill Hospital Pulse Report (9 of 9)

Note: Figures 90-111 are included with permission