THE CHILDREN'S HOSPITAL X PROJECT: A CASE STUDY IN BENEFIT AND COST ANALYSIS OF A LEAN-IPD PROJECT

A Thesis

by

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ABSTRACT

Lean processes have been utilized in healthcare design and construction, bringing both benefits and costs to the owners of healthcare projects. It is important to understand and detect the benefits and costs associated with lean processes, because if the benefits are greater than the costs, lean processes will become increasingly attractive to those who are interested in lean processes, but who are more risk averse than early adopters, and have therefore not yet adopted its processes.

However, it is unclear which metrics should be tracked to measure the benefits and costs associated with Lean-IPD. Researchers are particularly interested in understanding how Lean-IPD benefits and costs compare to the more extreme and linear delivery methods of Design-Bid-Build (DBB).

This research presents analysis of the Target Value Design process of a case study healthcare building. It is an attempt to collect benefit and cost data related to lean processes adopted by the project. An electronic database where design and estimating documents were stored served as the data source for this research. The collected benefits and costs data helped to build a framework for the basis of future benefit and cost analyses.

In this case study, the benefits generated from lean processes were shown to outweigh costs incurred.

DEDICATION

This thesis is dedicated to my mother and father, Xiulan Yan and Weimin Ai, who always love, understand, and encourage me. The endless support helped me keep strong through tough time.

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I would like to express my sincere gratitude to all those who help me complete the Master degree in Construction Science. I want to thank my academic advisor, Dr. Zofia K. Rybkowski for her instructions on my study and research. I appreciate my dear committee members, Dr. Jose L. Fernandez-Solis and Dr. Mardelle M. Shepley for their helpful discussions and suggestions on my work. Thanks to Dr. Upali Nanda and HKS for their supporting on data collection. Thanks to my boyfriend, Zhiqian Sun, and my dear friends, Chao Xiao, Xiaoqi Li and Nivedita Kalyanaraman. The completion of this work would not be possible without their help. This work was based upon Academy of Architecture for Health Foundation (AAHF) grant awarded to Dr. Nanda (CADRE and HKS) and Dr. Rybkowski (Texas A&M), and extends the scope of that original award.

NOMENCLATURE

CBA	Choosing by Advantages
CSP	Competitive Sealed Proposal
DBB	Design-Bid-Build
IPD	Integrated Project Delivery
IT	Information Technology
LRM	Last Responsible Moment
LPS	Last Planner System
MARR	Minimum Attractive Rate of Return
MEPF	Mechanical, Electrical, Plumbing and Fire
OAEC	Owners, Architects, Engineers, and Contractors
PDCA	Plan-Do-Check-Act
PLT	Project Leadership Team
SET	Senior Executive Team
TVD	Target Value Design
VSM	Value Stream Map
ΔIRR	Incremental Internal Rate of Return

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CHAPTER I

INTRODUCTION

Lean Integrated Project Delivery (Lean-IPD) method and Target Value Design (TVD) are being utilized more often, particularly in the design and construction of healthcare buildings (Ballard 2008). Compared with traditional project delivery methods, such as design-bid-build (DBB) and competitive sealed proposal (CSP), Lean-IPD introduces specific benefits and costs for each stakeholder of a project (El Asmar and Hanna 2012). Recognizing that there are specific upfront costs associated with Lean-IPD, it is becoming increasingly important for lean academics and project stakeholders to track and measure the benefit and cost metrics of Lean-IPD and TVD. In addition to finding the associated benefits and costs, the author evaluated the incremental internal rate of return (ΔIRR) for a Lean-IPD project. If the ΔIRR is greater than the Minimum Attractive Rate of Return (MARR)[1], Lean-IPD would become increasingly attractive to those who are interested in Lean-IPD, but who are more risk averse than early adopters, and have therefore not yet adopted its processes (Kent and Becerik-Gerber 2010).

Lean pioneers have performed extensive research on how lean processes from the manufacturing industry can be utilized in Lean-IPD design and construction (Koskela 1992). Several lean processes have been adopted, such as Target Value

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[1] MARR is the minimum rate of return on a project a manager or company is willing to accept before starting a project, given its risk and the opportunity cost of forgoing other mutually exclusive projects.

Design, Big-Room meetings, Co-location, and the Last Planner System of Production Control™ (Last Planner), etc. (Kemmer et al. 2011). Researchers have also explored the advantages and disadvantages associated with implementing lean processes (Ballard and Reiser 2004; Jacomit and Granja 2011). Even though a considerable amount of research has examined the advantages and disadvantages of Lean-IPD, few address the specific benefits and costs associated with the lean processes.

In this research, the author explored how Lean-IPD processes, like Co-location, Big-Room meetings (Rybkowski 2009) and full scale Mock-ups have been employed in a case study healthcare project, the Children's Hospital X located in a northern state of the US. Qualification data about the benefits and costs associated with lean processes from the perspective of the owner were collected from an electronic database where the design documentation of Children's Hospital X were stored. To further understanding of the true benefits and costs associated with Lean-IPD, the author also collected the cost and benefit data of a Lean-IPD project. The objective was to develop and validate a benefits and costs model for lean processes.

1.1 Problem Statement

Even though lean pioneers have developed many lean processes to use in the construction industry (Ballard 2008), and researchers have begun to consider the benefits and costs of lean processes (Ballard and Reiser 2004; Jacomit and Granja 2011), it is still unclear which metrics should be tracked to measure the benefits and costs associated with Lean-IPD. Researchers are particularly interested in understanding the magnitude of Lean-IPD benefits and costs compared to the more extreme and linear delivery methods such as DBB and CSP.

1.2 Research Questions

This research has investigated the following questions:

- How does the Children's Hospital X project utilize lean thinking and lean processes in both the project delivery method and design process? What are specific advantages and disadvantages (in terms of time, cost, quality, safety and morale) of lean processes and lean tools?
- What are the costs to the owner, when the owner is involved in the Lean-IPD process and practice TVD? What are main components of cost increases or decreases?
- What are the benefits to the owner, when the owner is involved in the Lean-IPD process and practice TVD? What are main components for incremental cost and benefit differences?
- How might we develop a framework and model to put measurable benefit and cost metrics together in order to access the incremental internal rate of return (ΔIRR) for owner?

1.3 Research Goal & Objectives

1.3.1 Goals

It has been claimed that Lean-IPD, TVD and other lean processes will bring long-term benefits to the stakeholders of a project. It has also been suggested that the more complicated a project, the more value there is to gain by implementing lean. Currently, there is no well-designed and documented method that shows how to calculate the benefit and cost of TVD and other lean processes. As a case study, this research collects the benefit and cost data of the Children's Hospital X which uses lean processes, and then builds a framework and model to analyze these data to assess the benefit and cost to the owner.

1.3.2 Objectives

The ultimate objective of this research has been to serve as a basis for construction of a benefit and cost model.

This study utilized the Children's Hospital X project as a case study to identify the specific lean tools and processes utilized. The researcher also analyzed the benefit and cost data of lean processes.

CHAPTER II

LITERATURE REVIEW

Lean is a new production philosophy imported and transformed from the manufacturing industry (Koskela 1992). Compared with traditional management, which is concerned more with waste from conversion processes, the new philosophy presented by the author focuses more on eliminating non-value adding activities in the flow. Several principles have been developed to be utilized in the construction industry.
In principle, increasing process transparency is an essential way to eliminate non-value-adding activities (Koskela 1992); the author points out that lack of process transparency increases the propensity to err, and reduces the visibility of errors.

In principle, reducing cycle time is another important way to eliminate waste (Koskela 1992). However, cycle time includes four parts--processing time, inspection time, wait time and move time. Only processing time is a value adding activity.

Lean pioneers have developed many lean processes and approaches to use in the construction industry for solving the current problems and challenges faced by the industry.

- The Last Planner System (LPS) (Ballard 2000) is a perfect example of an approach that applies lean manufacturing tools to construction. Ballard summarized LPS as "Should-Can-Will-Did." Furthermore, he demonstrates how to use LPS philosophy to change the work flow from push to pull, and increase a schedule's reliability.

The traditional schedule process is from top to bottom. The top, project manager, sends the schedule to the superintendent, and then the superintendent assigns his or her schedule to the subcontractors (the bottom). As a result, the traditional schedule process is always behind schedule. By contrast, LPS is from bottom to top. The bottom, the subcontractors, even the crews, plan their schedule based on planning objectives (should) and their capacity (can), and then give the reasonable schedule (will) to the top, the project manager. When using "five whys" to find a root cause for schedule delay, it may become apparent that the cause is a load that does not match capacity, or that materials or equipment are not being delivered on-time. The Last Planner System of Production Control can address and solve these problems.

- Co-location ("Big Room") meeting is a lean approach to reduce information cycle time and increase process transparency. For example, research has found that a co-location team that includes architects, a general contractor, and main sub-contractors can reduce the information traveling time from hours or days to seconds (Rybkowski 2009).
- Target Value Design (TVD) is a price-led design methodology (Rybkowski et al. 2012), which eliminates waste within project constraints and delivers customer value (Ballard 2011). The TVD approach involves designing to meet the target cost, which is "a structured approach to determine the life cycle cost at which a proposed product with specified functionality and quality must be produced to generate the desired level of profitability over its life cycle when sold at its

anticipated selling price" (Cooper and Slagmulder 1997). During this approach, multifunctional teams design collectively and continuously, re-estimating the cost as the product's design progresses. Research and case studies have shown that prospects designed using TVD may gain advantages not only in terms of cost, but also in terms of schedule. Table 1 (Ballard and Reiser 2004) shows comparisons between a TVD project, St. Olaf Fieldhouse, and a non-TVD project, Carleton College Recreation Center.

Table 1 A comparison of two delivery methods (Ballard and Reiser 2004)

	Carleton College Recreation Center	St. Olaf Fieldhouse
Completion date	April 2000	August 2002
Gross square feet	85,414	114,000
Project duration	24 months	14 months
Total cost (including A/E & CM [1] fees)	$13,533,179	$11,716,836
Cost per square foot	$158.44	$102.79

1. A (Architecture); E (Engineering); CM (Construction Management)

- Lean-IPD is a more collaborative method to complete a project with more process transparency than linear approaches, such as DBB and CSP. According to Matthews and Howell (2005), lean-IPD positively impacts shared manpower, encourages work across traditional boundaries, and costs more in the beginning but saves more downstream. These metrics illustrate the core value of lean, eliminating waste and adding value.

After revealing lean processes used in the construction industry, researchers began to consider the benefits and costs of lean processes. Systematic and case study research has been performed to give an idea of how lean processes benefit the Owners, Architects, Engineers, and Contractors (OAEC).

In Ballard and Reiser's (2004) case study of the St. Olaf Fieldhouse project, the authors addressed the benefits of TVD. They compared traditional approaches in construction, which involve designing to some degree of supposed completion, estimating its cost, then altering the design to within budget, to a better approach, TVD. This latter approach involves anticipating the cost consequences of different possible designs, and limiting eligibility to those that fit within the target cost. The comparison shows that the TVD approach is better and can benefit the OAEC by shortening a project's schedule, reducing its cost.

Rybkowski, Shepley and Ballard (2012) explored the potential implementation of TVD in newborn intensive care units (NICU); the authors discussed TVD practice in healthcare buildings, and the benefits and advantages it brings to the owner and other stakeholders.

Brazilian lean experts have also explored the benefits from lean processes (Jacomit and Granja 2011). In a study of Brazilian Public Social Housing Projects (SHP), the authors found that lean processes, such as design standardization, and replication of design can result in lower production costs. On the contrary, non-lean processes, like DBB, outsource design and reduce the benefits to the project.

A widely used decision-making tool, Choosing by Advantages (CBA), has been implemented in the TVD process to help architects evaluate the most valuable design alternatives. CBA includes four steps (Suhr 1999). In step1, the attributes of each alternative under different valuable criteria are addressed. In Step 2, each pair of attributes are compared to find the advantage that one alternative has over the others. In Step 3, the advantages are graded from 0 to 100 based on the owner's perception of the importance of that advantage. In Step 4, the total advantage score of each alternative is calculated. CBA helps decision-makers make sound decisions to make implicit benefits and costs explicit, and it has been employed to analyze the benefit and cost of lean processes.

CHAPTER III

METHODOLOGY

In this exploratory research project, the author collected data from design documents of a healthcare project that adopted lean-IPD and lean processes, such as TVD, Co-location and Big-Room Meetings. Benefit and cost analysis tools were utilized to analyze data. The final goal is to provide a framework upon which a benefit and cost analysis model can be built to assess the value of lean-IPD and associated lean processes.

The Children's Hospital X project, a typical lean-IPD and TVD project, was selected as the case study. Children's Hospital X is a 300,000 square foot expansion project which includes a 72-bed neonatal intensive care unit, a high-risk delivery area that includes labor, delivery and recovery rooms, an emergency department with enough room to meet current and future patient volumes, a new outpatient surgery center, and an enclosed concourse that takes patients and staff from the new 1,250-space parking garage to the new building and existing hospital.

3.1 Sources of Data

In the Children's Hospital X project, each key design decision made by the delivery team was stored in an A3 document that mapped the project goals, supporting research, CBA table, specific cost savings, and final recommendation (Nanda 2014). In some cases, cost savings were outweighed by proposed value (meeting a specific organizational/ healthcare goal), and this decision was documented as well.

An electronic database “e-Builder” was used to store and share all design documentation by various stakeholders, including owner, architects, interiors, Mechanical, Electrical, Plumbing and Fire (MEPF) engineers, and general contractors. The e-builder database stored the documentation, reports, and photos related to lean processes, such as the Big Room Meeting topics and schedule. Furthermore, e-Builder provided a place where each delivery team member could find related design decisions. The researcher accessed the e-Builder database in order to find lean process related design documents and A3 files.

3.2 Data Analysis

After collecting qualitative data from the literature review and design documents analysis, the data was analyzed using the following three steps:

(1) First, the lean processes adopted by Children’s Hospital X project were explored and documented. The principles and practices of these lean processes were recorded.

(2) Second, the benefit and cost analysis method framework was employed to assemble benefit and cost data. The benefit and cost of lean-IPD and target value design from the perspective of owners was sorted by either benefit or cost in a framework for future analysis (see Table 2).

Table 2 Total cost framework of TVD processes

			Cost items
I	Team Week Meetings and Co-location[1]	A. Material	White board
			Supplies (large Post-It notes ®, markers, flipcharts, push pins, masking tape)
			Floor plans of existing hospital
			Rolls of paper
		B. Labor	Owner and owner representative
			Architects
			General contractors
			Structural engineer
			MEP engineer
			Sub-contractors
			Vendors
		C. Equipment	Speakers
			Projector
			Conference call equipment
		D. Location Cost	Co-location space rent or build cost
II	Full Scale Mock-up[2]	A. Material	Cardboard
			Tape and nail to fix cardboard
			Furniture for mock-up scenario
			Food and Warehouse Amenities
		B. Labor	Lean facilitator
			Architects
			Healthcare administrators
			Physicians
			Nurses
			Clinical Staff Costs
			Former patients and their parents
		C. Equipment	Equipment for mock-up scenario
		D. Location Cost	Warehouse Rent
			Warehouse Construction labor
			Utility

1. Team week meetings and Co-location include lean training workshops, Big-Room Meetings, Project leadership Team meetings and innovation team meetings.
2. Full scale Mock-up includes workshop that designs and builds full scale cardboard mock-up of hospital interior.

(3) Labor cost was calculated using the following equation:

Labor cost = Mean hourly wages per participant X Number of participants X Number of hours spent

The Mean hourly wages were extracted from the Bureau of Labor Statistics (BLS) database.

The ultimate objective of this research is to serve as a basis for construction of a benefit and cost analysis model. The benefit and cost analysis model is based on the rate of return analysis, which finds the incremental internal rate of return (ΔIRR) at which the net present value of incremental cost and benefit in the cash flow equals zero.

The benefit and cost analysis model (Figure1) compares the cash flow between a defender project delivery process (DBB), and a challenger project delivery process, lean-IPD. And then it calculates the delta (Δ) between challenger and defender by using cash flow of challenger minus the cash flow of defender. Each project phase of DBB and lean-IPD is situated along a time axis, and the significant benefit and cost value for owners is recorded in the time axis. Once a framework is established, and actual data are entered, an initial ΔIRR can be calculated.

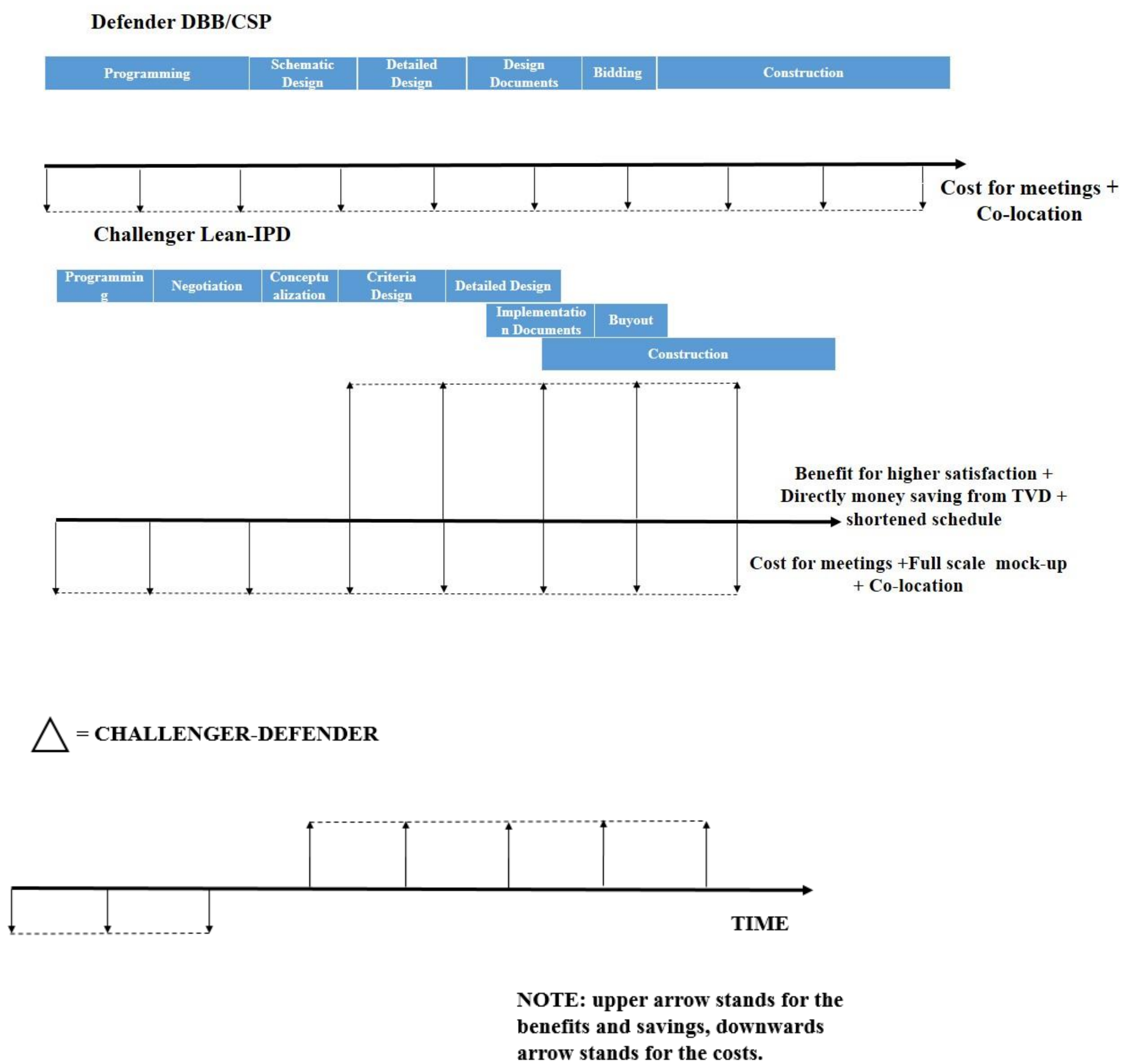

Figure 1 Proposed ∆IRR calculation model (Kenig 2011)

3.3 Delimitations and Limitations

3.3.1 Delimitations

This research focuses on healthcare buildings alone, because TVD has primarily been applied to healthcare facility design thus far.

Also, although there are additional benefits associated with the categories of schedule, quality, safety, morale, team knowledge enhancement, and client satisfaction. The scope of this research is limited to benefits directly associated with estimated construction cost.

3.3.2 Limitations

(1) Stakeholders of an IPD project are typically not limited to the OAEC team. However, this research takes only the owner's perspective to build the benefit and cost framework for the whole project. Because the owner is a core member of an IPD team, their opinion significantly influences the benefit and cost analysis.

(2) Only significant components of benefits and costs were recorded, because it is assumed that these significant components contribute most to the total benefit and cost calculation.

(3) For proper IRR analysis, comparable data from a typical Design-Bid-Build process needs to be collected so an incremental benefit and cost calculation can be made. However, Design-Bid-Build data collection was beyond the scope of this research. It is hoped that future research would be able to take this into consideration.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Children's Hospital X Delivery Team Organization

Before discussing lean processes and the benefits and costs associated with lean processes, this section briefly introduces the project delivery team organization structure. Compared with the traditional project delivery methods, like DBB or CSP, Children's Hospital X adopted a three-layered organizational structure (Figure 2). The top layer is the Senior Executive Team (SET), comprised of five senior and experienced members from the owner, two architecture firms, and two general contractors. The SET undertakes the responsibilities of final and significant decision making. The second layer is the Project Leadership Team (PLT) which consists of seven members. Three of the seven are from owner and owner representative firms, plus two architects, and the other two members of PLT are from each of the two general contractors. PLT is in charge of the Target Value Design alternatives selection and pull plan. The bottom layer is a combination of three main groups: six innovation teams, a production team and a workshop team. The innovation team members include architects, engineers, general contractors, sub-contractors and vendors. Based on different divisions of building, the six innovation teams are: (1) an interior team, (2) an enclosure team, (3) a structure team, (4) a site team, (5) a Mechanical Electrical Plumbing Fire (MEPF) team, and (6) an equipment/ information technology (IT) team. Each team has its own target cost to meet, and undertakes its own design alternatives development. The project production team members are from main sub-contractors. Their responsibility is to implement the design decisions. The workshop team facilitates lean philosophies.

The research subject, Children's Hospital X, adopted the following Target Value Design (TVD) processes associated with Lean-IPD: (1) Big-Room Meetings, (2) Co-location, and (3) full scale Mock-up.

4.1.1 Target Value Design

TVD is a key lean process adopted by the Children's Hospital X project. The TVD process was a reflection of the project delivery team understanding the owner's purpose, business needs, and values.

The TVD process ensures that the project delivery team, architecture firm, general contractor, and sub-contractor deliver the lowest cost project without compromising any of the owner's requirements. Meanwhile, the TVD process helps to achieve an appropriate long-term financial viability. The owner hoped to strengthen the hospital's brand and market via TVD creating a new healthcare facility with the following attributes:

- Efficient and sustainable operations.
- Uniquely satisfying patient and family experience.
- Design through the eyes of a child.

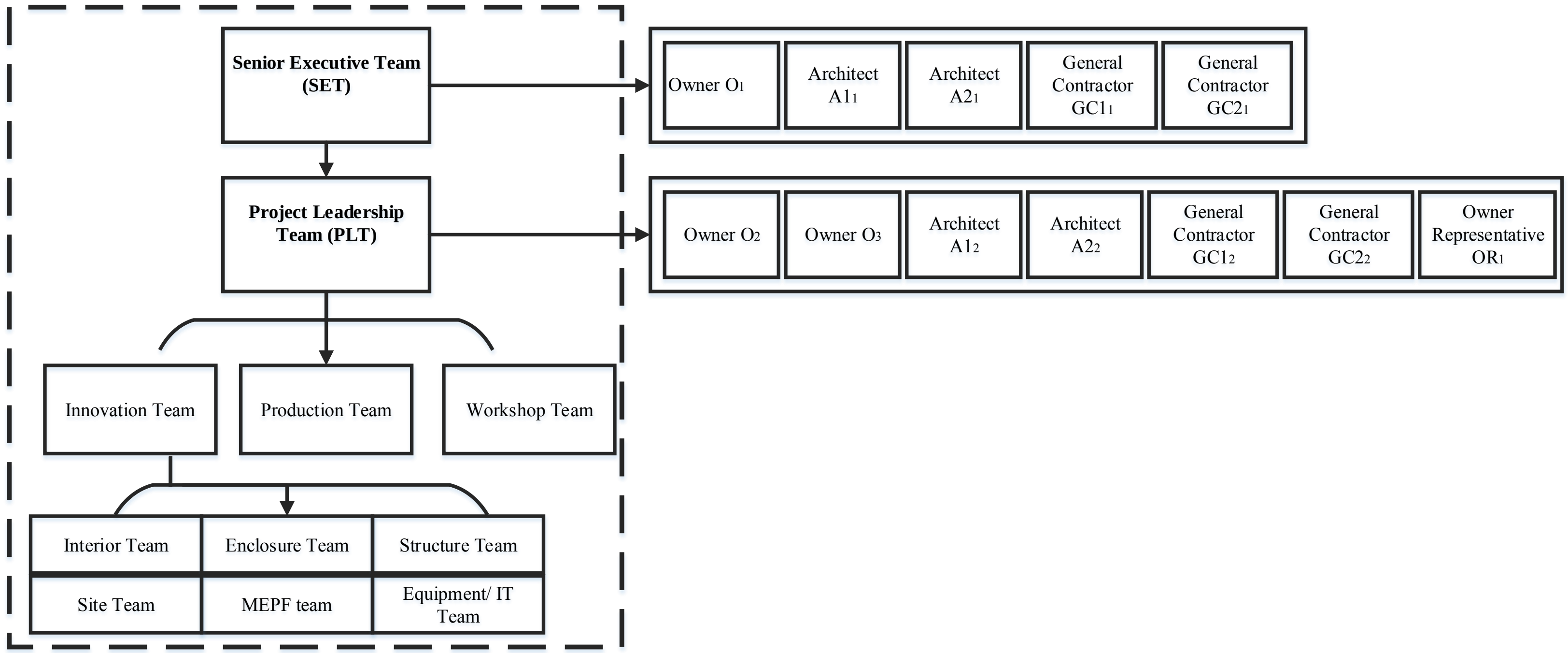

Figure 2 Children's Hospital X organizational chart

Note: subscripts connote separate individuals within same company

- A well designed healthcare facility which could attract the highest quality physicians and staff.

TVD has different goals during different design phases. In the very beginning Planning/ Programming phase, TVD must meet the requirements of right size and right fit. In the Concept Design phase, Design phase and Implementation phase, the TVD assumes the responsibilities of optimizing systems, parts and work flow.

The value stream map of TVD includes three parts: (1) plan, (2) research and analyze, and (3) assign and update estimates (Figure 3).

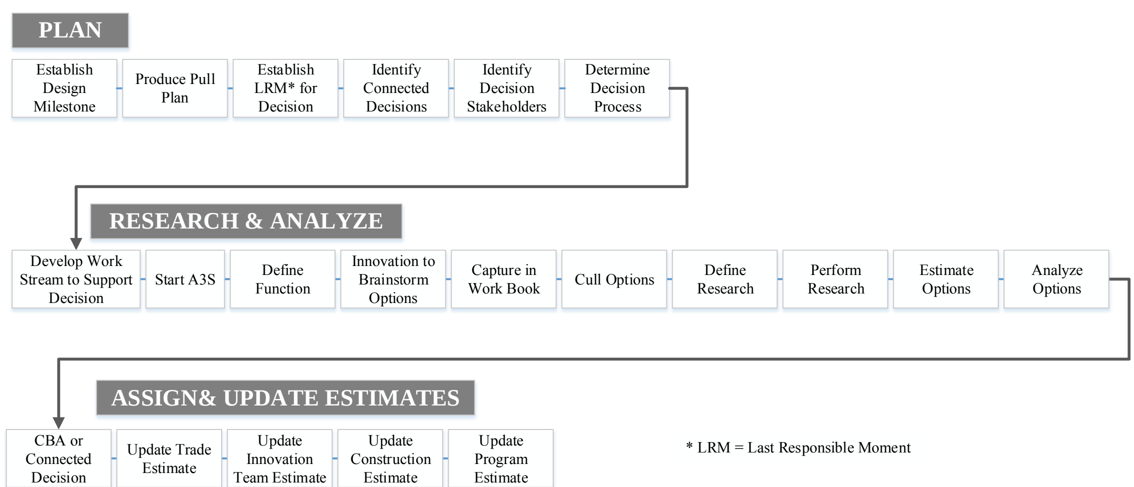

Figure 3 Value stream map of TVD

The TVD value stream map follows the principle of a Plan-Do-Check-Act (PDCA) circle. Utilizing continuous PDCA circles helps TVD continuously overcome the delta and approach an improved future state, which matches the definition of lean philosophy. In the first six steps of the TVD value stream map, the PLT and innovation teams set the objective of TVD and identify key participants—the “plan” step. After TVD plan, innovation teams brainstorm design alternatives, and build each A3 sheet and CBA table, which is the step of “Do”. In the following step, innovation teams research each alternative, which is the step of “check”. And finally, a design decision is made and implemented based on the first three steps.

Furthermore, six cross-populating innovation teams working together in the TVD process promote diversity of perspective and avoid surprises.

4.1.2 Big-Room Meetings

In the second floor of a garage next to the building site, the PLT, innovation teams and production teams were Co-located and held Big-Room Meetings. The site for the meeting was a 4,500 square space with conference area, pull plan wall and seats for Co-location (Figure 4).

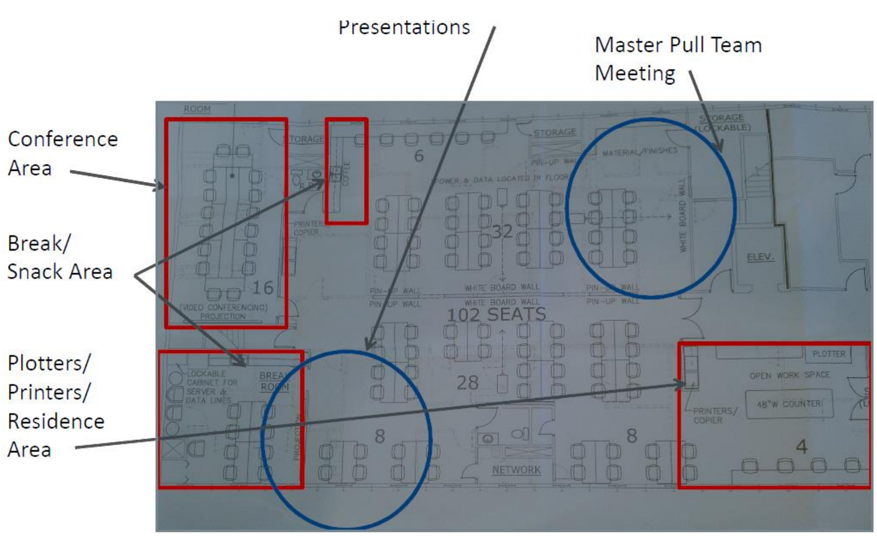

Figure 4 Big-Room layout (Beikmann 2013, with permission from author).

Big-Room Meetings were held every two weeks after the pre-construction stage, and extended to once a month after the project began construction. Related stakeholders, such as members in the PLT, Project Innovation Team and Project Production Team, attended Big-Room Meetings. During the Big-Room meetings, stakeholders discussed the pull plan, TVD and other significant issues.

A typical five day long Big-Room Meeting week is shown in Table 3.

Table 3 Typical Big-Room meeting schedule

M	T	W	Th	F
Pull Plan (10:00-12:00) & (2:00-4:00)	TVD Update Meeting (8:00-9:00)	General Contractor Meeting (MISSION CONTROL) (12:00-1:00)	Owner's call (8:30-9:30)	TVD Meeting Report Out (8:00-9:00)

4.1.3 Co-location

During team weeks, the PLT, six innovation teams and production teams that include key stakeholders are co-located on the same office floor (Figure 4). Physical co-location breaks down barriers between different stakeholders, and makes the communication among each stakeholder easier and faster (Rybkowski, 2009). For example, in the interior innovation team, members include representatives from the architecture firm, MEPF engineering firms, general contractor and drywall sub-contractor. The mixed team with different specialties and roles can help innovation teams to generate design alternatives that concern not only architects, but also structural engineers, MEPF engineers and others. Meanwhile, design alternatives generated by this innovation team will yield greater value with less conflict between functional entities.

4.1.4 Full Scale Mock-up

In Evidence-Based Design (EBD), architects and researchers simulate scenarios to maximize the end users' satisfaction with the design. In Children's Hospital X, architects and workshop teams not only used software to simulate, they also built a full scale mock-up scenario using cardboard in a warehouse (Figure 5). Owner and other end users, such as staff members, nurses, former patients, and patient family members were invited to test emergency scenarios instead of only reading the floor plans on the drawings. Inviting staff, nurses, and families to the warehouse workshop gave the design team an opportunity to directly access end user's' feedback about the spaces, functional areas and patient flow.

Based on this feedback, the innovation teams created design alternatives to meet owner and end users' satisfaction during the design phase, which avoided potential change orders during the construction phase.

Figure 5 Full scale mock-up (Beikmann 2013, with permission from author).

Figure 6 Scenario in full scale mock-up (Beikmann 2013, with permission from author).

4.2 Benefits Associated with Lean-IPD

Understanding the lean processes adopted by Children's Hospital X is fundamental to analyzing benefits and costs associated with lean processes. The lean processes mentioned in Section 4.1 brought benefits to Children's Hospital X project in the following aspects: (1) savings in estimated construction cost; (2) performance enhancement in schedule, quality, safety, morale, team knowledge; and (3) higher client satisfaction. This research only addresses benefit (1).

4.2.1 Direct Money Saving in Budget

Market construction cost per square foot of healthcare buildings in the city where Children's Hospital X project located is approximately $450. The target construction cost for Children's Hospital X project set by the owner was lower than the market cost, while the initial estimated construction cost was higher than the market cost. Figure 7 shows the relationship between the Market Cost, Target Cost and Estimated Cost per SF for Children's Hospital X project. This study used the drop between initial estimated construction cost and target construction cost to calculate the benefit form savings.

Considering that the initial estimated cost was higher than the market cost, the gap between the market cost and Target Cost is an appropriate way to calculate the benefits gained by the owner by conducting TVD. However, this study focuses on cost saving garnered during TVD exercises at Big-Room meetings that began with an initial estimated cost.

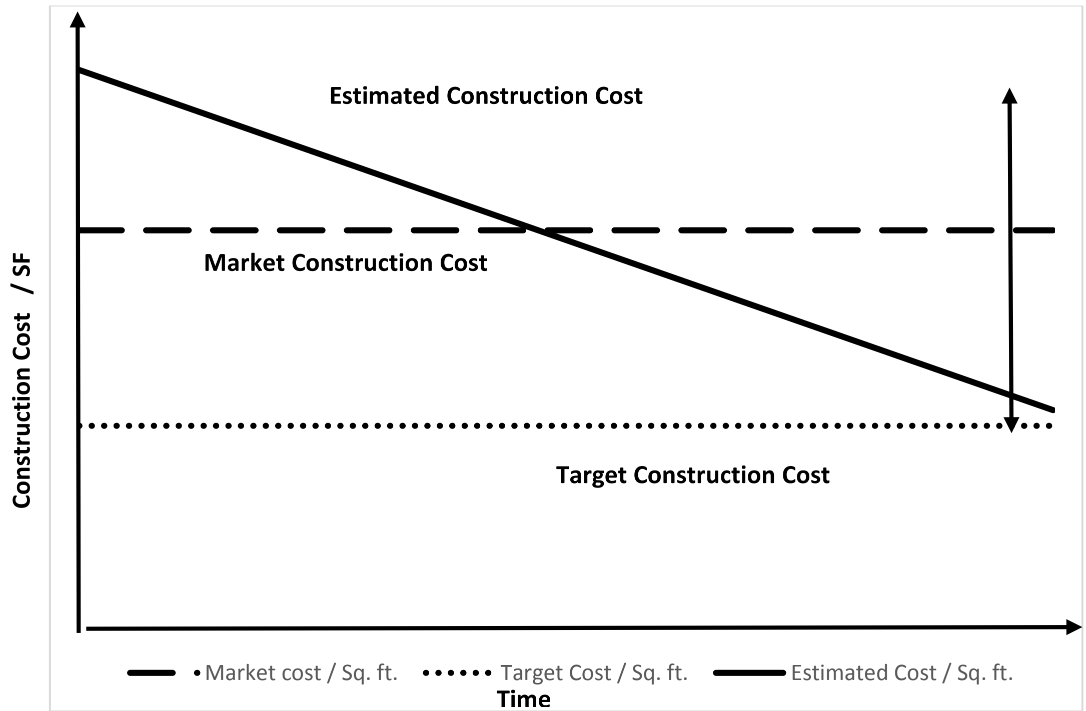

Figure 7 Relationship between Market Cost, Target Cost and Estimated Cost per SF
The x-axis represents time; the y-axis represents magnitude of cost value in dollars. For confidentiality reasons, actual dollar amounts are not shown.

In Children's Hospital X project, two kinds of cost were tracked by the owner, one is the project cost and the other is construction cost. Project cost includes not only construction cost, but also site acquisition cost, design and consultant fees, administration cost and contingency. The gap between the estimated project costs for the owner at the beginning of the pre-construction stage and project Target Cost set by the owner was about 29% of the initial estimated project costs. The gap between the estimated construction costs at the beginning of the pre-construction stage and the construction Target Cost was 34% of the initial estimated construction cost. (Figure 8).

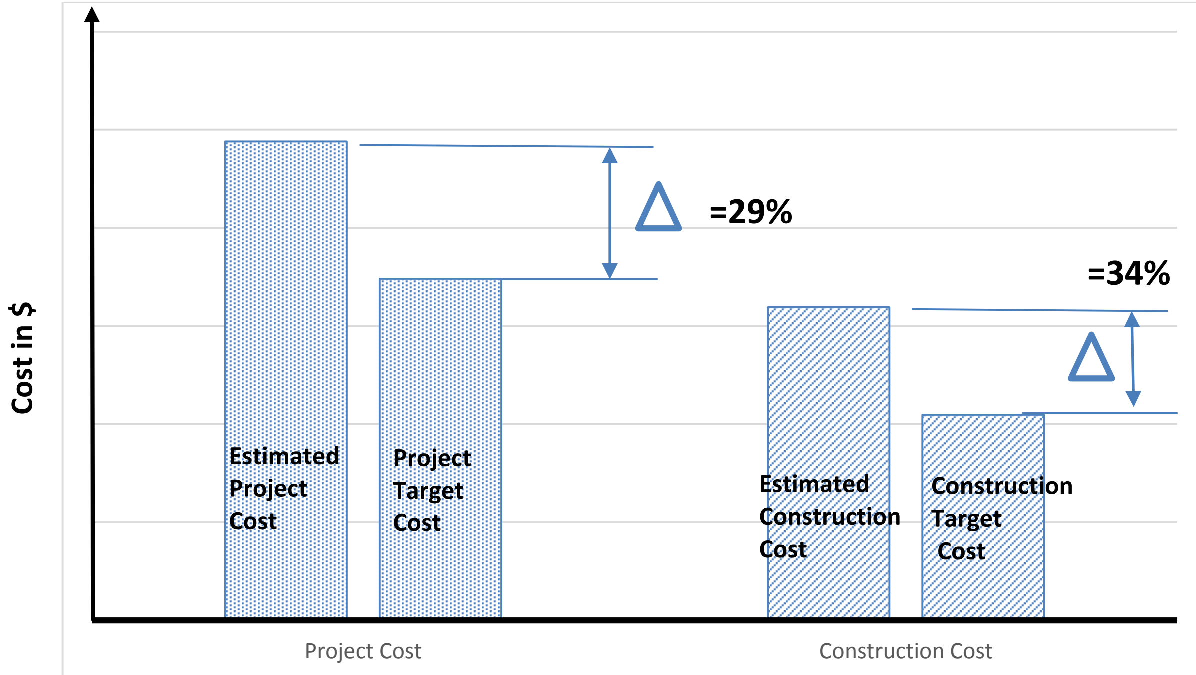

Figure 8 Gaps between estimated cost and target cost

To meet the requirements of the target construction cost, Children's Hospital X facilitated Target Value Design as mentioned before. The six innovation teams came up with design alternatives, and discussed during team weeks (co-location). After securing approval from PLT, the cost savings were recorded in estimating and reflected in the current estimate.

Figure 9 plots the overall construction cost estimating adjustment from August 2012, when the project moved to pre-construction stage, to November 2013. It gives an overall picture of how TVD and other lean processes help to reduce the construction cost budget.

From Figure 9, six findings are evident:

- With the support of TVD and other lean processes, the overall estimated construction cost for the owner decreased by $70 million - 30% of the original budget.
- The estimated line in Figure 9 has both an increasing trend and decreasing trend, which means the lean processes and Target Value Design not only brought cost savings, but also some cost increases. However, even though the estimated cost line includes both trends, it continuously approaches the Target Cost.
- Every single point in the estimated cost line is associated with several decisions, some from design changes, some from scope of work changes, and some from other considerations. For example, in January 2013, the estimated cost was reduced approximately $8,000,000. This reduction was due to Children's Hospital X's decision to remove level 4&5 clinics from the original budget. Therefore, the revised estimated cost no longer included costs for associated interior ceilings, drywall and doors and other items.

  Additional, in December 2012, there was a cost decrease of approximately $144,000. That was a decision produced by the enclosure innovation team to change the current design from wood grain Trespa paneling to painted Portland cement plaster. This simple design change not only brought cost savings, but also provided a "warm" sensation to enhance the patient arrival experience.

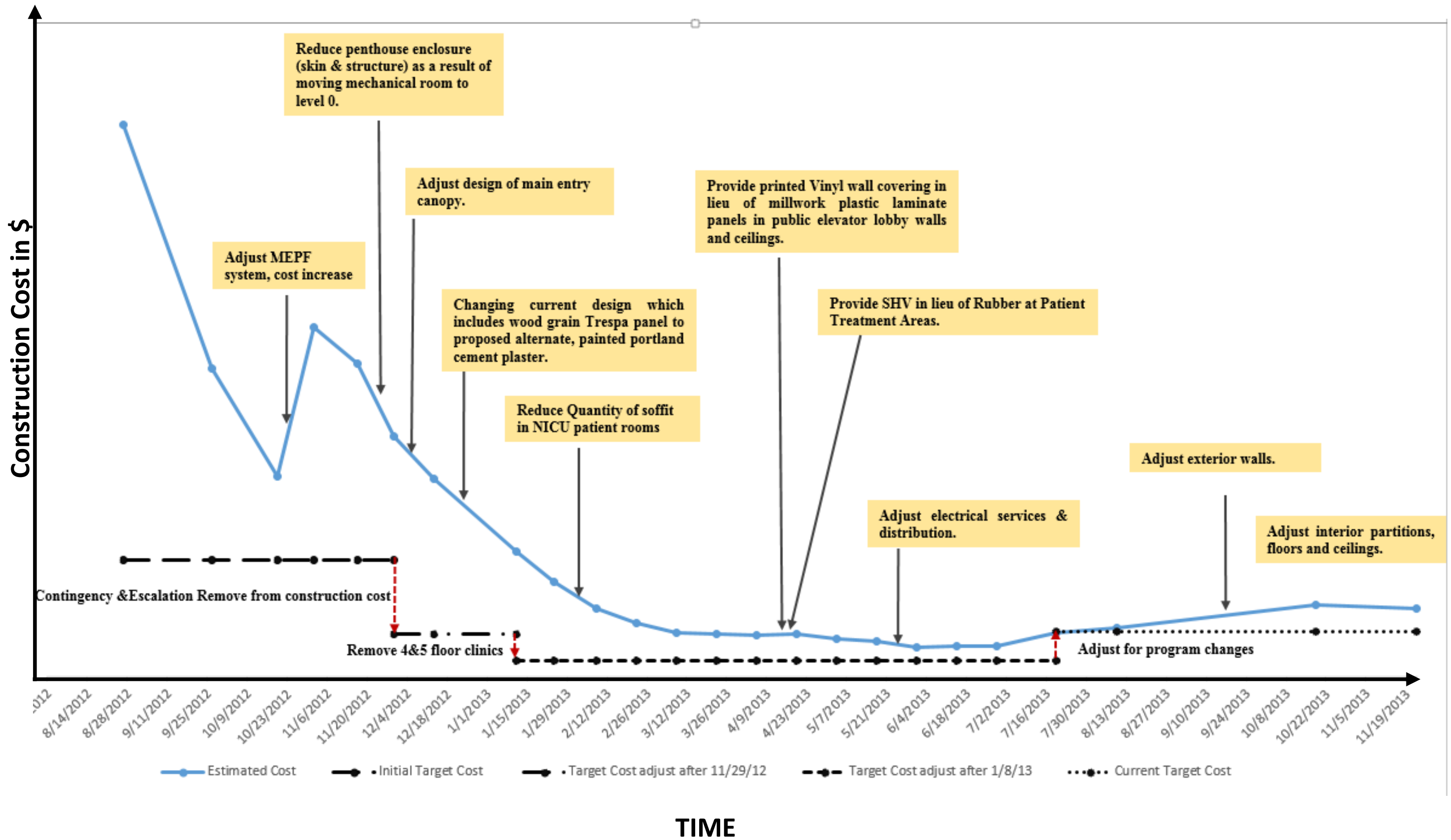

Figure 9 Estimated construction cost decrease diagram associated with TVD.
The x-axis represents time; the y-axis represents magnitude of cost decreasing. For confidentiality reasons, actual dollar amounts are not shown.

- Project innovation teams used A3 reports to support design decision making and choosing the most reasonable alternatives. From the Children's Hospital X budget report, there were 50 A3s developed by the enclosure innovation team, and 97 A3s developed by the interior innovation team. Even though some design alternatives were rejected by PLT, the accepted alternatives associated with A3s accumulated approximately $9,000,000 in savings, which included $1,769,287 from the enclosure innovation team, $1,250,000 from the interior innovation team, $ 1,000,000 from site innovation team, $247,000 from structure innovation team, $3,000,000 from MEPF team, and $ 2,000,000 from Equip./ IT team.
- Started in January 2013, the estimated cost adjusted every half month, which was a reflection of Team Week decisions. As discussed in Section 4.1, Team Weeks, along with the associated Big-Room meetings and Co-location, helped to proceed with TVD and save money.
- One could divide the analysis period (August 2012 to November 2013) into three main phases: (1) preconstruction start to project validation; (2) project validation data to foundation start; and (3) foundation start to November 2013 when the project was still under construction. The estimated construction cost decreased with different rates during the three phases (see Figure 10). The rate in phase (1) is highest, which is $17,000,000 per month. The rate in phase (2) is about $4,300,000 per month. And the rate in phase (3) is lowest, which is $1,437,000 per month.

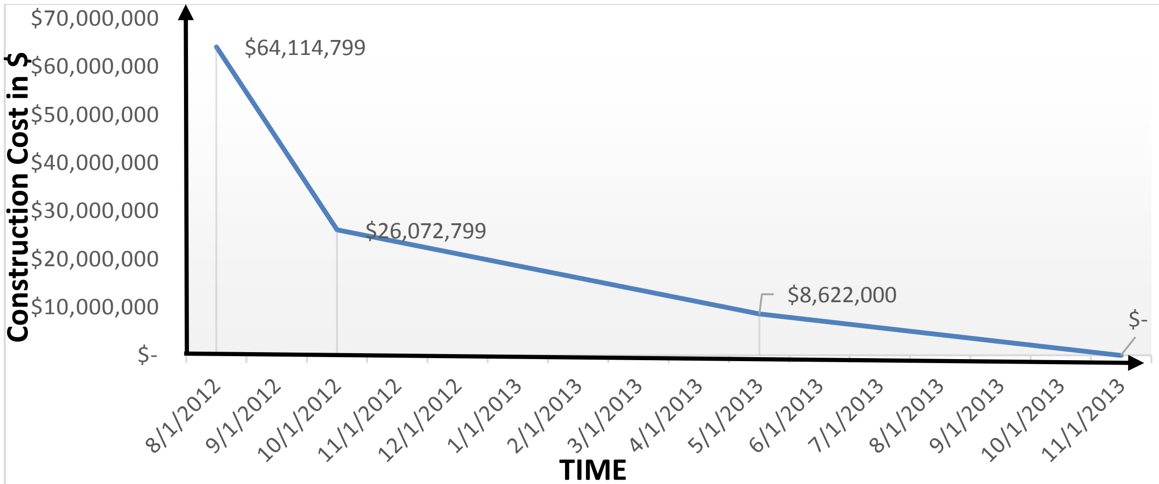

Figure 10 Decreases in estimated construction cost

The three different rates highly matched the first line of MacLeamy Curve, the simplified relationship between ability to impact cost and time (Figure 11). With the project moving from beginning pre-construction phase to construction phase, the ability to reduce costs falls. Meanwhile, as the project moves on, the cost of design changes increases.

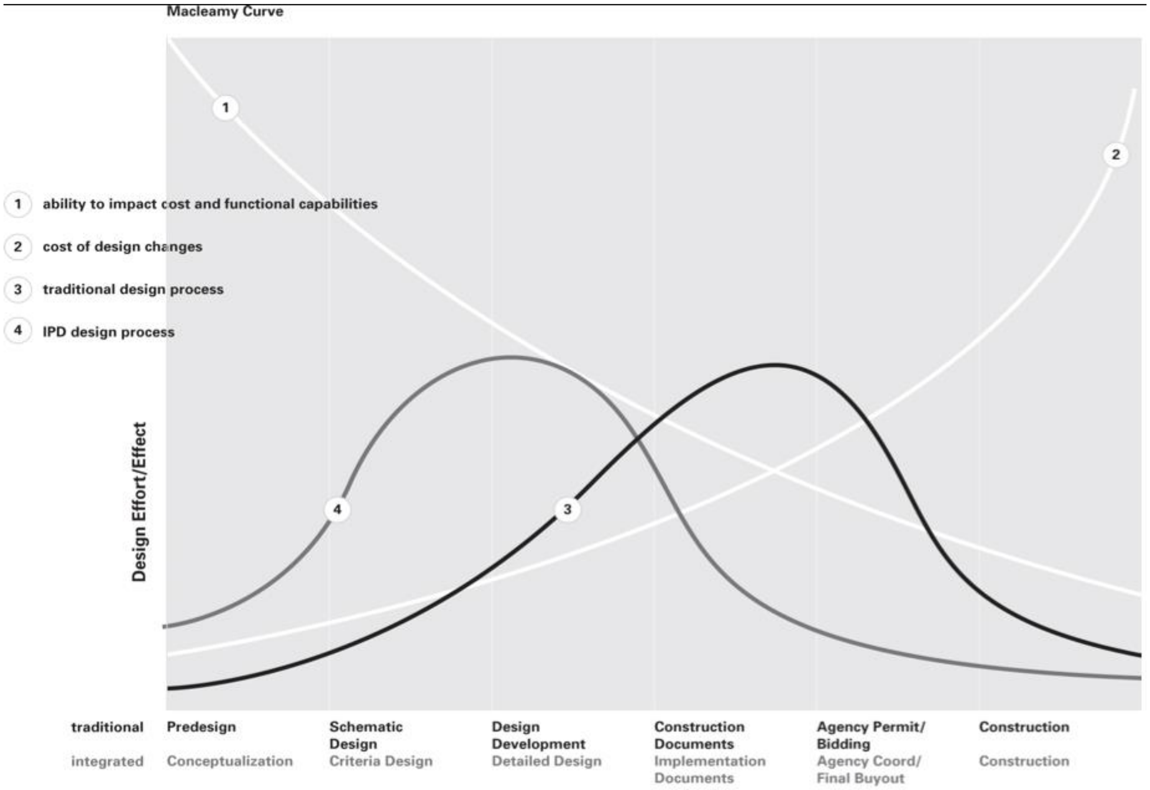

Figure 11 MacLeamy curve (Smith 2011).

The cost decrease was a combination of six main parts, each of them from one project innovation team. Looking inside the decreases contributed by each innovation team, the money saving from each innovation team is not scaled. There is cash flow between each innovation team. Figure 12 compared the cost of each innovation team between the beginning of preconstruction phase and end of the analysis period. The calculation uses final cost at the end of the analysis period minus the initial cost, then divides this result by the initial cost (Equation 1). The cost decreases or increases for designs by each innovation team. Because the delivery contract permits funds to freely flow between systems, the interior innovation team cost decreased 25%. Meanwhile, the

MEPF innovation team's cost decreased 20%. In addition to the interior innovation team and MEPF innovation team, Equip/ IT innovation team contributed most to the cost decreasing, its cost decreased 34%. However, estimated costs for the enclosure innovation team and site innovation team increased by 9% and 24%. The estimated cost for structure innovation team remained the same.

Equation 1: Cost decreasing percentage calculation

$$\frac{Cost_{Final} - Cost_{initial}}{Cost_{initial}} X\ 100\%$$

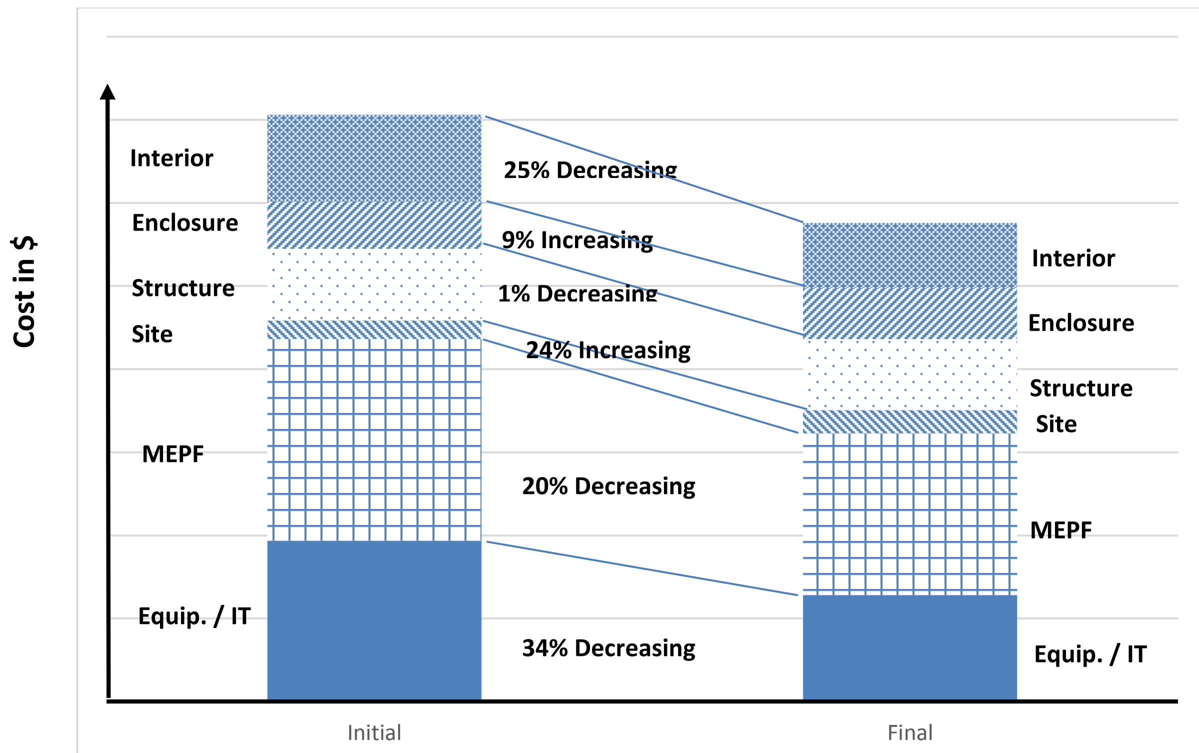

Figure 12 Estimated cost decrease of each innovation team

4.2.2 Performance Enhancement in Schedule, Quality and Safety

In addition to direct cost savings with lean processes, the Children's Hospital X project also realized benefits on higher performance in terms of schedule, quality and safety.

From the aspect of schedule, the bi-weekly Big-Room meetings promoted Pull Planning under the direction of the general contractors. Using a six-week look ahead schedule, each innovation team wrote its tasks on assigned color notes and stuck them on the pull plan wall (Figure 13). All pull plan meeting participants discussed each task, and then developed a more reasonable and less conflicted master schedule.

When innovation teams engaged in TVD, they took into consideration the possibility of shortening the schedule. For example, when the interior innovation team developed the CBA table to compare two alternatives (eg. Build-on-site or modular), build-on-site had lower costs but a longer schedule. Since a significant attribute to consider was a shorter schedule, the innovation team suggested adopting the modular alternative.

To improve quality, lean-IPD method involves general contractors earlier (AIA, 2007); this makes general contractors more familiar with the design. When general contractors participate as early as the design phase, their suggestions can help the design reach a higher quality.

Figure 13 Example of a master pull plan (Beikmann 2013, with permission from author).

4.2.3 Higher Client Satisfaction

Lean-IPD and lean processes bring higher client satisfaction. Children’s Hospital X facilitated a full scale Mock-up, and invited end users to simulate the workflow. The end users included former patients and their parents, nurses, and staff. Following feedback from them, the architects adjusted their design based on the end users’ advice. Taking end users’ demands into consideration can avoid errors and omissions.

Furthermore, the design was not developed in a vacuum; it was designed to support the actual daily functions of a healthcare facility.

For example, based on former patients' suggestions, the architects adjusted typical exam room space and added specific exam room lights (Figure 14). These small adjustments provided a more friendly space for both the patient and the doctor.

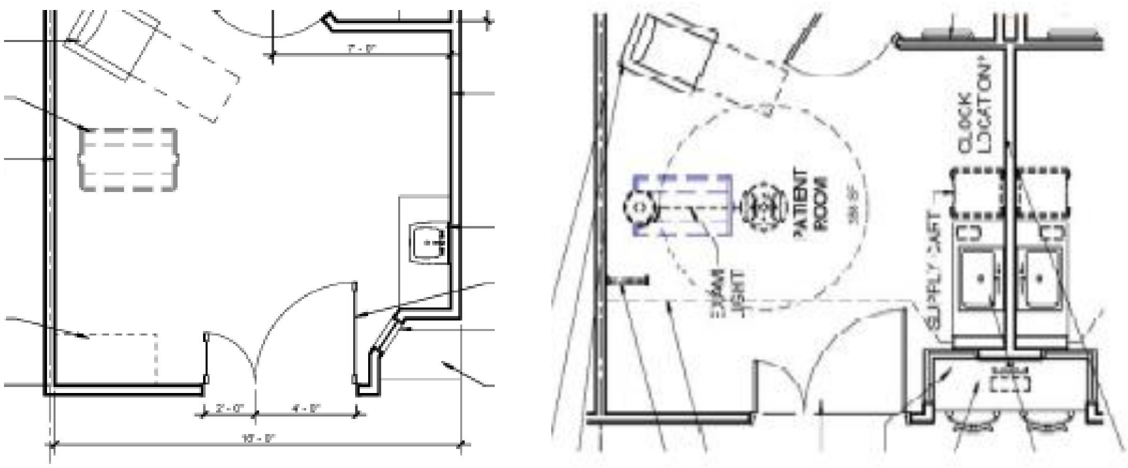

Figure 14 Example of a design adjustment (Beikmann 2013, with permission from author).

4.3 Costs Associated with Lean -IPD

Compared with traditional project delivery methods, such as DBB/CSP, Lean-IPD and associated lean processes encompass a higher level of delivery team collaboration and earlier involvement of each key stakeholder. Therefore, a specific budget cost arises to meet the lean-IPD requirement.

Similar to the benefits associated with Lean-IPD and lean processes, costs associated with Lean-IPD and lean processes also can be detected from the perspectives of (1) direct budget cost, and (2) time cost in lean processes.

4.3.1 Direct Cost in Budget

From the perspective of direct monetary costs of Lean-IPD and associated lean processes, the owner must pay for the labor, material, equipment and rent used for Lean-IPD and associated lean processes. For example, the physical space for co-location costs the owner rent each month, whereas a traditional delivery method without Co-location would not bear such a cost.

Table 4 illustrates each lean process' additional cost compared with DBB in each category. In the case of Children's Hospital X project, a warehouse for facilitating the full scale Mock-up was donated, so the rent for mock-up was eliminated.

Table 4 Lean processes' additional costs compared with DBB in each category

	Team Week Meetings and Co-location	Full scale Mock-up
Labor	X	X
Material	X	X
Equipment	X	X
Location Cost	X	X

From Table 4, it is obvious that each these represent TVD lean process contains costs in at least three categories.

4.3.1.1 Labor Costs

Children's Hospital X has a three level project delivery team, which includes about 100 persons from more than ten companies. Specifically, those members in SET and PLT were senior executives from each company/ stakeholder, which means their average unit labor cost were higher than the average level of the industry.

In the Children's Hospital X project case study, general contractors became involved beginning in January 2012 and structural and MEPF engineers became involved beginning in March 2012. The architecture firm became involved in April 2012. Main sub-contractors became involved in innovation teams and the production team to facilitate TVD and attend Big-Room Meetings beginning in January 2013. In a traditionally delivered project, the general contractor and sub-contractors do not participate in a project until the start of construction. In Children's Hospital X project, the start date of the foundation was May 30, 2013. General contractors were involved 14 months earlier and sub-contractors were involved five months earlier than on traditional DBB project. Labor costs associated with these periods for general contractors and sub-contractors represent additional costs for the owner.

Unlike traditional project delivery methods, DBB and CSP, in this project, PLT, innovation teams and the production team have to spend one week co-located every two weeks during the design phase, and every four weeks during the construction phase. During Co-location week, called Team Weeks by the delivery team, co-location participants spent their whole week discussing design alternatives, negotiating the pull plan and developing new design alternatives. However, in a traditional project delivery method where co-location is not mandatory, stakeholders usually manage multiple tasks of several projects at the same time (Rybkowski 2009).

In the full scale mock up session, most participants were volunteer former patients and Children's Hospital X employees. However, approximately 25 extra persons were assigned to organize and lead full scale mock-up days. Most of these participants were expert architects, engineers and lean facilitators. Additionally, it took 16 days to finish several workshops which focused on solving problems of space design, surgery center space and functional design, and NICU functional design in August, September and October 2012. Clearly, these items add to the costs associated with Lean-IPD and lean processes.

4.3.1.2 Materials Costs

Materials cost is an obvious tangible cost for adopting lean processes. To support Lean-IPD and associated lean processes, the owner had to provide necessary materials to the participants and build a lean and high efficiency working environment.

Basically, materials utilized in TVD, Big-Room Meetings and Co-location were the materials used in offices to support team collaboration. However, materials used for the full scale Mock-Up were specific materials needed to build the scenarios.

In Children's Hospital X project, key stakeholders co-located and had Big-Room Meetings in a former two-story garage. The owner provided all materials to transform the garage into an office place. Since it was an open space working area, only a few interior partition walls were erected. Furthermore, the owner provided some necessary furniture, several pull plan walls and several white board walls to meet the requirement of lean processes. Printers and projectors were also provided to this co-location space. Figure 15 gives an inside view of the Big-Room environment. In the Pull Plan process, participants needed to adhere their colored notes on the pull plan wall, so stickers and markers represent a large quantity of the consumed materials compared with traditional delivery methods.

Figure 15 Inside view of Big-Room environment (Beikmann 2013, with permission from author).

In a lean workshop, the owner prepared a seven page materials list that included various materials associated with lean processes. Large Value Stream Maps (VSMs), A3s, and TVD lean game materials were specific costs utilized to support the lean working environment and lean processes.

In Children's Hospital X project, material costs for the full scale mock-up process were about $50,000, which included costs for cardboard and materials associated with building the scenarios.

4.3.1.3 Equipment Costs

Equipment required by Lean-IPD and lean processes were also used to support collaboration. As mentioned earlier, the owner provided printers and projectors in the Co-location space. In addition to printers and projectors, to eliminate the effects of distance communication, the owner provided conference call equipment in the Big-Room, including a camera, an audio system and video conference call hardware and software.

4.3.1.4 Location Costs

In addition to labor, material, and equipment costs, location cost is another category for lean processes. The owner of Children's Hospital X paid for the two-story garage where the delivery team co-located and held Big-Room Meetings. The owner received a donation for the warehouse for the simulated full scale Mock-up; otherwise, use of the warehouse would have added rent cost.

Considering all four categories of cost--labor, material, equipment and location--labor cost and material cost were the most significant. All four lean processes discussed in this paper carried costs for labor and materials.

4.3.2 Time Cost Associated with Lean Processes

Section 4.3.1 discussed direct monetary costs of lean processes. If direct monetary cost is tangible, time cost of lean processes represents an intangible cost. Both costs were significant and the Children's Hospital X project delivery team and lean researchers needed to consider them.

In this project, the earlier involved delivery team, which included about 100 persons from more than ten companies, needed to spend time on each lean process. Considering the large volume of lean process participants, time cost for them should not be ignored.

To facilitate lean philosophy and lean thinking, the project delivery team participated in three two-day lean boot camps in March, June, and July 2012. Ten Kaizen workshops focusing on different design topics were held every single month from June 2012 to April 2013. The total time for these two kinds of activities was 46 days.

In addition to lean facilitating, the delivery team had to spend more time on co-location and Big-Room Meetings. As mentioned before, during co-location week, the participants spent the entire week on design alternatives discussions, pull plan negotiation and new design alternatives development. However, as mentioned previously, in a traditional project delivery method where Co-location is not mandatory, stakeholders usually have to multi task several projects at the same time (Rybkowski 2009).

4.4 Benefit and Cost Analysis Framework of Lean-IPD and Lean Processes

In this section, a benefit and cost analysis framework has been constructed as a basis for future analyses and to calculate ΔIRR associated with lean processes.

In the benefit and cost analysis model framework built by the author, benefit and cost data measured in dollars has been divided into four categories: (1) cost for co-location, (2) cost for Mock up, (3) cost for Big-Room meetings, and (4) savings from TVD. Savings from TVD include savings from each of the six innovation teams. Table 5 shows the cost items checklist associated with Children's Hospital X project lean processes.

The total cost for each lean activity equals materials cost plus labor cost plus equipment cost and plus location cost (A+B+C+D).

In Section 4.3, labor cost measured in time was discussed. To calculate the benefit and cost analysis of lean processes, average labor unit cost per hour was applied to quantify the labor cost measured in dollars. Table 6 shows two different sources of mean hourly wages, one is the national mean hourly wages of several construction related positions from Bureau of Labor Statistics, and the other is the real wages of participants of Children's Hospital X project, which include overhead and profits (see Table 6).

Table 5 Total cost framework of lean processes

			Cost items
I	**Team Week Meetings and Co-location[1]**	A. Material	White board
			Supplies (large Post-It notes ®, markers, flipcharts, push pins, masking tape)
			Floor plans of existing hospital
			Rolls of paper
		B. Labor	Owner and owner representative
			Architects
			General contractors
			Structural engineer
			MEP engineer
			Sub-contractors
			Vendors
		C. Equipment	Speakers
			Projector
			Conference call equipment
		D. Location Cost	Co-location space rent or build cost
II	**Full Scale Mock-up[2]**	A. Material	Cardboard
			Tape and nail to fix cardboard
			Furniture for mock-up scenario
			Food and Warehouse Amenities
		B. Labor	Lean facilitator
			Architects
			Healthcare administrators
			Physicians
			Nurses
			Clinical Staff Costs
			Former patients and their parents
		C. Equipment	Equipment for mock-up scenario
		D. Location Cost	Warehouse Rent
			Warehouse Construction labor
			Utility

1. Team week meetings and Co-location include lean training workshops, Big-Room Meetings, Project leadership Team meetings and innovation team meetings.
2. Full scale Mock-up includes workshop that designs and builds full scale cardboard mock-up of hospital interior.

Table 6 Mean hourly wages

Occupation	**Mean hourly wages from BLS (per hour)**	**Mean hourly wages from Children's Hospital X project (per hour)**
Healthcare administrators	$42.59	$ 192.00-$250.00
Physicians & Surgeons	$90.00	$ 330.00
Nurses	$31.48	$ 192.00-$250.00
Clerical and technical staff from Owner	NA	$ 192.00-$250.00
Construction Managers	$39.80	NA
Architectural Managers	$60.03	$ 120.00-$137.00
Engineering Managers	$60.03	NA
Architects	$35.14	$ 82.00-$ 90.00

Compared to the traditional delivery methods of DBB or CSP, this project used additional labor input for the full scale Mock-Up and Big-Room Meetings, from the perspective of owners. Utilizing mean hourly wages from BLS, labor costs per month for the Big-Room Meetings was calculated by multiplying the number of participants, time each participant spent on the activities, mean hourly wages and number of team weeks per month. This amount has also been added to the cost factor of lean processes.

Equation 2 Labor Cost Calculation Equation

Labor cost = Mean hourly wages per participant X Number of participants X Number of hours spent X Number of team weeks per month

Table 7 Labor cost calculation (mean hourly wages adopted from Children's Hospital X Project) [1]

Category	Role	Mean hourly wages (per participant)[2]	Number of participants	Number of hours spent (per team week)	Number of team weeks per month	Sub-total cost (per month)
Big-Room Meetings	PLT members	$155.00	7	7.5	2	$ 16,275
	Innovation/ Production Team members	$113.00	90	7	2	$ 142,380
	All members	$113.00	103	10.5	2	$ 244,419
	Workshop Committee	$190.00	6	8	2	$ 18,240

1. The mean hourly wages for Healthcare administrators, Physicians & Surgeons, Nurses, Clerical and technical staff, Architectural Managers, and Architects were from Children's Hospital X Project. The mean hourly wages for Construction Managers, Engineering Managers were from Bureau of Labor Statistics 2012.
2. Mean hourly wages per participant were calculated by averaging all participants' mean hourly wages.

The cost for full scale Mock-up collected by the owner was a lump sum cost for all the workshops, and it included labor cost, material cost and location cost. In Children's Hospital X project, the rent of warehouse was zero. However, if taking the rent into consideration, the average rent for a warehouse in the city where Children's Hospital X project located is $3 to $4 per SF per year.

Benefits and costs measured in dollars are graphed as a cash flow diagram by either one lump sum item or monthly cost (Figures 16 and 17). In Figure 16, two series of data are plotted. The fine dashed line represents the dollar amount spent on lean processes each month. The coarse dashed line stands for the benefit Children's Hospital

X project gained or saved each month. Moreover, in Figure 17, the solid line represents benefit minus cost, which is the cash flow for each month.

As Figure 17 shows, in the first four months, April 2012 to July 2012, the Children's Hospital X project had to pay initial costs to establish necessary lean tools and a lean working environment with no payback. However, starting in the fifth month, August 2012, the project began to significantly benefit from the lean processes. This trend extends to April 2013. After April 2013, when the project switched from its design phase to its construction phase, the benefit from TVD decreased to less than the monthly lean process maintenance cost. However, the benefits gained from August 2012 to April 2013 supported the project through a significant value payback.

As mentioned in figure 1 and item three of part 3.3.2 (limitation), a true IRR analysis need to subtract a defender situation from a challenger situation when calculating incremental cash flows. Because defender cash flow data was not available for this study, cash flow from only the challenger (TVD) situation have been included.

Additionally, if a future researcher would like to consider Life Cycle Costs of the Children's Hospital X project, savings from fewer change orders, and from shorter construction schedules should also be included as benefits incurred from implementation TVD and other lean processes.

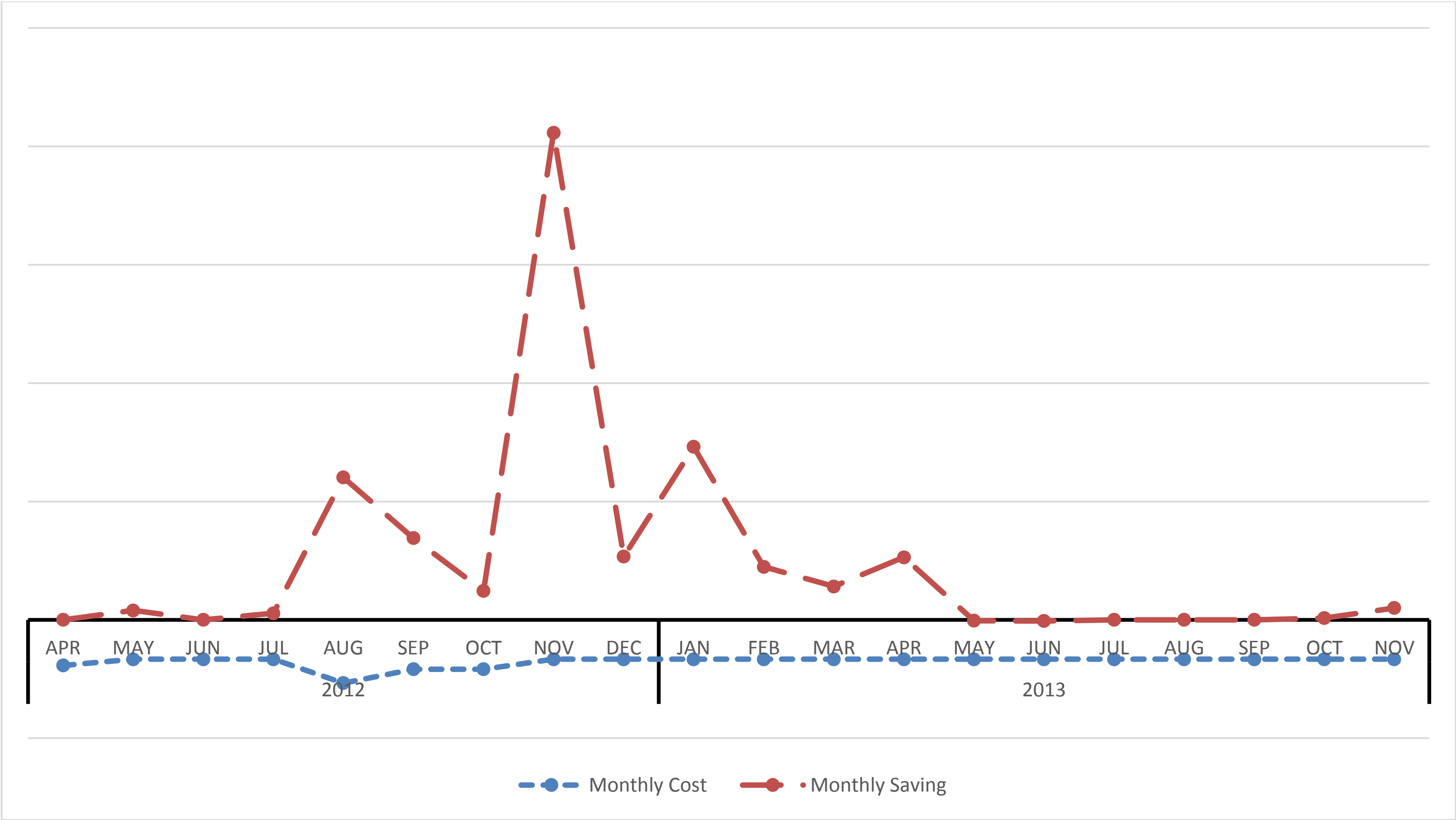

Figure 16 Monthly savings and cost diagram.
The x-axis represents time; the y-axis represents magnitude of cash flow. For confidentiality reasons, actual dollar amounts are not shown.

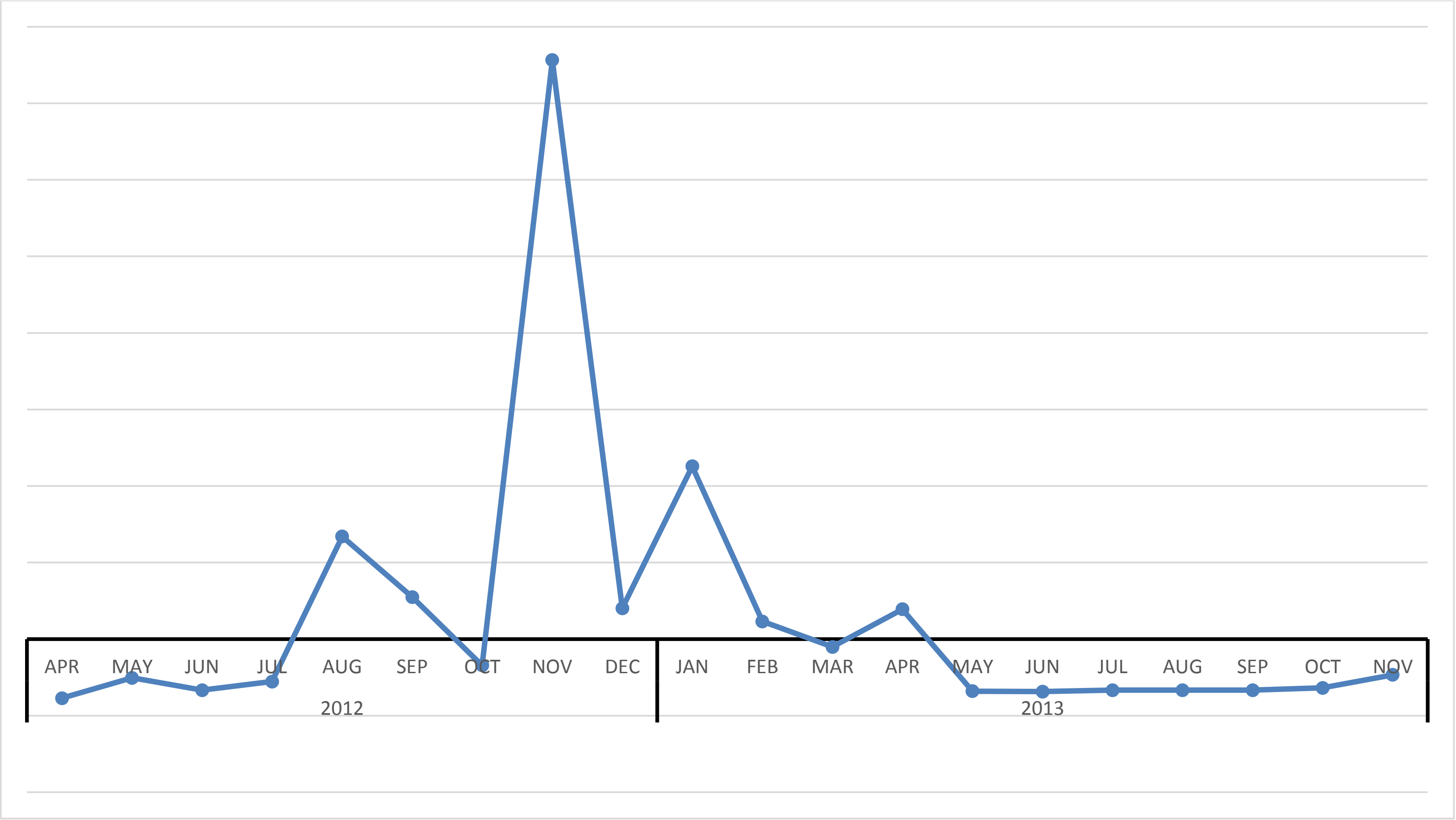

Figure 17 Cash flow diagram of Target Value Design for Company X.
Revenues and expense from Figure 16 have been combined. The x-axis represents time; the y-axis represents magnitude of cash flow. For confidentiality reasons, actual dollar amounts are not show

CHAPTER V

CONCLUSIONS

There are obvious benefits and costs associated with lean processes adopted by the Children's Hospital X project.

The benefits calculated in this thesis were derived mainly from direct monetary savings incurred due to the reduced estimated construction cost. This reduced cost resulted from TVD processes implemented during the lean delivery of the projects where innovation teams' conducted TVD exercise using A3 and CBA research methodologies in Big-Room and smaller group meetings.

The costs were attributed to labor, materials, equipment, and location costs associated with TVD: Team Week Meetings and a full scale Mock-up. The location and material costs comprised a one-time initial costs at the beginning of the pre-construction phase, while labor costs were continuous and needed to be considered every month.

The ultimate objective of this research was to build a benefit and cost analysis model framework, which can serve as a basis for construction of a ΔIRR model to better understand the benefits and costs associated with lean processes. In future work, additional benefits need to be considered and include schedule reduction, quality improvement, enhanced safety, increased team morale, augmented team knowledge enhancement and improved client satisfaction.

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