LEAN PRODUCT DEVELOPMENT AT CATHEDRAL HILL HOSPITAL PROJECT

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ABSTRACT

The Cathedral Hill Hospital (CHH) project is a 1.2 million square feet urban replacement hospital in San Francisco, California. It is not just designed to be a state-of-the-art hospital but also to break new grounds in multiple areas of design, construction, and operations. Since the beginning of project validation in 2007, the Integrated Project Delivery Team has been applying and testing Lean ideas, concepts, tools and processes to develop this very complex project. The paper's nurturing proposition is that CHH has implemented most principles related to the Lean product development system at Toyota, as described by Morgan and Liker, and that these principles are the foundation for the evolving operational system that supports its processes on a daily basis. The paper attempts to compare and contrast initiatives set forth at CHH with the 13 principles proposed by Morgan and Liker regarding the Toyota Product Development System. Additionally, the paper aims to explore the opportunities and limitations of experimenting and implementing Lean Product Development ideas and practices into design and engineering of the CHH project.

KEY WORDS

Product development, information flow, Integrated Form of Agreement, learning, leadership

INTRODUCTION

The Cathedral Hill Hospital (CHH) project in downtown San Francisco, California, has received considerable attention since its beginning in 2007 due to the implementation of novel ways to develop capital projects in construction (e.g., Nguyen et al. 2009, Heidemann and Gehbauer 2010). The project achieved notoriety after the team of professionals designing the project were collocated in a single floor of a building and started implementing a host of concepts, processes, and tools proposed by scholars of Toyota's lean production system. This arrangement was promoted by the innovative contract adopted by the project owner and described by Lichtig (2005) as an Integrated Form of Agreement (IFoA).The IFoA promotes the use of Lean Construction principles and tools to manage the project from the design stage, as well as creates conditions for the teams to share rewards and risks while working together to deliver the best value for the client.

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The paper's nurturing proposition is that CHH has implemented most principles related to the Lean product development system at Toyota, and that these principles form the basis for the evolving operational system that supports its processes on a daily basis. The paper uses Morgan and Liker's (2006) 13 principles regarding the Toyota Product Development System to compare and contrast initiatives set forth at CHH.

LEAN PRODUCT DEVELOPMENT

The discussion presented in this paper is framed after the work of Morgan and Liker (2006), which presents a comprehensive picture of Toyota's product development system (PDS) and has been a constant source of inspiration for the authors who are working at the CHH project. It is not the intention of this paper to present a comprehensive discussion about the Lean product development available in the literature at large.

The management of the product development process differs from the management of manufacturing in many different ways which have to be accounted for when one tries to apply lean concepts originated in manufacturing to design. In design, the flow of concern is that of data, this flow is often iterative as participants exchange information back and forth before proceeding with their tasks, the product of each process might not be as specific as in manufacturing, and multiple information outputs have to be identified and managed. The temporal measure for the product development stream is weeks, months, or years and the group tends to be more diverse than that of a manufacturing value stream (Morgan and Liker p. 314, 322).

Lean originated on the manufacturing side of Toyota and evolved for many years in that environment. Attempts to understand, document, and translate the concepts used in manufacturing to other functions at Toyota emerged over the years (e.g., Liker 2004). However, none came close to describing the product development process in the detail provided by Morgan and Liker, and that is the topic of the following section.

LEAN PRODUCT DEVELOPMENT AT TOYOTA

Morgan and Liker (2006) define the basis of the lean product development at Toyota as a mutually supporting system composed by process, skilled people, and tools and technology. Table 1 presents a list of the 13 principles that guide the product development at Toyota. These elements are discussed in this section.

The *Process* element is marked by a definition of value from the customer standpoint to guide the entire process. A Chief Engineer (CE) is appointed to guide the team, but before work can commence the CE has to "walk in the customers' shoes" to gain a deep understanding of their needs. Much effort is put in planning the process and evaluating multiple solutions to deliver the product, "*Plan carefully and execute exactly*" (p. 40) summarizes that drive. Additionally, module development teams (MDTs) "*responsible for each vehicle subsystem, meet to develop specific, measurable goals for each subsystem and communicate it to the CE team*" (p. 31). The CE by default has to possess deep knowledge of the process to guide team members and to understand what is needed and when. Along these lines, value stream maps (VSMs) are used to gain understanding of the process, its resulting products and milestones.

Table 1: Product Development at Toyota (after Morgan and Liker 2006)

	Principle number	Principle	Supporting characteristics of the system
Process	1	Establish Customer-Defined Value to Separate Value-Added from Waste	Establish an emotional connection with the customer, walk in customer's shoes, training to evaluate vehicles and identify opportunities for improvement, Chief Engineer (CE or *Shusa*) concept paper outlining the vision for the product.
Process	2	Front-Load the Product Development (PD) Process to Explore Thoroughly Alternative Solutions while there is Maximum Design Space	"Plan carefully and execute exactly" (p. 40), creation of several study drawings (*Kentouzu*) by Module Development Teams (MDTs) during the *Kentou* phase (study phase of a program), set-based concurrent engineering to evaluate multiple alternatives simultaneously, isolate and minimize variation trough standardization and platform planning.
Process	3	Create a Leveled Product Development Process Flow	Value Stream Mapping (VSM) used to visualize work streams and expose waste. Manage capacity, stabilize value streams. "Process logic determines who will do what and when" (p. 82), defines what PD teams need to deliver in specific milestones creating accountability.
Process	4	Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes	Design standardization (product/component design and architecture). Process standardization (tasks, work instructions, and sequences of tasks). Engineering skill-set standardization (capabilities across teams).
Skilled People	5	Develop a Chief Engineer (CE) System to Integrate Development from Start to Finish	The CE is viewed as the "Heavyweight Project Manager"... "charged with the success of the design, development, and sale of the car (p. 118) and "the CE is the *voice of the customer*." (p.137).
Skilled People	6	Organize to Balance Functional Expertise and Cross-functional Integration	Combination of functional and matrix organizations, engineers respond to a functional general manager (e.g., engine, body) and to a product planning CE (families of cars, e.g., Camry, Corolla) The *Obeya* room (big room) to schedule tasks and discuss solutions proposed by different MDTs.
Skilled People	7	Develop Towering Technical Competence in all Engineers	Go and see engineering. "Freshman project" assigned to new engineers to learn the Toyota Way. Engineers must be connected to the user and the products they develop. Detailed selection and mentoring process to develop competencies.
Skilled People	8	Fully integrate Suppliers into the Product Development System	Partnering with *Keiretsu* members. Careful selection and development of suppliers through a detailed process. Guest engineer program to promote integration.
Skilled People	9	Build in Learning and Continuous Improvement	*Hansei* (reflection) events: personal, real-time (at major milestones), post-mortem. Held frequently, close to the events, open dialog. Resident engineers exchange between partners in the PD, supplier demonstrations, competitor teardown analysis, checklists (organize knowledge from experienced members), know-how database (e.g., standards, design data and tools) maintained by users.
Skilled People	10	Build a Culture to Support Excellence and Relentless Improvement	*Kaizen* (continuous improvement). Customer first, Contribute to the society and the community. Defective parts are sent back to the plant to learn from failure. Managers share key activities daily with superiors, who also manage by walking around.
Tools & Technology	11	Adapt Technology to fit your People and Process	Technologies support processes and enhance people's capabilities, are tailored to specific purposes and should be seamlessly integrated.
Tools & Technology	12	Align your Organization through Simple, Visual Communication	Visual management. Travelling *obeya* moves closer to production as the PD process evolves. *Nemawashi* (slowly build consensus), share problems with those involved in the process, prepare A3s, obtain feedback, adjust before meetings. *Hoshin* (policy deployment in different levels).
Tools & Technology	13	Use Powerful Tools for Standardization and Organizational Learning	"The focus must be on tools that help the organization change the way things actually get done" (p. 279). Checklists, know-how database, decision matrices to evaluate alternatives, *Senzu* (stamping engineering drawing with requirements marked next to the parts).

According to Morgan and Liker (p. 29): "*The result of failing to involve and align all program participants means each functional group develops its own goals, causing confusion or conflict across development teams.*" Another important element is the use of standardization to allow the use of common parts across different cars; to make explicit skill-sets required from team members and major work streams and tasks that support the product development.

In the *Skilled People* element, it is important to have the "*Right Person, Right Work, Right Time.*" "*Unfortunately, the early stages of product development at many companies are poorly understood and unstructured*" stress Morgan and Liker (2006 p. 64). The CE has to understand the complex network of relationships, from beginning to end, and be able to define specific work streams that deliver specific results at the end of the day. This is not an easy task as members of the product development team might perform work independently while at the same time being highly dependent on the work of other team members. Thus, engineers work in a matrix type of organization in which they report to a functional general manager and to the CE managing the development of a specific car. This organization form combines the focus on the expertise necessary to excel at the function level without compromising the goals of the specific product. Suppliers, chosen based on a long process to demonstrate expertise and ability to meet Toyota's requirements, are integrated into teams and engineers are exchanged between suppliers and Toyota to promote cross-learning.

Engineers are selected based on technical expertise, receive extensive training and are mentored by senior engineers in "freshman projects" before being in charge of their own projects. This is in line with an overarching culture of learning based on go and see, reflection, building consensus over time, and learning from failures.

The *Tools and Technology* element's role can be understood based on the following quote: "*You can describe lean manufacturing as a set of tools (e.g., kanban, andon, poka yoke) that eliminates waste and creates flow of materials through a transformation process. You can describe lean product development the same way. But peel away another layer, and you discover the basis of both lean product development and lean manufacturing is the importance of appropriately integrating people, processes, tools, and technology to add value to the customer and society" (Morgan and Liker, p. 5).*

LEAN CONCEPTS FROM PRODUCT DEVELOPMENT APPLIED TO PROJECT DESIGN AND ENGINEERING IN CONSTRUCTION

Koskela et al. (1997) opened their paper on Lean Design Management with the following quote:

> "*It is not an exaggeration to say that the management of design and engineering is one of the most neglected areas in construction projects. Findings from research unanimously indicate that planning and control are substituted by chaos and improvising in design.*"

Over the past 15 years, Lean practitioners and scholars have joined forces to advance the management of design in the Architecture, Engineering, and Construction (AEC) industry and alleviate the problems pointed out by Koskela et al. in 1997. Despite recent advances in the field of design management, questions remain about how to use concepts, principles, tools, and processes discussed in previous publications in an integrated fashion. This is at the core of the present paper and the authors expect to contribute to this discussion through their own analysis of what was implemented at the CHH project and how that supported its PDS. To put this discussion in perspective, the authors reviewed the principles outlined by Morgan and Liker (2006) for the Toyota PDS in the previous section. The next section briefly discusses the LPS™ and attempts to use it to manage product development in AEC.

INTEGRATED PROJECT DELIVERY (IPD) AND PRODUCT DEVELOPMENT IN AEC

The term IPD has gained popularity in the United States after the development of the Integrated Form of Agreement (IFoA) by Will Lichtig (2005) for Health Care owner Sutter Health. The IPD and the IFoA discussed in this paper are forms of contracts, and have very distinct characteristics which promote collaboration in AEC beyond the product development phase.

The IFoA is a multi-party contract in which the project's core team (usually the owner, architect, general contractors, and major specialty contractors and designers) sign the same contract and share risks and rewards (Lichtig 2005). Stakeholders are involved early in the conceptual stages to define targets for the project and to deliver the best value for the client. In this environment, stakeholders contribute part of their profit to a contingency pool shared by the team, that is, when problems happen the fix is "financed" by the contingency pool and everyone loses. By having "skin" in the game, that is, risking their profits, companies are encouraged to collaborate early on to avoid problems, even if that means crossing organizational boundaries to find solutions with partners in the team.

PDS AT CHH AND ITS RELATIONSHIP WITH TOYOTA PDS

CHH is a large 1.2 million square feet urban replacement hospital. The project, like other hospitals in California, has undergone reviews by California's Office of Statewide Health Planning and Development (OSHPD). The project faced strong oversight and a lengthy discussion process with the hospital neighbors. To overcome these and other challenges related to designing and building a major hospital in California, the team resorted to Lean concepts, principles, processes, and tools.

This section presents characteristics of the PDS at CHH in broad strokes while comparing them to the PDS at Toyota as discussed by Morgan and Liker (2006) and summarized in Table 1. The discussion attempts to highlight principles that appear to be well implemented based on the point of view of this paper's authors and other principles that merit further discussion and development.

TEAM AND MAIN PARTNERS IN THE IFOA

The cornerstone of CHH's IFoA is to share risks and rewards between the partners, having them co-located to foster collaboration, and have all customers of the value chain integrated from the very beginning. The use of an IFoA supports principle 8 "*Fully integrate Suppliers into the Product Development System*" in that the main stakeholders designing and building the project work in an integrated fashion. It is worth noting that this new form of contract brings teams to a whole different level of collaboration, as evidenced at CHH. Thus, the environment promoted by the IFoA begs for a strong leader, along the lines of the chief engineer (CE) at Toyota, who would be well experienced in all fields of a design, fabrication, construction and operation of the project and empowered by the owner and all the other members of the team to lead the project. This leader needs to have in-depth experience of the project areas, as well as hands on experience in the different phases of design, engineering, manufacturing, and construction. At Toyota, the CE's intimate understanding of the project's goals helps him/her lead the team to meet nearly impossible targets, to deal with trade-offs and "*be the glue that holds the whole product development system together*" (Morgan and Liker 2006 p.13); this idea was born with Toyota when its founders led by getting their hands dirty while the TPS was developed (Liker 2004). However, one can say that this well-versed leader profile might not exist (yet) in the construction industry which is much broader in its range of products than the manufacturing industry. Thus, the authors of the present paper believe that principle 5 "*Develop a Chief Engineer (CE) System to Integrate Development from Start to Finish*" is still a work in progress in the AEC industry as there might not be many CE leaders who are fully knowledgeable about the construction process from start to finish, especially when a much broader range of project types are considered.

Closely related to the need to have a strong CE to manage the process is the need to "*Develop Towering Technical Competence in all Engineers*" (principle 7). At Toyota, and in countries like Germany, technical competence is gained through hands-on experience and a strong mentoring process that supports the building of skills necessary to climb the corporate ladder. Principle 7 was not fully implemented at CHH due to the challenge to devise and implement a policy (or multiple policies for the IFoA signatories) to encourage engineering mentoring programs to support towering technical competence. Looking at the corporate policies of the major contractors and the two companies which form the general contractor enterprise for the project, they do not have any formal technical mentorship or technical/engineering training programs. Nevertheless, there is support for technical trainings on managerial routines and sharing information from *gemba* walks on the project level.

Another principle related to the Skilled People category depicted in Table 1, and observed at CHH, is principle 6 "*Organize to Balance Functional Expertise and Cross-functional Integration*". At CHH a "Big Room" exists where every Tuesday all project participants meet and discuss design, engineering, estimates, and milestones. Once a week the main system leaders meet in a stand-up meeting and exchange the work in progress and interdisciplinary constraints. Special task engineers for cross-functional engineering coordination have been assigned to coordinate rated wall tie-ins of interior rated walls transitioning to exterior walls. Involved parties include: interior wall structural engineer, fire protection engineer, interior architect exterior envelope architect, contractor for interior walls and the contractors for the three different systems is led by the cross-functional engineer to agree on solutions.

ORIGINS – USING LEAN CONCEPTS TO MANAGE THE PDS AT CHH

The product development phase started with book reading meetings in which 10-15 professionals read The Toyota Way (Liker 2004) and discussed how the book teachings could be applied to the project. At that stage, the intention was to translate the concepts presented at The Toyota Way book to the environment at CHH, and some concepts were very much applicable (e.g., collocation) and others were not as much. For example, the book talks about the 14 principles of the TPS and various examples of how to apply them in manufacturing and production of cars, it only talks in very small portions about the product development (design/engineering) phase of a car. Most examples provided in that book are geared towards production, and therefore hard or difficult to apply in design, especially design in construction.

The true north of the project was given by the five big ideas developed by Sutter Health (the owner) with the assistance of Lean Project Consulting (Lichtig 2005): collaborate really collaborate; increase relatedness among all project participants; treat projects as networks of commitments; optimize the project not the pieces; tightly couple action with learning. The true north provided guidance to implement principles 1 "*Establish Customer-Defined Value to Separate Value-Added from Waste*", 9 "*Build in Learning and Continuous Improvement*", and 10 "*Build a Culture to Support Excellence and Relentless Improvement*". Despite having a true north in terms of how the Lean deployment should occur, the practical roadmap or the framework for implementation was not there and the team was set to sail into uncharted territories.

At the beginning of the product development at CHH, there was some structure for the clusters (the MDTs at Toyota), some implementation of the LPS™ which matched what is outlined on principle 2 "*Front-Load the Product Development (PD) Process to Explore Thoroughly Alternative Solutions while there is Maximum Design Space*". However, this was all organized at a very high level and did not have enough detail to make the system move on a daily basis. The operational model to manage the work, and called for in the IFoA, was not in place in the early phases. There was no "how to" indicated in the IFoA. To be fair, there were academic papers discussing this new type of contract and its implications but to the practitioners at CHH they looked fuzzy, and the project managers at CHH had to develop their own "how to operational model book" as the project unfolded.

Simple tools that helped the project managers to organize the operational system to manage the teams at CHH are the swim lane diagrams and VSMs. Although VSMs are used, they can become very cumbersome when managing information flows coming from multiple stakeholders who collaborate in a very iterative fashion. The simplicity of the swim-lane diagrams provided a clear way to depict the exchange of information over time (Figure 1). Swim lane diagrams are a clear visual display of how the information flows and with that CHH stakeholders could make sense of the processes to learn, capture, and visualize the information flow. Once managers and participants perceived that the process adequately captured the information flows and the routines involved, efforts were made to standardize the process or adjust it to improve its results. These efforts matched what is called for in principle 12 "*Align your Organization through Simple, Visual Communication*" and 13 "*Use Powerful Tools for Standardization and Organizational Learning*".

By mapping the processes and exposing their details to participants, the team has improved how to:

- Design and perform effective pull planning sections;
- Collect and disseminate information to the right people at the right time;
- Manage interfaces between disciplines and trades;
- Define what is a workable backlog in design;

- Decide when to stop the line in design (to deal with what they call "the gorillas" which represent constraints); and
- Decide when the information is "good enough for now" so that it can go to the next station and/or stakeholder in the line.

Additionally, the mapping process ties into principle 3 "*Create a Leveled Product Development Process Flow*" as it allowed a better management of the workflow between different stakeholders.

The use of swim lane diagrams also supported principle 4 "*Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes*". At CHH the diagrams are used as a basis for continuous improvement (Plan-Do-Check-Act), that is, the processes are mapped, implemented, feedback is gathered from participants, and changes are made as necessary to improve their performance.

Another element that supports the product development at CHH is the use of Building Information Model (BIM). It is a basic requirement of the CHH project that all trades, architects, and engineers design and draw in BIM software, which opens the opportunity to see adjacent scope and changes, and adjust systems/components before they create clashes (clash avoidance early on in design). The use of BIM is related to principle 11 "*Adapt Technology to Fit Your People and Process*". The BIM software on the project is parametric which makes changes directly visible. The use of 4D simulations at CHH (equivalent to Toyota's Digital Assembly) enables the study of how individual building components will be built/assembled. Workability studies provide details on the effects of a certain design and the impact it will have on ergonomic issues involved in building certain parts of a building.

LESSONS LEARNED FROM MANAGING THE INFORMATION FLOW AT CHH

This paper's nurturing proposition is that (so far) CHH has implemented most principles related to the Lean product development system at Toyota, as described by Morgan and Liker (2006), and that these principles are the foundation for the evolving operational system that supports its processes on a daily basis. The previous section compared and contrasted Morgan and Liker's 13 principles about Toyota's PDS to what can be found at CHH's PDS and indicated a few areas in which the principles are not fully implemented (principles 2, 5, and 7 still need more work to be fully implemented). This section points out to some lessons learned about the journey to define the operational system of CHH's PDS.

"*Our knowledge of its details was actually very limited. After all, we were academics, not hands-on product development engineers, and our access to Toyota was limited*" (Morgan and Liker 2006 p. xv). The previous quote illustrates a reflection by Morgan and Liker about their understanding of the product development system at Toyota. In a very similar fashion, this quote reflects the views of the co-authors of the present paper. They started reading Morgan and Liker's book independently and to some extent independently started applying some of the book's teachings. According to the discussion presented in previous sections of this paper, most principles listed by Morgan and Liker were implemented by the team at CHH and others are still work in process. Based on the experience gained at CHH, the authors of the present paper believe that there are two elements that should be at the core of a Lean PDS: role of leadership during the transformation to a lean enterprise and the effective management of the information flow.

Two of the most broadcasted characteristics of the product development process at CHH are the collocation of its team in the same floor of a building in downtown San Francisco and its intense sharing information using visual systems throughout the floor. Collocation fosters collaboration and *promotes* communication; however collocation may not necessarily *improve* communication as there might be an overload of information in the environment. Morgan and Liker (2006 p. 96) underscore the importance of managing and sharing information in a lean system:

> "*In lean manufacturing, pull production eliminates overproduction by having downstream activities signal their needs (demand) to upstream activities. Kanban cards usually signal (control) production in a pull system. In product development, knowledge and information are the materials that are required by the downstream activity. However, not all information is equal to all people. The lean PD System uses 'pull' to sort through this mass of data to get the right information to the right engineer at the right time. Knowledge is the fundamental element (material) in product development. Toyota does very little "information broadcasting" to the masses. Instead, it is up to the individual engineer to know what he or she is responsible for, to pull what is needed, and to know where to get it.*"

As suggested in the previous quote, information is not equal to all people. It is the task of the cluster leaders (MDT leaders at Toyota) to make sure information is available to those who needed it, but information should not be broadcasted to all people in the team. This can avoid confusion or extra coordination efforts that arise when team members have to sort through an overload of information. Morgan and Liker (2006 p. 261) highlight that: "*The lean view of communication is: If everyone is responsible, no one is responsible; If everyone must understand everything, no one will understand anything very deeply; If all communication is going to everyone, no one will focus on the most critical communication for their role and responsibility If you inundate your people with reams of data, no one will read it.*" Product development in AEC involves a great deal of complexity and it is very important for the product development team to "embrace" and "appreciate" the complexity in all aspects of the product. This is probably the most challenging part of the process where you continuously work on the "mental models" that align the team. Having a leader who understands the complexity and sees the whole is crucial for the outcome.

CONCLUSIONS

This paper used Morgan and Liker's 13 principles related to the product development system (PDS) at Toyota to analyze the PDS at CHH. The authors aimed to share some details about the journey the CHH team went through as these principles were used as a basis to develop the operational system that supports the PDS at this project. According to the discussion presented, most principles have been implemented to some extent, and a few still need to be worked on (principles 2, 5, and 7). The authors also presented lessons learned from the journey to develop a Lean PDS at CHH and indicated that leadership and the management of information are essential elements of a Lean PDS. Additionally, throughout the paper, the authors highlighted the importance of running the Plan-Do-Check-Act cycle in different formats and continuously using the resources available to improve the processes to deliver more value to the final client.

Finally, the authors would like to close this paper with an important reminder: Morgan and Liker (2006) place a very strong emphasis on the importance of leadership at Toyota, leaders lead by example and get to know their projects inside-out. The leaders are directly responsible for the success of their projects and how tools are used. "*Only by adding new energy to arrest entropy (atrophy), can you maintain or improve a system. Leaders are the primary source of energy; they arrest the atrophy of lean tools and keep them thriving and evolving in the culture. It is they who can sustain lean thinking*" (Morgan and Liker 2006 p. 237). To conclude, here are a few more pieces of advice for those planning to embark on a lean journey starting from the product development stage (Morgan and Liker 2006 p. 333-334):

1. "*Transforming PD into a lean process is more complex and less precise than transforming manufacturing into a lean process.*" Appreciate the complexity and embrace uncertainty.
2. Take an honest look at the current reality and empower the team to follow up with real action.
3. True North is very important for a strong "liftoff" but the team needs to work on alignment continuously. This applies for the overall project team as well as for smaller sub-groups on a project.
4. "*Engineers are engineers and tend to want to reduce lean PD methodologies to technical tools.*" Focus on the integration of tools with people and organization.
5. "*Senior leaders must be intensely involved in the transformation process*" (...) "*Senior leaders must understand the commitment and have patience*", and go to *gemba*.

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