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LEAN IMPLICATIONS FOR THE DESIGN OF PRODUCTS

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1. Introduction

The application of lean principles for process improvement in companies around the world has been accelerating in recent years. Originally known as the Toyota Production System, lean principles have transformed the way thousands of companies operate. A company practicing lean principles strives to constantly make value so that it appears to flow as product is produced at the rate of customer demand (Womack and Jones, 1996). The company constantly strives for perfection. This paper is a brief introduction to lean concepts and how they can extend from the manufacturing and service business context to that of the interaction between a person and how they use a product. Philosophically, we believe lean principles can set a new context for thinking about ergonomics as it relates to product design, specifically to improve the interaction between the user and the product.

Lean has three main concepts—value, pull, and flow. At the heart of lean is the concept of value. The ultimate goal of a lean company is to deliver value to its customers and abandon activities that consume resources, but serve no useful purpose from the point of view of the customer. When activities pull, they are prompted by the next downstream activity. They become a response, not an initiation. When the only activities that are taking place are those that add value at the pace of need, the process appears to flow. Not too much, not too little. Not too fast, not too slow. This describes the ideal process--constantly creating value in response to customer need.

The pursuit of lean is not easy. It takes careful planning and a workforce educated in lean concepts. There are numerous tools, methods, and programs for implementing lean. Do a search on the term *lean* and one will find references to 5S, kanban, Value Stream Mapping, etc. The driver behind all of these approaches is the elimination of waste. By waste, we mean any activity that does not add value to the product or service from the customer's point of view. If we can eliminate all waste, we will have the characteristics of value, pull, and flow; which ultimately leads to perfection. This is a state we can not achieve but its pursuit keeps an organization heading in the right direction.

Until recently, the primary application of lean has been in manufacturing. Companies have made tremendous improvements to the time it takes to make a product by eliminating much of the waiting, handling, and tracking that materials require while being transformed into a shipped product. It is common for companies to report 90% improvement in a product's lead time, 80% reduction in work in process, 75% reduction in space requirements, and so forth.

Applications of lean have begun to move beyond manufacturing and into other areas of the company in recent years. Known as lean for service, or transactional lean, similar principles, tools, and methods have been used in programs to emphasize value in non-manufacturing activities. Lean reduces the time and increases the efficiency of any process (George, 2003). Applications of lean have been documented for service processes such as procurement, construction permitting, bank transactions, order entry, and so forth. The design process has also been the recipient of lean applications.

Past research into the application of lean towards design exists but is minimal. Pavnaskar and Gershenson (2004) have investigated the application of lean, particularly value stream mapping, towards engineering processes. Later they present a ten-step process for engineering waste elimination (Pavnaskar and Gershenson, 2005). There are other works related to lean product development, again based on practices at Toyota Corporation (Sobek, et.al., 1998). All of this research looks at the activities of engineering design. Whether manufacturing an automobile, constructing a house, or admitting a patient into the emergency room, all of these endeavours are processes that consist of numerous activities. As such, all of these processes can benefit from the application of lean principles by seeking to eliminate the wasteful activities and focus on those that add value.

2. Lean Wastes

A value-added activity is one that increases the form or function of the product or service. Theoretically, these activities are those for which the customer is willing to pay, such as forming a part in a manufacturing process or administering medicine during a doctor visit. In contrast, a non-value added activity is one that does not add to the market form or function and is not necessary. Theoretically, the customer would have no interest in paying for these activities, such as moving materials from one machine to another or removing medicine from a shipping box and storing it in a supply cabinet. These activities consume resources but do not add value. Applications of lean provide the means of using fewer resources—less time, less equipment, less space—and creating the value expected by the customer (Womack and Jones, 1996).

There are seven types of waste in the lean philosophy: overproduction, transportation, motion, inventory, waiting, excess processing, and defects (Asay, 2003). From a manufacturing point of view, one can readily recall activities that do not add value. For example, the raw materials spend time waiting while they are delivered to the plant and make their way to the production area. Then they wait to be added to the product. During the "touch time" value is being created but the additional time spent waiting for the next process step, or sitting on a shelf waiting to be shipped does not add value. This waiting also delays the cash flow cycle for the manufacturer which increases cost. Additionally, there are numerous instances where waste at one point in the process encourages additional forms of waste in other areas. For example, conducting process steps at a workstation faster than needed by the downstream workstation causes excess work in process (WIP). WIP builds between process steps requiring additional space and transportation activities to manage it while waiting to be further processed.

When one looks at services, waste is very prevalent yet sometime more difficult to identify (Keyte and Locher, 2004). For example, the waste of excess processing can be commonly seen by the practice of routing a form for multiple signatures. There are usually good reasons why signatures are needed but upon examination companies find that many of those on the signature list are only being informed, not being sought for approval. Even approvals, while deemed necessary, are a form of waste. Engineering design is a service type process and therefore exhibits the same types of waste. For our same example, think about the multiple approvals that are often required on an engineering change order. Even the act of printing a drawing for a design review is waste.

The lean approach advocates that waste should be eliminated, simplified, or reduced. Some forms of waste are easy to eliminate. For example, parts could be immediately delivered to the production line rather than storing them in a warehouse. Other wastes, such as delivering raw material to the plant, can only be reduced by finding a more direct route to the plant or perhaps delivering only what is needed each day. All companies must live with some waste while they continuously strive to eliminate it. In this way, they are in constant pursuit of value, pull, and flow.

3. Lean Implications to the Nature of the Product

In the first two sections of this paper we have considered lean as it pertains to manufacturing processes and the extension of lean into services or transactions. Since engineering design is a service type of process we have also established the applicability of lean to the process of engineering design. We have also discussed the foundation of lean—the elimination of wasteful activities in a process so

that those remaining appear to flow as value is created at the pull of the customer. What about the product that is being developed by the engineering design process. Does the lean approach have any implications for the product itself? The product is not a process as it is not comprised of a series of activities. It is a thing; an artefact. By its very nature it does not contain value-added or even non-value added steps. Therefore lean and the identification and elimination of waste does not apply directly.

From a philosophical point of view, one could argue whether a product has any value except for its interaction with a living being, typically a person. (It is not our purpose in this paper to debate this issue but to assume there is value during user-product interaction.) We can think of this interaction as a series of activities which describes a process. Following this logic then, lean principles would apply to the user-product interaction, something commonly addressed in the field of ergonomics (Rogers and Eggleton, 1983). There are several aspects of this interaction for which lean has implications. We will discuss the influence that the product has on the user-product interaction. That is, how does the very nature of the product, its size, shape, features, etc.; allow value to flow at the pull of the user.

A product has a high degree of value if it brings about a high degree of satisfaction to the user (quality), at the desired time, within an acceptable cost. When these conditions begin to wane—quality, time, or cost—value is decreased. Quality is often defined as conformance to requirements. This definition makes a major assumption; that the specified requirements lead to customer satisfaction. Assuming that they do, a lean product would contribute to a satisfying experience in response to the user (pull). It would not force the user into certain actions but would respond to the needs of the user. If this ideal condition were met, the user's level of satisfaction would be met continuously during the interaction with the product.

Given this concept of a lean product, one that facilitates the flow of value at the pull of the user, one wonders what makes a product less lean. In other words, what is it about a product that would make the user-product interaction less than ideal? One way to answer this question is to look at the seven categories of waste (recall Section 2 above). Examples of waste during manufacturing or transactional processes are well known. What about waste during the user-product interaction? If we understand how a product allows waste during this process perhaps we can gain insights into how to design a product to prevent it. Keep in mind that one can never totally eliminate all waste. Lean is a journey towards perfection. The design of a truly lean product is also a journey with an end that should be sought but can never be reached.

3.1 Overproduction

In traditional lean thinking, the waste of overproduction refers to activities that result in excessive production. This thinking includes making more than is required, making it sooner than required, or making it faster than is required by the next downstream process. When this waste occurs WIP grows and must be managed. The product spends more time waiting for the next process and the cash flow cycle is increased. In a transaction, we can say the same things about information. That is, providing more information than the next person in the process needs, providing information to them sooner than they can use it, or providing them with information faster than they can accept it. Again, the information must wait and the entire process slows down. By the time it is addressed, the situation often changes and the information must be reprocessed and sometimes changed. In both cases we are interrupting the flow. During the user-product interaction there are times when the product is more productive than the user desires and is not timed to the capabilities of the user. An excellent example is the design of an airplanes cockpit. Scores of people have careers focused solely on matching the controls of the plane to that of the pilots. Automobiles are capable of much greater speeds than a person can handle. It is easy to provide too much capability in a product.

3.2 Waiting

The waste of waiting refers to idle time by both people and equipment. In lean thinking, the waste of waiting refers to the time parts are in the plant but not being processed. Or perhaps people are idle because they have no work to do at that time or are waiting for an upstream activity to be completed. During this time, no value is being created but resources for space and monitoring the product are

being consumed. While material is waiting in the warehouse or finished product is stored in finished goods, resources are being consumed and no value is being provided to the customer. The waste of waiting is even more noticeable during a transaction. Standing in line at the checkout counter, waiting to be served, delivers no value. In fact, one could make a case that this kind of waiting detracts from the value of the shopping experience. Email is another example. By its very nature every message has a waiting period for a response. During the user-product interaction, no value is created when the user must wait for the product to respond. Think of the time the user must wait while his or her computer is booting up or a software application is loading. The waiting that occurs while a printer is going through a calibration cycle is also a waste. A lean product instantly provides value in response to the user. If this response is not instant, then the condition of flow is not met as the interaction becomes sporadic. In order for pull to occur the product must always respond to the user. Time spent trying to get a product to do what it is supposed to do is also a form of waiting, since the user is waiting for value to flow from the interaction.

3.3 Transportation

In traditional lean thinking, the waste of transportation refers to the movement of material around the plant while the product is being built. While moving parts from one machine or workstation to another may seem to be a necessity, it is still waste. The customer does not care that the producer must move material here and there. Whether a product travels 50 meters through the plant or 500, this expense provides no value to the customer. In a transactional process, documents such as forms and letters are used to communicate information. All are waste and add no value to the transaction from the point of view of the customer. Anytime paperwork is moved around we have waste. Again, the company may encourage filing documents, putting them into a repository, and storing them. Sometime this must be done by law. But the fact remains that it is waste. In the user-product interaction, typically little transportation activity takes place. There are times, especially if the product is designed to be portable, that it must be transported to be used. In these cases it is important to minimize this effort by assuring that the product does not weigh more than needed, is not bulky, or of a shape that is difficult to handle.

3.4 Excess Motion

In traditional lean thinking, the waste of excess motion refers to the motions a worker must do that are in excess of those needed to perform the task. It could be that the workstation is not designed well so they are reaching too far for parts and tools, walking to get parts, or attaching things in a sub-optimal way. It could also be that the person is not adequately trained so that they are performing activities differently or in an inconsistent way. It may be that the motion is too slow, too fast, or perhaps being made in an awkward posture. In a transactional process, a person's desk may be poorly laid out or people are working too long without a break and are not working effectively. Central printers or fax machines create unnecessary trips by people. Any movement that a person is doing that is not adding value is waste. The user-product interaction is typically full of excess motion. Any time the product is designed such that the user must make adjustments, or execute multiple actions to get performance, there is waste. Simply the task of having to operate a product and use it rather than the product automatically doing was the user wants, is a waste. An interesting example is the difference between manual and automatic windows in an automobile. The manual windows cause excessive motion compared to automatics. But then again, the designer must look at value and what is the user seeking. The automatic windows create less waste but cost more. How does the user perceive this from the point of view of value?

3.5 Inventory

In traditional lean thinking, the waste of inventory refers to parts or products that are being retained inside or outside of the company. Examples are raw material sitting in the warehouse, work in process on the assembly line, or finished good sitting on the shipping dock. This waste has a number of causes. Sometimes inventory exists because of uneven cycle times between workstations. Some is due to poor factory layout. In the finished goods area it might be there to cover shipments if a large

order arrives. Whatever the reason, the presence of inventory does not add value. Inventory covers up problems, it does not solve them. In a service process, inventory may be recognized as forms and letters in a person's in box. It may be email messages requesting information in someone's computer. It could even be a design project that is underway or waiting to be completed. In the interaction between a user and a product the waste of inventory is difficult to recognize and somewhat controversial. In this instance we need to think about issues of capacity or capability. As an example, think about the personal computer. Most systems today contain hard drives in excess of 100 or 200 GB. Is all of this capacity needed? A heater for the home is usually sized for maximum need and therefore has excess capacity most of the time. The fuel tank in an automobile is a trade off. Too small and the user must fill it too often and has reduced range. Too large and the weight hurts the fuel efficiency. Herein lies the controversy. Manufacturers resolve this issue by producing multiple models with various capabilities and capacities. The more models, the better fit of the product to the needs of the user and thus less inventory waste. However if there are too many models, users can become confused by the choices and the manufacture must support too much variety. The product that results in a lean interaction is one that is infinitely variable in its capacity and can instantly respond to the needs of the user—a state that can not be achieved but can be pursued.

3.6 Unnecessary Processing

In traditional lean thinking, the waste of unnecessary processing refers to any production activity that does not add value to the finished product, from the point of view of the user. At first glance, all production steps seem to add value—that is how the product is built. But upon close examination one can observe many process steps that are there to make other steps happen or perhaps vestiges from previous process procedures. Because of sequencing, some steps are taking product apart to make other operations possible. Often worker do the same job different ways, because of poor training, which leads to unnecessary process waste. Some examples are more subtle. Starting a drill bit too far above the work wastes process time each time it goes down and up from the work. Using screws that are too long requires unnecessary turns with a torque driver. In the service area, unnecessary processing is perhaps the biggest form of waste. Because of the non-physical nature of transactions these steps are more difficult to identify. Wading through nonpertenent information to find the facts one needs results in unnecessary processing. Making extra copies of a paper or working on a task that someone else also happens to be working on, is a waste. Other examples are filing travel expense reports, expediting, expense accounting, creating budgets, month-end closeouts, and searching for files on your computer. All of these activities may seem valuable to the company but they provide no value to the customer. Concerning the user-product interaction designers are challenged to include the correct amount of features in a product. Too many features lead to capabilities that are not needed and therefore delivers waste. The mass of a part that is in excess of what is needed to support the loading could also be an example of this type of waste.

3.7 Defects

In traditional lean thinking, the waste of defects refers to the defects themselves, the task of inspection, addressing customer complaints, and repairing product. The fact that inspection is a waste often surprises people. But the reality is that inspection provides no value to the customer, it only helps a manufacturer catch their mistakes. The customer would prefer that no mistakes and no inspection takes place and the savings be passed on to them. The process of rework adds no value, only restoring the value that should have been there if the product were built correctly the first time. We see numerous defects in the service area as well. Examples would be errors in data entry, drawing errors, incorrect calculations, or processing engineering change orders. From the user-product perspective, a defect waste is anything about the product that causes the interaction to be less than ideal. Instructions must be clear and the operation of the product should be so intuitive that no mistakes are made in its operation. How often have we been frustrated while trying to change the time on a digital watch or programming the remote control for a television or stereo set? Digital cameras and recorders can be frustrating and are rarely used correctly all of the time except for a small group of expert users. If a product contributes to mistakes in its operation, waste exists.

4. Conclusions

This paper is a brief introduction to lean concepts and how they can extend from manufacturing and service processes to that of the interaction between a person and how they use a product. We have shown how the main concepts of lean—value, pull, and flow—pertain to the relationship between the user and the product. We have also shown how the seven categories of waste -- overproduction, transportation, motion, inventory, waiting, excess processing, and defects—provide a framework for the waste that occurs during the user-product interaction. Reducing this waste should result in a product that provides the user with a more satisfying experience. Philosophically, we believe lean principles can set a new context for thinking about ergonomics as it relates to product design.

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